Evaluating the Effect of Dragline Sprinkler Operating Pressure, Riser Height, Nozzle Size and Wind Velocity on Irrigation Water Application under Different Wind Speed Conditions; The case of Tedecha Large Scale Irrigation Scheme.

By:

Alemayehu Mengistu Debela

Thesis Submitted to

Water Resource Engineering Program

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirements for the Degree of Master in

Irrigation Engineering

Office of Graduate studies

Adama Science and Technology University

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APPROVAL SHEET OF BOARD OF EXAMINERS

I, the undersigned, members of the Board of Examiners of the final open defense by *Alemayehu Mengistu* have read and evaluated his thesis entitled "*Evaluating the Effect of Dragline Sprinkler Operating pressure, Riser height, Nozzle size and Wind speed on Irrigation Water Application under different Wind speed Condition. The case of Tedecha Large Scale Irrigation Scheme*." and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Master's in *Irrigation Engineering.*

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DECLARATION

I hereby declare that this MSc Thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

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DEDICATION

Dedicated to the Almighty of God,

The Alpha and Omega,

The beginning and the end,

The first and the last

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ACRONYMS

AELQ	Actual Application Efficiency of Low Quarter
a.m.s.l	Above Mean Sea Levels
ASABE	American Society of Agricultural Biological Engineers
CU	Coefficient of Uniformity
CWR	Crop water requirement
D	Nozzle diameter,
DU	Distribution Uniformity
ESC	Ethiopia Sugar Corporation
FAO	Food and Agricultural Organization of the United Nations
H	Riser height
HVA	Handlers Vereenging Amsterdam
ICMCS	Irrigated Crop Management Centre standard
LQ	Low-quarter
MAD	Management allowable deficiency
MARC	Melkasa Agricultural Research Center
RH	Relative humidity
PAE	Potential Application Efficiency
PEP	Polyethylene Pipes
PELQ	Potential application efficiency of low quarter
PVC	Polyvinyl Chloride
SMD	Soil moisture deficiency
TLSIS	Tedecha Large Scale irrigation scheme
U	Wind velocity
USDA	United States Department of Agriculture
WAF	World Agriculture Forum
WSE	Wonji Sugar Estate
WWDSE	Water Work Design and Supervision Enterprise

ABSTRACT

The worldwide climate change and its incidental effect on scarce water resources have further reduced the amount of water available for agriculture. Owing to an increasing demand for irrigation water associated with the remarkable expansion of sugarcane irrigation schemes in Ethiopia, there is a desire to use the available water efficiently and effectively. Under this circumstance, the use of pressurized irrigation systems can be an alternative for enhancing the efficiency of water consumption. Hence, a study was conducted to evaluate the effect of riser height, nozzle size, operating pressure and wind velocity on irrigation water application of new dragline sprinkler system at Tedecha large scale irrigation scheme, Bofa. The study was conducted under five wind phases (morning, mid-day, afternoon, early and late night) where wind speed is expected to vary using four levels of riser height, three levels of operating pressures and two levels of nozzle sizes. Catch can test were carried out for uniformity measurement using four sprinklers configurations. Results of the field evaluation indicated that the average evaporation and wind drift losses (E %) range from 3.33% to 13.65% in the morning, 8.63 to 19.90% in the mid-day,6.85% to 17.12% in the late afternoon, 2.98% to 13.01% in the early night and 2.04% to 11.56% in the late night, PAE range from 51% to 93%, PELQ of 25.7 % to 78.3, AELQ of 24.2% to 69.1%, CU range from 59.5% to 90% and DU range from 55% to 87.2% were achieved under different test combinations. DPR and WIP range from 0.75 to 1.22 and 0.59 to 1.53 was obtained under different test combinations, respectively. Emanating from the experimental results were most of the combinations failed to meet the expected values in all parameter and lower operating pressure and higher wind velocity were the major factors responsible for the low water distribution uniformity and efficiency. It's recommended that the out growers should rehearse night time rather than day time by applying the best combinations of optimum operating pressure (3.0 bar) for 4.4mm and 4.8 mm nozzle sizes and 3.5 bar for 4.8mm with 4 m riser height at evening to efficiently utilize the available water.

Keywords: *operating pressure, riser height, nozzle size, wind velocity, uniformity, efficiency.*

1. INTRODUCTION

1.1 Background

With increase of the worldwide population, the contribution of irrigation towards boosting agricultural production is enormous. Particularly, in arid and semi-arid regions, the practice of successful profit-yielding agriculture often depends on irrigation. Irrigation is, in turn, dependent upon a water supply which is limited. The highest possible efficiency should be maintained if maximum utilization of the available water resources for irrigation is desired.

At global scale 60% of the diverted fresh water for agriculture does not contribute directly for consumptive use to agricultural production (WAF, 2009). Parts of discharged water lost by runoff, percolate to saline groundwater or to poor quality drainage water. However, in some cases, discharged irrigation water can be recovered in the downstream reaches but effectual and maintainable use of water resources for agriculture has turn out to be a worldwide priority of imperative importance, necessitating exigent and instantaneous solutions in perspective of intensifying water withdrawn for agriculture.

Sprinkler irrigation system allows, among others systems, high water application efficiencies with good distribution uniformities (Baha, 2002). Efficient and uniform distribution of irrigation water throughout the root zone of crop is an important characteristic of any irrigation system. Abo-Amera *et al*., (2015) and El-Habbasha *et al.,* (2015) stated that, pressured irrigation system can achieved different levels of uniformity rate, increasing of water use efficiency and improving the quality and quantity of yield.

Sprinkler irrigation has been found in many cases to provide a more efficient and uniform distribution of water in the soil surface than other methods of irrigation (Molenar, 2002, Wilcox, 2005). It can results in less water wastage because water is conveyed in pipes and irrigators can control the amount of water applied and its timing more easily which can increase the productivity per unit of water (El-Noemani *et al.,* 2015). This is especially true on light soils with irregular topography. The use of properly designed sprinkler systems and good management eliminates the dry zones which occur in the space between corrugations and avoids deep percolation losses at the end of surface runs (Criddle, 2007).

The sprinklers used for irrigating sugarcane field usually cover circular areas. Therefore, an absolutely uniform application is not possible due to wind distortion and the cost to prevent all losses is expensive. So, some water losses are expected and accepted in good irrigation system design, installation, and management. Thus, excessive loss may be caused by ineffective irrigation system design, improper installation, poor management, and equipment failures.

It is difficult to apply the optimum amount of irrigation water required with perfect uniformities because of differences properties such as soil types, variation in irrigation system components, pressure loss in system due to friction and elevation changes and other are set off an event (causes). Wind speed, evaporation and deep percolation are the main causes of water losses (Suheri *et al.,* 2005). The losses through evaporation and wind drift are from 5% to 20%, but can be higher with increasing air dry (Merkley *et al.,* 2004).

The degree of sprinkler uniformity is largely dependent upon the spacing of the sprinklers, wind velocity, pressure variations, speed and uniformity of rotation, nozzle shape and size, riser height, and lateral set-up (Jacobson, 2004). Wind causes the change in water droplet size and distribution process in two ways; (i) It affects the breakup of the water due to air resistance; and (ii) it blows all the resulting drops around (Maroufpoor, 2010).

The drift loss and uniformity coefficient of sprinkler irrigation system has obvious effect on the application efficiency and on the crop productivity (Dechmin *et al.,* 2003). The poor water application uniformity causes low application efficiency as a result part of the field will be either over-irrigated or under-irrigated (Haman *et al.,* 2013). As Lopez Mata *et al.,* (2010) indicated that by increasing application efficiency in terms of uniformity of water in the soil could result in 4% increase in yield and reduce cost of irrigation water by maintaining uniform water application and reducing application water losses (Montazar and Sadeghi, 2008).

Therefore, evaluating sprinkler parameters and improving irrigation water application efficiency of irrigation schemes through different interventions is considered a key issue for addressing the need for increased productivity of irrigated lands under pressure on water resources. Many irrigation schemes, particularly in less developed and emerging countries, are characterized by a low levels of overall application efficiency and affected by different design parameters.

The technical and economic efficiency of pubic irrigation schemes (large scale irrigation scheme) in these countries has generally been far below potential, and in some cases is particularly very low (Darghouth, 2005).These schemes have been characterized by high unreliability of water supplies. Areas of poor irrigation water application efficiency include mismatch of supplies and demands, insufficient maintenance, inadequate manual operation of structures and system, operational leakages and field losses, effect of wind, poor irrigation service, water logging and salinization.

Agriculture plays a crucial role in the development of the economy of Ethiopia. The sector supplies raw materials to the agricultural industry, income support and food security to a large proportion of the rural households, a market for industrial products and an earner of foreign exchange. The diverse agricultural activities that occur in the country include sugarcane production, citrus fruit, vegetable crops, maize and other cereal crops, cotton, and livestock production.

Sprinkler irrigation started in Bofa after an expansion project had been carried out by Wonji Shoa Sugar Factory since 2011, subsequently an agreement was endorsed between Sugarcane Out - Growers Farmers Associations and Wonji Shoa Sugar Factory. There are 32 Sugarcane Out - Growers Farmers Associations which in total have 9,100 member farmers and 7000 hectares at Dodota-Sire Woreda, Bofa including Tedecha large scale irrigation scheme on the way of Adama to Upper Awash Agro-Industry. Dragline irrigation system is used to irrigate this Tedecha cane fields.

The Factory, beyond supplying the farmers with selected seeds, and rendering professional as well as technical support to them, has made irrigable land and water available to all. The Water source for this scheme is Awash River. Water is pumped from Awash River, Melkassa pumping station and conveyed by means of an extensive earthen canal system which is constructed by Oromia Water Work and Construction Enterprise. All the entire field of out-growers is fed from this pumping station.

Spray evaporation losses within the air mainly depend on air relative humidity, air and water temperature, drop size and wind speed (Sazab, 2007). Wind drift losses depend on wind speed, drop size and the distance to be covered before landing. In Bofa, Dodota-Sire woreda and its surrounding, experiment was conducted, wind is a serious restricting factor to sprinkler irrigation, due to its high frequency and intensity which affects water distribution uniformity. More than 70% of daily average wind speed registered in the area was higher than 2.8 m/s (Abebe, 2012).

It is highly desirable that everything possible be done to assure good uniformity and application efficiency by sprinklers. To accomplish this, it is necessary to understand the factors that affecting uniformity and application efficiency of sprinkler system.

Under this circumstance, this experimental study was initiated with the objective to evaluating the effect of sprinkler operating pressure, riser height, nozzle size and wind speed on irrigation water application under different wind speed condition of dragline sprinkler irrigation system of Tedecha Large Scale Irrigation Scheme (TLSIS), at various test combinations.

1.2 Statement of the problem

Efficient and effective use of water resources is crucial to increase sugarcane production. This can be achieved through uniform irrigation water application and by reducing application losses. Sprinkler irrigation has been operational at Bofa; Dodota - Sire Woreda; Tedecha large-scale irrigation scheme owned by Sugarcane Out - Growers Farmers Associations and under the management of Wonji Shoa Sugar Factory (WSF) since 2011.

Water application efficiency and impact of environmental factor on distribution pattern has not been studied and updated well in parallel with existing wind speed (ESC, 2005). Sprinkler irrigation systems have large potential for improving water productivity (water use efficiency) of sugarcane cultivations.

The basic aim of sprinkler irrigation systems is to apply irrigation water as uniformly as possible to the crop root zone. The uniform distribution of the applied water depends on factors such as operating pressure, nozzle size, riser height, sprinkler spacing, wind speed and direction of wind (Baha, 2002; Topak *et al*., 2005 and Liu, 2009). As a result, some areas of the field may not receive an adequate and uniform amount of irrigation water and this causes decreased of irrigation efficiency as a part of the field were either over-irrigated or under-irrigated. High wind speed together with operational pressure, riser height, nozzle size and leakage conditions are believes to be the limiting factors for inefficient irrigation water application uniformity and distribution pattern in the areas and need major concern.

The growth of the sugarcane is not uniform throughout the field (Abebe, 2012). This may be one indication for non-uniform application of water in the area and for poor irrigation water management. In fact, long years metrological data registered in the area indicates that the average wind speed is 2.8 m/s. This research is initiated to evaluate the effect of sprinkler parameter on water application and improve the existing sprinkler irrigation in saving of water, to develop technical interventions for capacity building of out growers to better manages their irrigation schemes in order to achieve the irrigation's goal efficient water application.

1.3 Objectives

1.3.1 General objective

- The general objective of this study was to evaluate the effect of dragline sprinkler operating pressure, riser height, nozzle size and wind velocity on irrigation water application under different wind speed condition for the betterment of system operation and sustainable crop and water productivity.

1.3.2 Specific objectives

The following are the specific objectives of the study:-

- To study the effect of operating pressure, riser height, nozzle size and wind velocity on irrigation water application.
- To determine the optimum combination of operating pressure, riser height and nozzle size for prevailing wind speed conditions for the existing sprinkler system.

1.4 Significances of the study

This study introduces the total effect of operating pressure, riser height, and nozzle size and wind velocity on irrigation water application under different wind speed condition in Tedecha large-scale irrigation scheme, which used modern pressurized irrigation system.

Thus, to make irrigation water application effective and efficient in the area, the contribution of this study is fundamental and supportive. It’s true for the designers, irrigation engineers and decision makers to take appropriate decisions on sprinkler irrigation system parameter and to take some mitigation measure.

1.5 Scope of the study

The scope of this research was limited to examine the effect of dragline sprinkler operating pressure, nozzle size and riser height as well as wind velocity on irrigation water application under different wind speed conditions, in Tedecha large scale irrigation scheme owned by Out-Growers Farmer Association managed under Wonji Shoa Sugar Factory.

In addition to these to determine the optimum combination of operating pressure nozzle size and riser height for the prevailing wind speed conditions for the existing sprinkler system parameter in irrigation water application, saving of water and energy, and put forward the major differences and key issues in each case.

2. LITURETURE REVIEW

2.1 Sprinkler Irrigation System

A sprinkler system is a collection of component devices which, powered by a pump, transports water from either groundwater or surface water (e.g, a small man-made reservoir, or a natural water body like a pond, stream or lake) that projects water into the air and deposits it onto the surface of the ground(Foade, 2002). It consists of metal or plastic pipes, which are either horizontal (mains, sub-mains, and laterals) or vertical (risers), and rotating sprinkler heads, made mostly of metal, with nozzles mounted in them. The horizontal pipes are typically buried under the surface. There are also a number of other parts including fittings, valves, vents, filters, etc.

In modern irrigation technologies, like sprinkler and trickle irrigation, can result in less water wastage because water is conveyed in pipes and irrigators can control the amount of water applied and its timing more easily which can increase productivity per unit of water (Keller and Bleisner, 2000, Mader, 2010). Plastic pipes or polyethylene pipes (PEP) can be used with static or mobile machines. There is overhead equipment such as mobile gun travelers.

The use of medium and low pressure nozzles (100 kPa or less) has helped to develop sprinklers such as drag line. They have gained popularity in African countries. Sprinkler irrigation systems have large potential for improving water productivity (water use efficiency) of crops (Kahlown *et al.,* 2007) due to water is conveyed in close pipes and irrigators have a tendency to maintain system operation to avoid loss due to wind drift.

A sprinkler irrigation system uses pressure energy with the help of a pump to releases water similar to rainfall through a small diameter nozzle placed in the pipes (Mader, 2010). Water is distributed through a system of pipes, sprayed into air and irrigates in most of the soil type due to wide range of discharge capacity.

Based on portability, sprinkler system are classified into Portable system, Semi- portable system, Semi-permanent system, Solid set system, permanent system (Foade, 2002). Based on precipitation rate sprinkler system are classified as; Low Volume Sprinkler(less than 13 mm per hour), medium volume sprinkler (13-25 mm per hour), large volume sprinkler (above 25 mm per hour (Garg, 2006).

2.1.1 Water distribution in sprinkler methods

In the sprinkler method of irrigation, water is sprayed into the air and allowed to fall on the ground surface somewhat resembling rainfall. The spray is developed by the flow of water under pressure through small orifices or nozzles (ICMCS 108, 2002). Nozzles may be rotated to cover circular or part-circle land areas, or they may be fixed and equipped with deflectors that break up the water stream and deflect it onto the area to be irrigated. High uniformity of water application achieved by overlapping the spray patterns from adjacent sprinklers (Samir *et al.,* 2010).

The pressure is usually obtained by pumping. With careful selection of nozzle sizes, operating pressure and sprinkler spacing the amount of irrigation water required to distribute and refill the crop root zone can be applied nearly uniform at the rate to suit the infiltration rate of soil (Jumman, 2009). The degree of distribution pattern of the system depends on climate factor such as; wind speed and direction, the system design parameters such as; the sprinkler spacing, riser height, operating pressure, nozzle diameters and management (Williams *et al.,* 2007 and Liu, 2009).

2.1.2 Suitability of sprinkler irrigation method

Sprinkler irrigation method is on the increase in Ethiopia, with approximately 15% of the sugar industry already using this method (ESC, 2009). The main reasons for the rapid adoption of this system are low cost per hectare, low labour and energy requirements, ease of operation, high application and distribution efficiencies and the prospect of increasing or maintaining yields while using less water (magwenzi, 2006).

Sprinkler irrigation mainly used by large-scale growers, Sugarcane Corporation. Although sprinkler irrigation has also proved suitable for small-scale farmers in organized associations. It is suited for most row, field and tree crops. Sprinkler irrigation adaptable to any farmable topography, whether uniform or undulating.

The lateral pipes supplying water to the sprinklers should always be laid out along the land contour whenever possible. This will minimize the pressure changes at the sprinklers and provide a uniform irrigation (Hill *et al.,* 2008). Sprinklers are best suited to sandy soils with high infiltration rates although they are adaptable to most soils. The average application rate from the sprinklers (mm/hr.) is always chosen to be less than the basic infiltration rate of the soil so that surface ponding and runoff can be avoided.

Sprinklers are not suitable for soils which easily form a crust. If sprinkler irrigation is the only method available, then light fine sprays should be used. The larger sprinklers producing larger water droplets are to be avoided. A good clean supply of water, free of suspended sediments is required to avoid problems of sprinkler nozzle blockage and spoiling the crop by coating it with sediment (Brouwer *et al.,* 2001 and magwenzi, 2006).

2.2 Factor influencing water application.

2.2.1 Operating pressure

In the sprinkler method of irrigation water is applied above the ground surface as a spray somewhat resembling rainfall. The spray is developed by the flow of water under pressure through small orifices or nozzles. The pressure is usually obtained by pumping, although it may be by gravity if the water source is high enough above the area to be irrigated. The irrigation water is distributed to the field through pipelines. Sprinkler effectiveness is reduced by operation at either excessively high or low pressures. Pressures that are too high produce fogging and irregular turning. Fogging produces too many small droplets that fall too close to the sprinkler.

Pressures that are too low cause improper jet breakup, producing a doughnut-shaped spray pattern. Under either condition, water is not uniformly distributed (Smajstrla *et al.,* 2005).The discharge rate of a sprinkler head is determined by the size of the sprinkler nozzle and the operating pressure. Reducing the operating pressure of the sprinklers reduces the sprinkler discharge rate. For a particular nozzle size, the discharge rate is not significantly changed by small changes in operating pressure. Caution should be taken in reducing the sprinkler pressure since it can negatively affect the sprinkler application uniformity. Operating a sprinkler below its recommended pressure range may result in unacceptable breakup of the sprinkler spray pattern and poor irrigation uniformity.

High application uniformity is desirable since it helps to ensure all areas receive the same amount of water. Reducing the sprinkler nozzle size may be an alternative for reducing the application rate (Schwankl *et al.,* 2007).Sprinkler irrigation is adaptable to most cash crops, soils and topographical circumstances. However for an economical system and even water distribution over the total land surface, careful judgment of the design parameter/criteria/ is required. With careful selection of nozzle sizes, riser heights, operating pressure, sprinkler spacing and field condition water can be applied uniformly at a rate lower than the infiltration rate of the soil, thereby preventing runoff and the resulting damage to land and crops (Merwe, 2001 and Samir *et al.,* 2010).

2.2.2 Wind

On the other world the basic aim of sprinkler irrigation systems is to apply irrigation water as uniformly as possible to the crop root zone. The uniformity distribution of the applied water depends on factors such as operating pressure, nozzle size, riser height, sprinkler spacing, and wind speed and direction (Ahaneku, 2010)

Wind drift loss occurs when wind carries water droplets away from the irrigated area. Droplets may either evaporate while they are being transported or may fall outside the irrigated area. In either case, the water is lost because it is not available to the plants being irrigated. Wind drift loss increases as wind speeds increase and as droplet sizes decrease. At higher wind speeds, larger droplets can be transported by the wind, and droplets can be transported greater distances (Smajstrla and Zazueta, 2003).

In this system, the water distribution pattern is strongly affected by wind speed and distribution. Consequently, some areas of the field may not receive an adequate amount of irrigation water and makes spot (Dechmi, 2002). Much work has been done in various countries to describe the effects of wind on sprinkler irrigation systems. Results indicate that the effects, when combined with other environmental factors, are more pronounced in some areas than in others and may vary from region to region under similar wind conditions, with daytime losses as high as 25 percent (Marco *et al*., 2002).

Water application losses, like wind drift, increase as wind speeds increase and droplet sizes decrease. At higher wind speeds, larger droplets can be transported by the wind, and droplets can be transported greater distances (Smajstrla *et al.,* 2002; Smajstrla and Zazueta, 2003). Such losses can be fairly significant if the sprinkler nozzles are located high above the crop canopy where they are subjected to higher wind velocities than those that occur close to the canopy because of greater opportunity time for evaporation (Samir *et al.,* 2010; Al-Ghobari and Al-Rajh, 2001).

2.2.3 Riser height

Riser height has a significant effect on sprinkler water application especially in windy areas. Wind drift and evaporation losses are lower if sprinklers are located closer to the soil, but this could reduce wetted radius, implying shallower flooding with possible run-off in sloped areas and reduces water distribution uniformity (Ahaneku, 2010). As the riser height decrease water application uniformity also increase (Al-Ghobari and Al-Rajih, 2001).

Irrigation systems should be evaluated to establish uniformity of water application and to identify run times that minimize dry areas and irrigation water application is related to sugarcane yield. Sugarcane growth may be affected due to non-uniform irrigated water application of water and creation of dry spots. Research conducted by Lecler and Jumman (2009) in South Africa clearly indicates that there are substantial differences in sucrose yield for different uniformities and soil depths (shallow and deep soils) for the same water application. Lopez-Mata *et al.,* (2010) also indicate that an increase in uniformity of water in the soil could result in 4% increase in yield. Thus, it is possible to increase cane yield and reduce cost of irrigation water by maintaining uniform irrigation water application and reducing application water losses (Montazar and Sadeghi, 2008).

2.3. Water losses in sprinkler system

In any irrigation system, some water losses are expected and accepted in a proper irrigation system design, installation, and management. It means that no irrigation system will apply water without some waste or losses because the cost to prevent all losses is prohibitive (Liu, 2009). However, excessive waste may be caused by poor irrigation system design, improper installation, poor management, and equipment failures. It is not possible to apply the exact amount of irrigation water required with perfect uniformity because of variations in soil properties, variations in irrigation system components, pressure losses in systems due to friction and elevation changes, or other causes (Smajstrla *et al.,* 2002). Evaporation, wind drift, and deep percolation are chief causes of water loss (Hill *et al.,* 2008).

Evaporation and drift losses are typically from 5 to 20%, but can be higher when the air is dry, there is a lot of wind, and the water droplets are small (Merkley and Allen, 2004).

2.3.1. Evaporation loss

During sprinkler operation, water evaporates from droplets sprayed through the air. The amount of evaporation losses from sprinklers are dependent upon both climatic demand, time available for evaporation to occur, surface area of water droplet and operating conditions (Baha, 2002).

The climate demand is a measure of the energy available for evaporation and the capacity of the air to store and transmit water vapor. The evaporation process requires 580 calories of energy to convert 1 gram of water from the liquid to the vapor form (Zazuete, 2009). This energy must be available from the environment surrounding the sprinkler.

Energy is readily available during summer months, as indicated by high air temperatures and high levels of solar radiation. Conversely, low temperatures and low levels of solar radiation during winter months provide less energy for evaporation (Williams *et al*., 2007; Zazuete, 2009). Wind increases evaporation rates by transporting water vapor away from the evaporating surface. It also increases evaporation by transporting warmer or drier air from surrounding areas to displace the moist, cool air above an irrigated surface.

The time available for evaporation to occur is the relatively short time beginning when a water droplet leaves the nozzle and ending when it falls on the ground or vegetated surface. When water is sprayed at greater heights and over greater distances, this opportunity time for evaporation is increased. Thus, more evaporation would be expected to occur from a sprinkler installed on a tall riser than from the same sprinkler (operated at the same pressure so that the drop size distribution is the same) installed on a short riser. Wind speeds are faster at greater heights above the ground surface, where there are few obstacles to air movement. Thus, evaporation loss from sprinklers mounted on tall risers is also increased because of these higher wind speeds.

Evaporation occurs from the surface of the water droplets, the total surface area of the water droplets greatly affects the amount of evaporation loss. For a unit volume of water, the surface area doubles as the droplet diameter decreases by half (zazuete, 2009). For this reason, evaporation rate increases as droplet size decreases if other factors remain constant, and the factors that cause droplet size to decrease will cause evaporation loss to increase. Evaporation loss from a sprinkler irrigation system can be reduced by changing the sprinkler operating conditions to increase the sizes of water droplets or by irrigating when climate demands are low.

Furthermore evaporation loss will be reduced by changing either or both of the following operating conditions: (1) increasing the nozzle diameter, or (2) decreasing the operating pressure. Both of these changes will increase the proportion of large droplets, thus decreasing the surface area from which evaporation can occur (Smajstrla and Zazueta, 2003).

2.3.2. Wind drift loss

In sprinkler irrigation the climatic factors which causes wind drift loss are wind speed and direction. Wind drift loss occurs when wind carries water droplets away from the irrigated area. Droplets may either evaporate while they are being transported or may fall outside the irrigated area. In either case, the water is lost because it is not available to the plants root being irrigated.

As wind speeds increase and as droplet sizes decrease; wind drift loss increases. At higher wind speeds, larger droplets can be transported by the wind, and droplets can be transported greater distances (Smajstrla and Zazueta, 2003). Such losses can be fairly significant if the sprinkler nozzles are located high above the crop canopy where they are subjected to higher wind velocities than those that occur close to the canopy (Samir *et al.,* 2010)

During irrigation some wind drift loss is unavoidable. To avoid excessive wind drift loss, irrigation systems should not be operated when wind speeds are high. Also, a sprinkler should be operated only within the operating pressure range for which it was designed. If operating pressures are too high, too many small droplets will be created and wind drift loss will increase (Smajstrla and Zazueta, 2003).

2.4 Swath radius and droplet size

The goal of any sprinkler irrigation system is to apply the desired amount of irrigation water to the crop's root zone as efficiently and uniformly as possible. The factors that determine sprinkler performance characteristics include swath radius (wetted diameter), droplet size (jet break up) which is a function of the operating pressure, the flow rate or discharge, the application rate, and uniformity of water application among others (Ahaneku, 2010).

Swath radius which is called wetted diameter; is defined as the distance across a water application pattern from dry soil in front of the system to dry soil behind the system (Michael, 2005). The wetted diameter defines a circular area that is wetted by a single sprinkler device and by a series of overlapping sprinkler devices.

In addition to the sprinkler device selected, operating pressure of the irrigation system and height of operation are factors in determining wetted diameter. Wetted diameter decreases most significantly with lower operating pressure (Yonts *et al.,* 2007). Some break-up of the jet of water is necessary to attain uniformity of coverage and to minimize the presence of excessively large drops. The larger drops lose less velocity and travel farther. They also strike the soil surface at a higher velocity, with more energy to cause structural deterioration of the soil surface. There is a natural tendency of jets to break-up because of air resistance, and the break-up increases with pressure (Michael, 2005; Ahaneku, 2010).

2.5 Evaluation of sprinkler parameter's

The ambition of any sprinkler irrigation system is to apply the desired amount of irrigation water to the crop's root zone as efficiently and uniformly as possible. Sprinkler water application efficiency and uniformity can be affected by sprinkler system parameter (Ahaneku, 2010).

The goal of evaluating sprinkler systems parameters is; to determine how sprinkler parameters affect the efficiency of the system, to obtain information that will assist engineers in designing systems; and to obtain information that enable mangers to comparing different methods, systems, and operating procedures as a basis for economic decisions in addition to optimize an irrigation system (Bos *et al.,* 2005).

Irrigation systems require a number of resources such as labor, water, power and time, so optimizing an irrigation system by combining the correct type, design and operation of the system including choosing appropriate conditions allows the use of these resources to be minimized (Wigginton and Raine, 2001).

Therefore, the ultimate purpose of evaluating irrigation system parameter performance is to achieve efficient, productive and effective irrigation and drainage systems by providing relevant feedback to management at all levelss in specific place (Bos *et al.,* 2005; Ahaneku, 2010). To determine the related degree of satisfaction, a systematic and timely flow of actual (measured or collected) data on key parameters of a system must be compared with intended or limiting (critical) values of these data (Wigginton and Raine, 2001).

2.6. Irrigation system performance index

Not all water taken from a source (river, well) reaches the root zone of the plants. Part of the water is lost during transport through the pipe and in the fields. The remaining part is stored in the root zone and eventually used by the plants (FAO, 2002). In other words, only part of the water is used efficiently, the rest of the water is lost for the crops on the fields that were to be irrigated.

It is crucial value to ensure that indexes that are selected to quantify the performance for a system that describe parameter performance in respect established objectives. A meaningful index can be used in two distinct ways. It tells a manager what the current performance is of the system and, in conjunction with other index, may help to identify the correct course of action to improve performance within that system (Garg, 2006).

Separating of applied irrigation water underlies the evaluation of certain performance index, notably, efficiencies which expressed as percentages and these are fractions of the irrigation water volume that are destined for certain functions. Certain of these efficiencies are impossible to define without careful specification of subject region and time period. Others, by virtue of built-in assumptions, can avoid these issues. The different efficiencies have different purposes and should be carefully differentiated. FAO, (2004) as cited by Zamaniyan *et al.,* (2014) other indicators are more properly expressed as ratios and address concepts such as uniformity of water distribution within a field.

The most common used performance indexes to measure the system application performance in sprinkler irrigation system are application efficiency and application uniformity (Samir *et al*., 2010; Zamaniyan *et al.,* 2014). This application efficiency is potential and actual application efficiency of low quarter and application uniformity is distribution uniformity, uniformity coefficient.

2.6.1. Application efficiency

Irrigation application efficiency is defined as the ratio between irrigation water actually utilized by growing crops and water diverted from a source (as a stream) in order to supply such irrigation water(ICMCS 108, 2002). Application efficiency is the average ratio of the amount of water applied and stored in the root zone to the gross amount of water applied (Howell, 2003). It gives an idea of the magnitude of losses that occur during application. Application efficiency depends on the uniformity of irrigation and system management. It varies during the season depending on environmental factors such as wind speed, temperature, and humidity (Howell, 2003; Thomas, 2003).

Water application efficiency is an irrigation concept that is important in both system design and irrigation management. It can be divided into two components, water losses and uniformity of application. When either the water losses are large, or uniformity is poor, efficiency will be low. Although both components of efficiency are influenced by system parameter design and management, losses are predominantly affected by management, while uniformity is predominantly affected by system design (Topak *et al.,* 2005).

2.6.1.1 Potential application efficiency

The concept of potential application efficiency, PAE, is also useful in measuring the performance of a system for a single irrigation event. PAE is based on the concept that the application could be terminated at such time that the target would be just met by the average of the lowest values in the irrigation infiltration distribution. Deep percolation losses would then be held to a minimum, and the application efficiency would be at a maximum without significant under-irrigation. Burt *et al.,* (1997), as cited by Frank, (2009) deep percolation would be minimized, and due only to no uniformity of the distribution.

Potential application efficiency of low quarter (PELQ) indicates how efficiently the tested sprinkler system can apply water if the system is run the correct length of time (under optimum management neglecting pre-nozzle losses) to just satisfy the MAD (management allowable deficiency). It is, therefore, a measure of the best that management can do and should be thought of as the potential for the system under the tested conditions to the extent that the tested area is representative of the field (Kieffer and Huck, 2008).

The potential application efficiency of low-quarter (PELQ) is the efficiency that is obtainable, expressed as percent, when the average low-quarter (LQ) depth of irrigation water infiltrated and stored just equals management allowable deficiency (MAD) (Kieffer and Huck, 2008). The PELQ is always a little lower than the DU of a sprinkler irrigation system because the average water applied (which is the denominator for PELQ) is larger than the average water caught (which is the denominator for DU). The numerator for both PELQ and DU is the average low quarter depth of catch. The difference between the average water applied and the water caught or received is an approximation of losses due to evaporation and wind drift plus loss of water due to some of the area's being ungagged and some evaporation from the gauge cans(Samir *et al.,* 2010).

2.6.1.2 Actual application efficiency

Actual application efficiency of low quarter (AELQ) is the ratio of the average low quarter (LQ) depth of irrigation water infiltrated and stored in the root zone to the average depth of irrigation water applied (calculated from nozzle discharge) (Kieffer and Huck, 2008). The average LQ depth infiltrated is the average of the lowest one-fourth of the measured values where each value represents an equal unit of area and cannot exceed the soil moisture deficiency (SMD).

Values of AELQ indicate both the uniformity of water distribution and adequacy of irrigation. When the LQ value is less than the SMD or the desired management allowed deficiency (MAD), under-irrigation is indicated. The numerical value of the LQ average depth indicates the adequacy of the irrigation. The AELQ requires that the soil moisture deficit be known since this is the maximum depth that can be stored. The actual applied depth neglecting pre-nozzle losses is calculated using the application rate for the duration of the set (Kieffer and Huck, 2008).

The difference between PELQ and AELQ is a measure of management operations. Low PELQ values indicate design problems. This is the only efficiency term that should be used to compare systems or methods (Kieffer, and Huck, 2008; Crawford *et al.,* 2001).

2.6.2. Irrigation uniformity

The first requirement for the efficient operation of an irrigation system is the uniform application of water (Crawford *et al*., 2001).The ability of a sprinkler system to apply water uniformly throughout the irrigated area is a major factor influencing whether or not proper crop growth can be maintained. Solomon, (1990) as cited by Megersa, (2004) ideally, an irrigation system would apply water in a completely uniform manner so that each part of the irrigated area receives the same amount of water. Unfortunately, there seems to be no way to achieve this. Even natural rainfall is not completely uniform. So the phrase "irrigation uniformity" actually refers to the variation, or non-uniformity in the amounts of water applied to locations within the irrigated area. Therefore, irrigation uniformity is a concept that all areas within an irrigated field received the same amount of water (Keller and Bleisner, 2001; Heermannet *et al.,* 2005).

High uniform application of water does not ensure high efficiency since water can be uniformly under or over-applied (Crawford *et al.,* 2001). However, in order to achieve good crop yields, both a highly efficient system and uniform application of water are required. Keller and Bleisner, (2000) noted that, the uniformity and minimal loss of sprinkler irrigation is a central design goal. Uniformity relates to how evenly water is applied over a given area. Since no irrigation system can apply water precisely to all areas of the field. Therefore it becomes necessary to estimate the uniformity of water application in order to assess the effect of operating pressure and riser height on irrigation water application under different wind speed condition of the system.

Uniformity of irrigation is a measure of the evenness of the application. As higher uniformity of application is achieved, variation in the depths applied at different points in the field differ less from the average depth. An irrigation system with good uniformity of application saves water, because it allows avoiding over irrigating parts of the field while concentrating on putting adequate water on dry or other problem areas (Thomas, 2003).

The “catch can” method is used in the field determination of application uniformity. The theory behind it is to measure the collected depths of water in a sampled region of the field to represent the water distribution throughout the whole field. The general procedure includes setting out catch cans, operating the system, measuring the amount of water collected in each can, and computing the application uniformity coefficient (Liu, 2009).

Keller and Bliesner (2004) classified the irrigation uniformity in solid set systems as “low” when CU was below 84% and distribution uniformity was below 75% for high value crops. There are many measures of irrigation uniformity in use. The two most common measures of that expressing uniformity are the Christiansen uniformity coefficient and distribution uniformity (Solomon, 2004).

2.6.2.1 Christiansen uniformity coefficient

Coefficient of uniformity is a measure of non-uniformity of water application for a given sprinkler head, nozzle type, operating pressure, riser height and sprinkler spacing combination. On the other hand CU calculates the average deviation of the catch compared to the depth of the catch. It is thus an index of irrigation uniformity. The main stream agricultural industry has long used a calculated coefficient of uniformity to measure the non-uniformity of water application (ASAE, 2003).

Bradley *et al.,* (2011) found CU as the most commonly used quantitative measure of irrigation uniformity. This coefficient measures the average deviation from the mean application depth. Hence, for a perfectly uniform application the CU is 100%, which is impossible to achieve on a field scale due to equipment deficiencies and limiting environmental factors.

CU values of 80-94% is attainable for set-move systems which are properly designed and maintained, operating under moderate wind speeds less than 17.3 km/hr (Bradley *et al.,* 2011). It has been found that CU values as low as 60% can occur with systems on undulating topography, with worn or plugged nozzles, and/or under windy conditions (King *et al*, 2000).

Sprinkler uniformity is generally affected by the combination of wind speed and direction, operating pressure and sprinkler spacing, in the case of set-move sprinkler system. Dalton *et al*., (1999) as cited by Bradley *et al.,* (2011) found that a wide range of irrigation uniformity coefficients are used when evaluating irrigation systems parameter's performance and that one of the basic measures of any irrigation system's performance is Christiansen's uniformity coefficient (CU).

Smith, (1995) as cited by Frank, (2009) indicated that, the uniformity of application is acceptable for CU values greater than 0.84 or 84%. Keller and Bliesner, (2001) also wrote that in general CU of at least 85% is recommended for delicate and shallow rooted crops such as potatoes and most other vegetables, whilst values between 75% and 83% and above is acceptable for deep-rooted crops like alfalfa, corn, cotton and sugar cane.

2.6.2.2 Distribution uniformity

Distribution uniformity is usually defined as a ratio of the smallest accumulated depths in the distribution to the average depths of the whole distribution (Ascough and Kiker, 2002), while DU compares the driest quarter of the field to the rest. This uniformity measure is also called low quarter distribution uniformity and it is often used to quantify irrigation uniformity of surface systems (King *et al*, 2000).

The DU coefficient takes into account the variation of catch can readings from the mean but concentrates on the lowest 25% of readings. Wilson and Zoldoske, (2001) stated that the disadvantage of the DU coefficient is that it treats under watering as the critical element but does not indicate how big or severe the dry spot really is.

2.6.3 Adequacy

Adequacy indicates the ability of an irrigation system to deliver the required amount of water that can be stored in the effective root zone and meet the crop water requirement. The concept of adequacy addresses the question of what portion of a field received at least the net irrigation requirement. Those sections of the field which received a depth of applied water equal to or greater that the net irrigation requirement are said to be adequately irrigated. The remaining sections of the field are under irrigated. Any depth of applied water equal to more than the net irrigation requirement goes to deep percolation. If 25% of the field receives at least the net depth of irrigation, then the field is said to have an adequacy levels of 25% (Frank, 2009).

According to Burt *et al.,* (1997) as cited by Heermannet *et al.,* (2005) the relation between adequacy and uniformity of application determines the amount of deep percolation for a sprinkler system. Application efficiency is not a sufficient measure of irrigation performance. Some measure of the adequacy of irrigation is required. (Samir *et al.,* (2010). the low quarter adequacy of irrigation is a good implication measure to identify under and over irrigations.

Different crops and different growing stages require different application depths, irrigation scheduling, application rates and elevations of the sprinklers above the land surface. The primary losses associated with sprinkler irrigation (other than those due to over watering) are evaporation from droplets and wet soil surfaces, transpiration from unwanted vegetation, wind drift, field border losses, leaks and system drainage (Liu, 2009). The allowable evaporation losses are 5 - 20% acceptable limit value but it extent up 30% (Smajstrla and zazueta, 2003).

Raine *et al.,* (2002) observed that the ability of the in-field irrigation system to apply water uniformly and efficiently to the irrigated area is a major factor influencing the agronomic and economic viability of the farmers' production system. In addition, Solomon (1988) as cited by Merwe, (2001) noted that due to the fact that irrigation uniformity relates to crop yield and the efficient use of resources, engineers regard it as an important factor to be considered in the selection, design and management of irrigation systems.

Irrigation systems should apply water in the most efficient way possible to prevent unnecessary losses and water wastage. In order to achieve this, the uniformity coefficient with which the irrigation system applies water will have to be high (Schwankl, 2007).

The uniformity coefficient of a sprinkler irrigation system has a direct effect on the system's application efficiency and on the crop yield (Li and Rao, 2000, Dechmi *et al.,* 2003). Nutrients can be leached out of the soil due to excess water being applied to overcome poor irrigation uniformity (Schwankl *et al.,* 2007). Kahlown, (2007) stated that specific quantitative study of sprinkler irrigation uniformity started with the work of J. E. Christiansen in 1942. High irrigation uniformity can't water being applied adequately with little excess and low uniformity indicates that some portions of the field would be deprived of water while other locations will become over-irrigated.

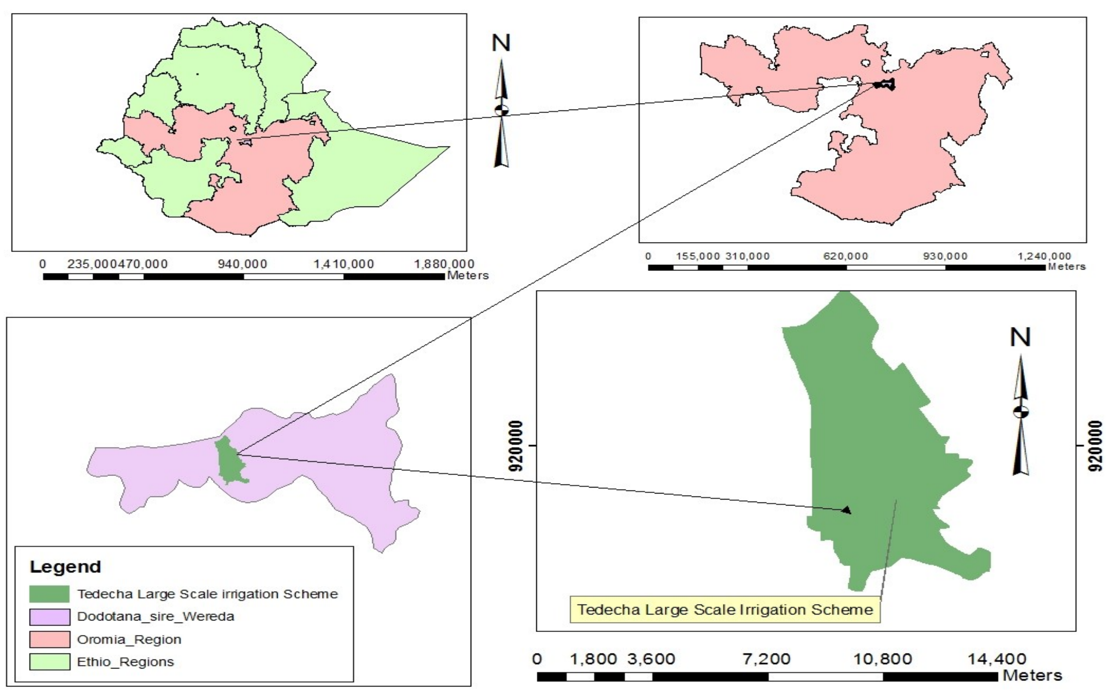
3. MATERIALS AND METHODS

3.1. Description of study area

3.1.1. Location and topography

The study (Figure 3.1) was conducted at experimental field of Tedecha large scale and public irrigation scheme which is owned by Out Grower Farmers Association. It is located at an elevation of 1466 m above mean sea levels (a.m.s.l) with latitude of 8º24' N and longitude of 39º23' E, that is to the north of Sodere on the way of Upper Awash Agro-Industry; Dododota-Sire woreda and approximately 38 kilometers south of Adama (or Nazret) and 135 kilometers southeast of Addis Ababa in the Misraq Shewa Zone of the Oromia Region on the way of Adama to Merti road.

Dododota-Sire is bordered on the south by Tena, on the southwest by Hitosa, on the north by the Misraq Shewa Zone, on the east by Jeju, and on the southeast by Sude. The works are part



of the Wonji Shoa Sugar Factory expansion project, a major implementation program launched to expand the irrigable cane growing area from the 2018; 12,000 ha to 17,000 ha.

Figure 3.1. Location map of the study area

3.1.2. Climate and Vegetation

The climate of the project area is tropical with seasonal wet and dry seasons. There is small rain in March and April. The main rainy season stretches from the beginning of July up to the end of September. The mean annual maximum and minimum daily air temperature is 28.8 ºC and 13.9 ºC, respectively. The yearly average precipitation, wind speed, relative humidity, sun shine hour is 66 mm, 2.83 m/s, 54 %, 8.45 hours respectively. The land was cultivated to dry crops such as maize, teff, barley and wheat. But now a day the land is growing cane and prepared for sugarcane cultivation by Out Growers Farmer association with the aid of Wonji Shoa Sugar Factory and provides the cane to the factory.

3.1.3. Soils and Irrigation Practices

The soils in the study area is described as Sandy clay loam formed from volcanic derived colluviums and alluvium on plains and terraces draining to the Awash valley. The mean annual soil temperature at 5 cm is 25.6 ºC. Effective soil depth is predominantly 1.0 to 2.0 meters except in few fields where it is below 1.0 meter and all soils are non-saline and non-sodic (WWDSE, 2010).

The water source for irrigation is Awash River, which is regulated by the Awash Melkassaa diversion which is located 15 km upstream of project area. The water from the river is considered to be good quality (WWDSE, 2010). The water is diverted by gravity to the canal with carrying capacity of 600 l/s. On the intake there is a trash screen to trap floating debris and flow of water into the canal is controlled by a vertical gate. On the canal there is a settling basin structure to settle down sediments by reducing the water flowing velocity.

Dragline sprinkler irrigation system is used to irrigate the sugarcane fields in Tedecha scheme. The work is the part of the Wonji Shoa Sugar Factory expansion project and a major implementation program launched to expand the irrigable cane growing area. Full irrigation is practiced for 9 to 10 months and supplementary irrigation is practiced in July, August and September depending on the weather condition. Spacing between laterals is 54 m and the riser valves are placed at an interval of 18 m on the lateral. The length of the hose is 20 m which is attached to risers of 4 meter height above the ground. Each sprinkler serves 12 positions on 18 m x 18 m grid. One sprinkler serves for an area of 0.3888 ha for irrigation.

3.2 Data Collection

3.2.1 Meteorological data

The actual daily climate data including, maximum and minimum temperature, relative humidity, sunshine hours, relative humidity (RH), radiation and wind direction, were recorded from Sodere resort meteorological station at the beginning and end of tests that is during early morning, mid-day, late afternoon, early night and late night in which the wind speed were expected variable.

The direction and magnitude of the prevailing wind, during the test, was determined with the aid of a portable anemometer. Humidity was determined using a portable thermo hygrometer by measuring the ambient dry bulb temperature and the ambient wet bulb temperature. In addition to these operating pressures at the hydrant and sprinkler nozzle was measured using pressure gauge in a specific irrigation block.

3.2.3 Soil sampling and moisture content determination

Soil samples from the experimental field were collected for determination of bulk density, permanent wilting point, field capacity, moisture content and soil texture. Bulk density was analyzed by collecting undisturbed soil samples from two depths (0-30 cm and 30-60 cm) at three positions of the experimental fields due to core sampler height (30 cm). The samples were weighed, oven dried at temperature of 105 $^{\circ}$C for 24 hours and weighed again. Moisture holding capacity of the soil at field capacity and permanent wilting point were determined using pressure plate apparatus.

Undisturbed soil samples before and after each irrigation were collected using core sampler at the depth of 0 – 30 cm, and 30 – 60 cm as recommended by (Hunsigi, 2001). Soil water content in the cores was determined gravimetrically and bulk density was used to calculate moisture content by volume of the soil samples. FAO (2004) method was used to determine the bulk density and moisture content. The hydrometric method was used for the particle size analysis for the determination of the soil texture.

3.2.4 Soil infiltration rate

Soil infiltration rate was measured using standard double ring infiltrometer technique. Infiltration rate of the soil before sprinkling was measured to compare it to the sprinkling rate. This infiltration rate equals the average application rate at which water does not accumulate on the soil surface when the soil moisture in the soil profile is at field capacity. The result of infiltration test was presented in appendix table 17.

3.3 Methods

This sub-section provides an overview of the methods that has been employed to accomplish the objectives stated in the introduction. Site selection and preparation, catch can size selection and arrangement, pressure and sprinkler discharge measurement approach has been enumerated. Material which sprinkler head are made, sprinkler head type, working mechanism has highlighted. Furthermore, Sprinkler spacing (on and between laterals) which is sprinkler configurations also been outlined.

3.3.1 Site Selection and Preparation

The test plot was cleared or the vegetation growth was less than 8mm in height and the slope of the field was less than 2% was selected. The ASABE (2009) recommended that the vegetation on the testing site should not exceed 150 mm in height.

3.3.2 Catch-can Description and Set-up

Cans of identical measurement were used for the test and they have diameter and height of 80 mm and 130 mm respectively, with a volume of about 600ml. Most irrigation experts recommend 16-20 cans per test zone for collection of data (Wilson and Zoldoske, 2001). Irrigated Crop Management Centre (ICMC 2002) also recommended at least 30 cans, of minimum height of 100mm, for the evaluation of sprinkler irrigation uniformity. For this study, 36 catch-cans per block and 432 catch-cans per test events were used for the determination of the sprinkler water distribution pattern involving four sprinklers for the block tests. These were therefore within recommended standards (ICMC S 108, 2002, ASABE, 2009).

In field and laboratory tests, catch-cans are most often arranged in either a rectangular grid or radial grid which converges to a common center more catch-cans are arranged near to sprinkler position. The catch-can setup for this test was the full rectangular grid because it provides more representative data especially when there is significant wind during test. When radial legs are used, there should only be one sprinkler operating, otherwise the analysis would not be representative of the actual conditions. Furthermore, the radial configuration is best suited to the evaluation of center pivot sprinkler systems.

For the purpose of evaluating sprinklers, the typical catch-can spacing used should be 2m or 3m (Merkley and Allen, 2004). The catch-can spacing used for this study was 3m × 3m, considering the radius of throw of the sprinklers greater than 12m (ASABE, 2009). The rectangular grid arrangement was adopted in this study. The layout for evaluating the block system is depicted Figure 3.2.

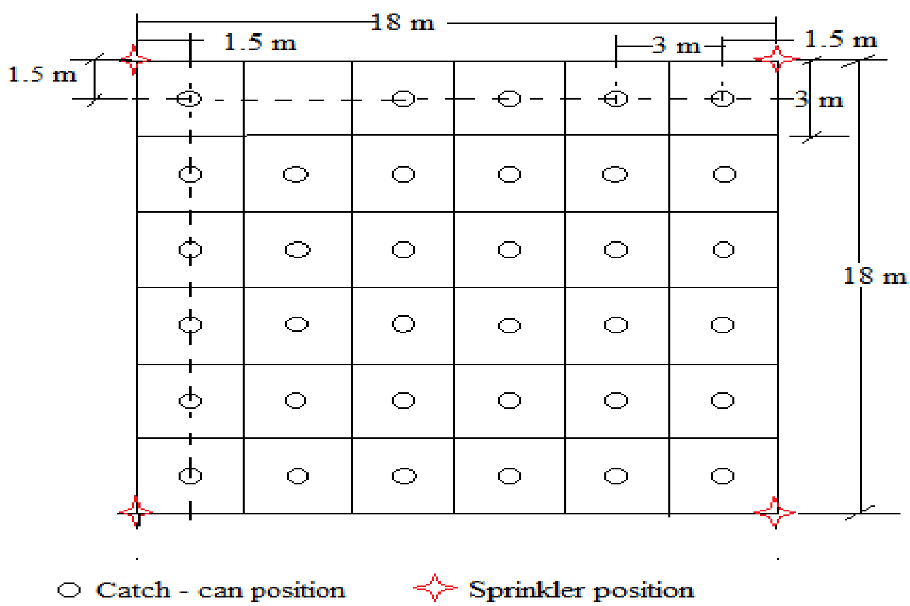


Figure 3.2.*Catch-can and sprinkler layout for block test.*

3.3.3 Swath radius determination

The sprinkler head of a system can only distribute the water over a given area. Throw distance which is called swath radius/wetted diameter/ was determined by footprint measurement which involves observing the boundary between the wetted area and unwetted areas in front and behind the system to dry soil the system, by making the boundaries, and measuring the distance.

The measured wetted diameter was compared with that in the manufacturers` chart with a specific nozzle pressure. A difference within 15% of the wetted diameter value provided by the manufacturer is acceptable (Liu, 2009).

3.3.4 Sprinkler head and spacing

The sprinkler heads used for this study were of the full circle rotating impact sprinkler type with both range and spray nozzles. An impact sprinkler is a water application device equipped with two nozzles and an impact arm to cause sprinkler rotation and water stream breakup. Sprinklers was made of brass or engineering/heavy-duty plastics with internal or external threaded connections.

Sprinkler spacing (on and between laterals) can be in square configurations. When testing sprinklers, it is common to have only a single operating sprinkler. In practice, however, it is most typical to have multiple overlapping sprinkler positions. Consequently, a single sprinkler test was performed to ascertain the distribution pattern of the sprinklers.

So the data obtained was used to simulate other overlapped configurations. Moreover, a block test, which is representative of multiple sprinkler positions, was conducted. The sprinkler spacing used was the 18m × 18m, involving four sprinklers per block.

3.3.5 System operating pressure

The output of a nozzle, the droplet sizes and distance that the sprinkler throws water is highly dependent on pressure and pressure losses though out the system. A pressure gauge with Pitot tube was used for the measurement of the nozzle operating pressure during the test. Throughout the measurement processes of block test, where more than one sprinkler was operating on one pipe line or lateral, the curved end of the Pitot tube was inserted into the nozzle and hydrant key gauge assembly was inserted into hydrant (Figure 3.3) to obtain the representative nozzle and lateral pressure.

Measurements were taken for all sprinklers in the block test zone. All pressure measurements were taken before the catch-cans were overturned to start the collection of precipitations.

a *b*

a. Gauge & Hydrant key b. Hydrant key-gauge assembly

Figure 3.3. Gauge and Hydrant key-gauge assembly used for pressure measurement.

3.3.6 Sprinkler discharge test

The sprinkler discharge test was carried out by both direct measurement of actual flow of water from the nozzles over a given time frame, and by computation to determine the intended or expected flow rate of the sprinklers based on their spacing. The volumetric discharge was measured with the aid of a flexible water hose and a 10 liter bucket. The time taken to fill the bucket was recorded. Actual rate of discharge and required sprinkler discharge was evaluated using eqn. 3.1 and 3.2 respectively.

$$q = \frac{v}{t} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3.1)$$

Where,

v is volume of water collected in liters (l).

t is the container fill time(sec).

q is actual rate of sprinkler discharge in l/sec.

$$Q = \frac{Sl * Sm * I}{360} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

Where,

Q is required discharge of individual sprinkler, l/sec

S_l is spacing of sprinklers along laterals, m

S_m is spacing of laterals along the main, m

I is optimum application rate, cm/hr.

3.3.7 Delivery performance ratio

The data generated from the discharge tests was used to compute the delivery performance ratio (DPR) of the sprinkler system which is a measure of the system performance. The DPR was computed using the relation Molden & Gates, (1990) as cited by Bradley, A et al., (2011).

$$DPR = \frac{actual\ discharge}{required\ discharge} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.3)$$

3.3.8 Water distribution test

Field experiments was carried out at Tedecha Large Scale Irrigation Scheme at Out Growers Farmer association from during dry seasons of the year 2017 G.C to evaluate the effect of operating pressure, riser height, nozzle size and wind speed on irrigation water application under different wind speed condition. Field evaluations were conducted at six (6) farms field, four laterals per field and one block per lateral.

The test procedure according to ASABE S436.1 (2009) standards was utilized for the determination of the uniformity of water distribution of the sprinkler system. The test was conducted on a square plot measuring 18 m x 18 m and bounded by four sprinklers. The sprinkler nozzle sizes are 2.2x4.4 and 2.2x4.8 mm, while the sprinkler spacing is 18 x 18 m as practice by out growers to establish experimental rectangular array of squares.

According ASABE S436.1, ICMC, 2000 recommendation 36 catch cans per block was selected. The test time was 60 minutes for each run; for seven month with three days intervals as irrigation practice by out growers. The individual catch can volumes were recorded by pouring the water collected in to a graduated cylinder, in milliliters. The stopwatch time was used to determine the true effect of operating pressure and riser height on irrigation water application and precipitation rate of system under different wind speed conditions.

The distribution data was obtained by measuring the volume of water caught in each collector at the end of the test period. The cans were located along lines parallel to the pipeline by establishing three meter by three meter rectangular array of squares and placed three meter apart since the sprinkler radius of throw was more than 12 m in accord with ASABE S398.1 (2009) standards and was placed 1.5 m from the boundary lines of the block.

Each catch can was placed on wooden pegs of height 25cm. Based on the cross-sectional area of the catch cans, the water volume was converted to depth of water in millimeters (mm). No evaporation suppressant was used.

Three levels of hydrant operating pressures (2.5, 3.0 and 3.5 bar), four levels of riser heights (2.5, 3, 3.5 and 4.0 m) and two levels of double nozzle sprinkler size (4.4 mm and 4.8 mm) as more commonly used by estate were tested under five wind speed condition: - morning, mid-day, late afternoon, early nigh and late night in which the wind speed were expected variable.

Relative humidity and temperature data were recorded during each test was from Sodere resort metrological station which located about 2.0 km distance from the experimental site. Furthermore, four catch cans, with 1 cm depth of water, on each test fields was placed outside the testing area in order to estimate the volume of water lost by evaporation in catch cans during the field test. The evaporation in the catch cans was taken into account to determine the potential application efficiency of the low quarter.

The general procedure was included setting out catch cans, operating the system, measuring the amount of water collected in each catch can, and computing parameter (Liu, 2009) which were used for analyses.

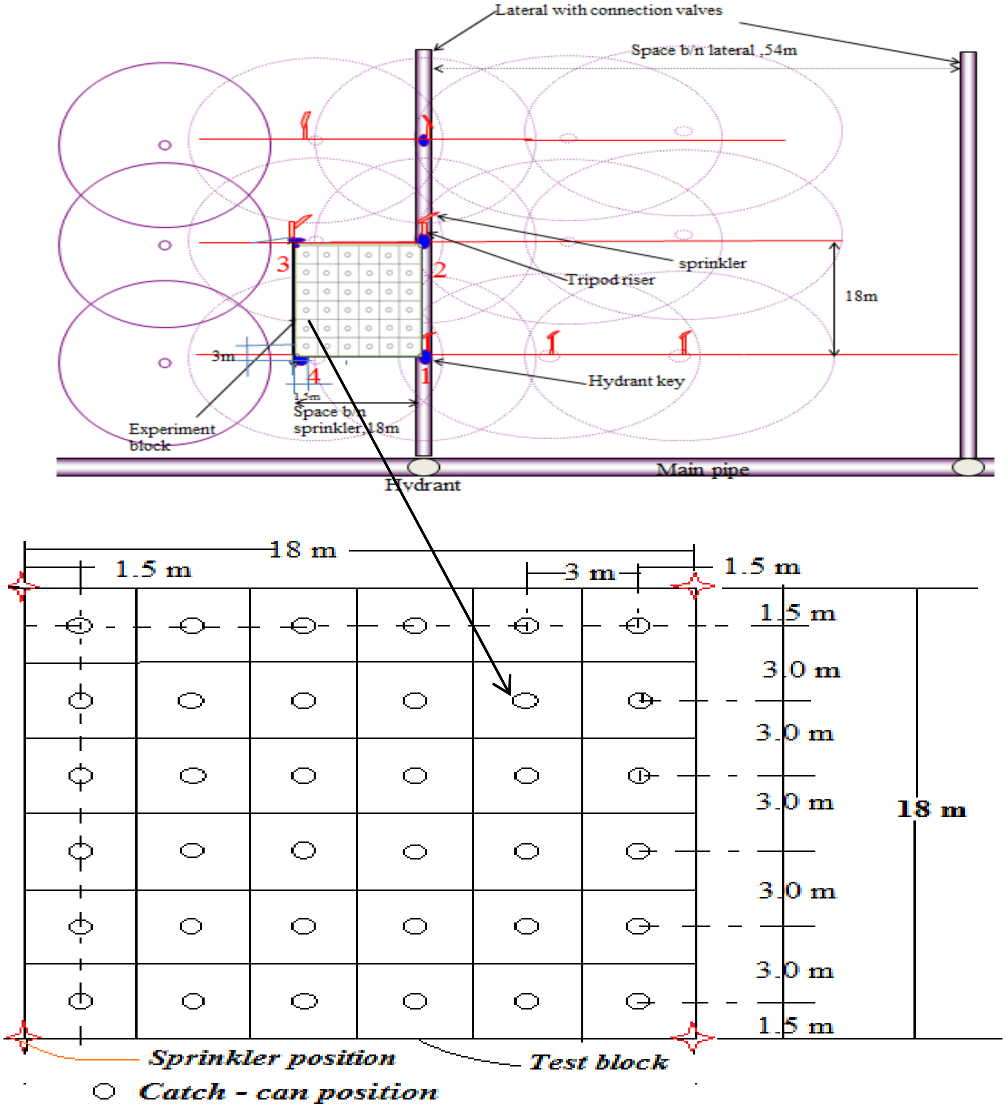


Figure 3.4: Experimental design profile for Tedecha Large Scale Irrigation Scheme.

3.4 Treatments Design

Three operating pressure levels at the hydrant (2.5 bar, 3.0 bar, and 3.5 bar), four levels of sprinkler riser height (2.5 m, 3 m, 3.5 m and 4 m), two levels of double nozzle size and five levels of wind speed condition (early morning, mid-day, late afternoon, early night and late night) were used to evaluate the effect of different combination and sprinkler system parameter.

By taking the 4th factor: wind speed condition as a temporal replication, it was combine two factor which is operating pressure and nozzle size (PN) which said factor A and the 3rd factor riser height (R) would remain alone and call as factor B.

So it was combine in design two factorials A and B arranged in Randomized Complete Block Design (RCBD) factorial design with five (5) replications. The combination of factorials is presented in Table 3.1 and 3.2.

Table 3.1. Combinations of hydrant pressure and nozzle diameter

	p_1	p_2	p_3
N_1	P_1N_1	P_2N_1	P_3N_1
N_2	P_1N_2	P_2N_2	P_3N_2

Table 3.2. Combinations of hydrant pressure, Nozzle diameter and riser height Combinations.

	P_1N_1	P_2N_1	P_3N_1	P_1N_2	P_2N_2	P_3N_2
R_1	$P_1N_1R_1$	$P_2N_1R_1$	$P_3N_1R_1$	$P_1N_2R_1$	$P_2N_2R_1$	$P_3N_2R_1$
R_2	$P_1N_1R_2$	$P_2N_2R_2$	$P_3N_1R_2$	$P_1N_2R_2$	$P_2N_2R_2$	$P_3N_2R_2$
R_3	$P_1N_1R_3$	$P_2N_2R_3$	$P_3N_1R_3$	$P_1N_2R_3$	$P_2N_2R_3$	P_3N_2R3
R_4	$P_1N_1R_4$	$P_2N_2R_4$	$P_3N_1R_4$	$P_1N_2R_4$	$P_2N_2R_4$	$P_3N_2R_4$

Where,

P_1, P_2, P_3 are operating pressure at the hydrant 2.5, 3.0, 3.5 bar respectively.

N_1, N_2 are nozzle diameter 4.4 and 4.8 mm.

R_1, R_2, R_3, R_4 are riser height at 2.5 m, 3.0 m, 3.5 m, 4.0 m respectively.

The more detail combinations of operating pressure (p_n) nozzle diameter (N_n), riser height (R_n) and wind speed condition (C_n) are presented in appendix Table 1.

3.5 Empirical Equation and Analyses of Basic Index

Data recorded from block bounded by four sprinklers which have the same riser height which used to determine the evaporation and drift losses, irrigation application efficiency (potential application efficiency of low quarter and actual application efficiency of low quarter), irrigation uniformity (distribution uniformity, uniformity coefficient) and adequacy parameters were presented in the succeeding sections.

3.5.1 Evaporation and wind drift losses

Evaporation and wind drift losses was computed using (Trimmer, 1987) equation as cited by (Samir *et al.,* 2010) which was developed based the regression relationships and the geometry of the Frost and Schwalen:

$$E = [0.98(D)^{-0.72} + 0.22(e_s - e_a)^{0.63} + 3.6x10^{-4}(h)^{1.16} + 0.14(u)^{0.7}]^{4.2} \text{............}(3.4)$$

Where, E is evaporation and wind drift (%),

D is nozzle diameter (mm),

h is nozzle operating pressure (kPa),

U is wind velocity (m/s) and

e_s - e_a is vapor pressure deficit (kPa).

The vapor pressure deficit is given by:

$$e_s - e_a = 0.61\exp[17.27\frac{T}{(T + 237.3)}(1 - RH) \text{..}(3.5)$$

Where, T is Air temperature, ^{0}C

RH is Relative humidity, fraction.

By accounting the riser height as a variable, the best model for predicting the evaporation and drift losses from sprinkler method is shown below. The model is based on multiple regression analysis and the adequacy of the model is judged by using the criteria suggested by Drapper and Smith (1966) and Abo-Ghobar, (2002):

$$\ln E = 4.506 - 0.518\ln D + 0.703\ln H + 0.137\ln U - 0.04\ln RH + 0.022\ln T \text{................}(3.6)$$

Where, E is Evaporation and drift losses, %

D is Nozzle diameter, mm

H is Riser height, m

U is Wind velocity, Km/hr

RH is Relative humidity, %

T is Air temperature, ºC

3.5.2 Irrigation application efficiency

3.5.2.1 Potential application efficiency

Potential application Efficiency (PAE) is calculating by using equation Merriam *et al.,* (1983) as cited by (Kieffer, and Huck, 2008):

$$\text{PAE} = \left[\frac{\text{average depth of water received by can}}{\text{average depth of water applied at nozzles}}\right] x100 \ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots.(3.7)$$

3.5.2.2 Actual application efficiency of low quarter

Actual application efficiency of low quarter (AELQ) (%) was calculated by using equation Merriam *et al.,* (1983) as cited by (Kieffer, and Huck, 2008):

$$\text{AELQ} = \left[\frac{\text{average low quarter depth of water infiltrated and stored}}{\text{average depth of water applied}}\right] x100 \ldots\ldots(3.8)$$

3.5.3. Irrigation application uniformity

Irrigation application uniformity is evaluating using Christiansen uniformity coefficient (CU) and distribution uniformity (DU)

3.5.3.1 Christiansen uniformity coefficient (CU)

Christiansen uniformity coefficient (CU) is commonly used in agricultural sprinkler uniformity assessment and can be expressed by (ASAE, 2009)

$$CU = 100\left(1 - \frac{\sum_{i=1}^{n} / D_i - D /}{\sum_{i=1}^{n} D_i}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.9)$$

Where, CU is Christiansen Uniformity Coefficient (%),

D_i is individual depth caught in can (mm)

D is the mean depth caught (mm) and

n is the number of catch cans.

3.5.3.2. Distribution uniformity/Pattern Efficiency/

This uniformity measure is also called low-quarter distribution uniformity and it is often used to quantify irrigation uniformity of surface systems (King et al, 2000). The DU coefficient takes into account when the variation of catch can readings from the mean but concentrates on the lowest 25% of readings.

According to Ascough and Kiker, (2002) the commonly used lower quarter fraction, which has been used by the USDA since the 1940s is as follows

$$DU = 100\left(\frac{M_{25}}{M}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.10)$$

Where,

DU is distribution uniformity (%),

M_{25} is average low quarter depth /lower 25% of all the can readings

M is average depth of water accumulated in all catch can.

On the other hand distribution uniformity to be defined by (Burt *et al.,* 1997) as cited by Ascough and Kiker, (2002): from above equation (eqn.3.10) the low-quarter distribution

Uniformity, DU_{lq} can be defined as

$$Dlq = \frac{D_{ave.ld}}{D_{ave.}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.11)$$

Where,

$D_{ave,lq}$ (mm) is average low quarter depth.

D_{ave} (mm) is the total volume accumulated in all catch cans divided by total number catch cans.

3.5.4 Pressure variation and discharge rate

Pressure variation was calculated using the following equation (Beer and Bhembe, 2008):

$$\Delta P = \left(\frac{\text{Pmax} - \text{Pmin}}{Pave}\right) \text{x}100 \ldots\ldots\ldots\ldots\ \ldots\ldots\ldots\ldots\ldots (3.12)$$

Where,

ΔP is Pressure variation, %

P_{max} is Maximum operating pressure (Kpa)

P_{min} is Minimum operating pressure (Kpa)

P_{ave} is Average operating pressure (Kpa)

The discharge was calculated using the following formula (Beer and Bhembe, 2008):

$$q = \left(\frac{\text{average volume of water measured in catch can (lt)}}{average\ duration\ to\ fill\ catch\ can(\text{sec})}\right) \ldots\ldots\ldots\ldots (3.13)$$

Where, q is actual sprinkler discharge rate, l/s

The discharge and pressure variation across the lateral was checked against the maximum recommended values (±10% for discharge and ±20% for pressure). Then, the average gross application rate under the sprinkler was computed by the following formula (Samir Y. at el., 2010):

$$d_g = \left(\frac{q}{Sl\ x\ Sm}\right)360 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.14)$$

Where, d_g is Gross application rate, cm/hr.

q is Sprinkler nozzle discharge, l/s

S_l is Lateral spacing, m

S_m is mainline spacing, m

Multiply this by the set time in hours to find gross depth applied. Gross depth is multiplied by the application efficiency to find the average net depth applied. This is the amount of water available to the crop in the root zone as a result of irrigation (Thomas, 2003).

3.5.5 Jet break-up index

The drop size condition was computed using the empirical formula suggested by Tanda (Pillsbury, 1968; as cited in Michael, 2005) provides an index of jet break-up:

$$P_d = \left(\frac{h}{10q}\right)^{0.4} \text{...}(3.15)$$

Where,

P_d is Index for jet break-up

h is pressure head at nozzle, m

q is sprinkler discharge, l/sec

It has been noticed that if P_d is greater than 2, the condition of drop size is good; if 4, the condition of drop size is best; and if greater than 4, pressure is being wasted (Michael, 2005).

3.5.6 System Uniformity

In order to evaluate the whole system two additional coefficients are determined: the system uniformity coefficient (System UC) and the system distribution uniformity (System DU) by considering the pressure variation in the system according to Keller & Bliesner, (2000),which can be calculated with the following:

$$CU \text{ system} = \text{CU x} \frac{1 + \sqrt{(\text{Pn}/\text{Pa})}}{2} \dots\dots\dots\dots\dots\dots\dots (3.16)$$

$$DU \text{ system} = \text{DU x} \frac{1 + 3\sqrt{(\text{Pn}/\text{Pa})}}{4} \dots\dots\dots\dots\dots\dots\dots (3.17)$$

Where,

P_n is the minimum sprinkler pressure, KPa

P_a is the average sprinkler pressure, KPa

3.5.7 Crop water requirement

The crop water requirement (CWR) and irrigation scheduling of sugarcane was determined by using CROPWAT 8.0 computer program which is based on the modified FAO Penman-Monteith equation for the calculation of the reference crop ET. The meteorological data required to estimate CWR was obtained from Sodere Resort Meteorological Station.

The need for the determination of CWR is to fix the irrigation set time based on the recommended sprinkler combination. Since the crop is ratoon and already established root, by making an observation the effective root depth was taken as 0.55 m. When there was rain fall during irrigation, the effective rain fall was reduced from the next irrigation and it is calculated using the (USDA SC) method available from CROPWAT 8.0:-

$$Peff = \frac{(P(125-0.2P)}{125}, \text{ if P } \leq 250\text{mm} \ldots\ldots(3.18)$$

$$Peff = 125 + \frac{1}{10}P, \text{ if P } > 250\text{mm} \ldots\ldots(3.19)$$

Where,

P_{eff} is effective rain fall (mm)

P is total rain fall (mm)

3.6 Data Analysis

Analysis of the effect of dragline operating pressure, riser height, wind speed and nozzle diameter on irrigation water application under different wind speed condition, a number of combination and performance parameter measurements were determined by the equation mentioned earlier (eqn. 3.1 – 3.17) and statistical analysis.

Data collected during field studies were subjected to analysis of variance using the Microsoft excel (ANOVA) software package for statistical analysis and CROPWAT 8.0 software package to schedule effective irrigation interval of specific combination

4. RESULTS AND DISCUSSION

4.1. Evaporation and Wind Drift Losses

Average results from the analysis of evaporation and drift losses are shown in Figure 4.1 and Figure 4.2. Climatic variables; air temperature, humidity, wind speed and direction together with the effects of factors assumed; operating pressure, riser height, nozzle size, were the base for quantifying and modeling evaporation and drift losses.

Considering the operating pressure as a variable, by using Trimmer (1987) as cited in Smajstrla, and Zazueta, (2003) evaporation and wind drift losses equation, the losses ranged from 3.38% for 4.8 mm nozzle size and 2.5 bar operating pressure to 7.56% for 4.4 mm nozzle size and 3.5 bar operating pressure in morning wind speed condition 8.63% for 4.8 mm nozzle size and 2.5 bar operating pressure to 17.32% for 4.4 mm nozzle size and 3.5 bar operating pressure in mid-day wind speed condition, 6.86% for 4.8 mm nozzle size and 2.5 bar operating pressure to 12.55% for 4.4 mm nozzle size and 3.5 bar operating pressure in late afternoon wind speed condition, 2.98% for 4.8 mm nozzle size and 2.5 bar operating pressure to 6.54% for 4.4 mm nozzle size and 3.5 bar operating pressure in early night wind speed condition, from 2.04% for 4.8 mm nozzle size and 2.5 bar operating pressure to 5.43 for 4.4 mm nozzle size and 3.5 bar operating pressure in late night wind speed condition (Figure 4.1).

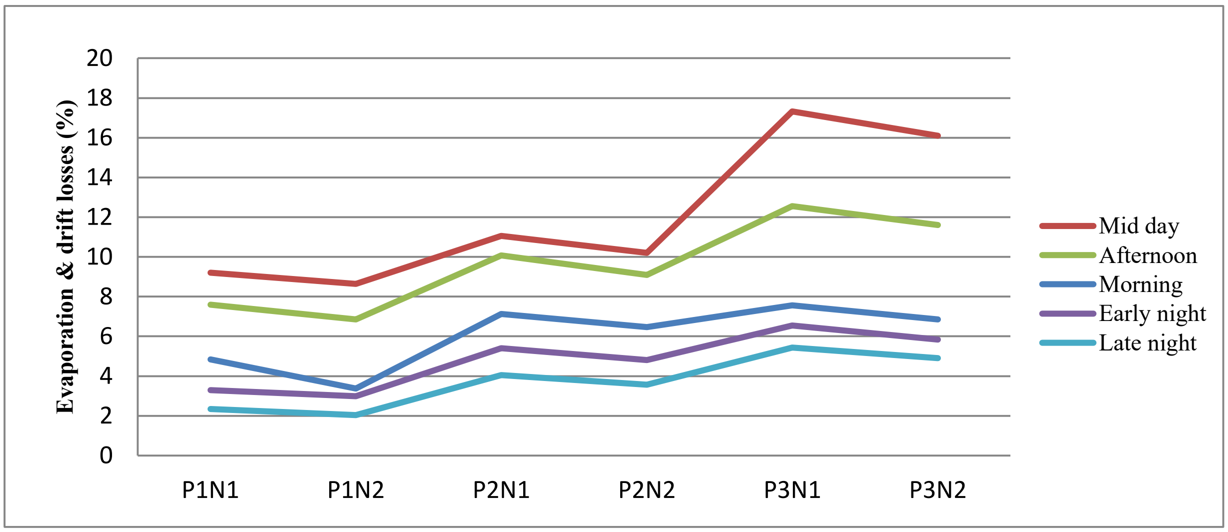
Climatic conditions was their own effect on evaporation and wind drift losses. Evaporation and drift losses increased as wind speed increased (Table 4.1). High evaporation in the mid-day wind condition is related to warming of the air. Winds during the mid-day was heavier and warm but during night was calm or quite light. The surface layer of air (the air that cools off at night) becomes somewhat heavier than warmer air above it and friction causes its wind to become calm or much lighter than in the warmer air.

In the morning, when sunlight returns and begins to warm the surface layer, the wind from above gradually builds downward and returns to the surface. At night, winds above the surface layer often increase in strength because its energy is not dissipated by contact with the ground. It can be observed from the result as wind speed increased; evaporation and wind drift also increased.

This circumstance leads to high evaporation and drift losses at day irrigation time than night irrigation time. Detail was presented in appendix table 4-8.

For the same pressure, evaporation and wind drift losses (E%) increased in N_1 as compareред N_2 because small droplet create by small nozzle size (N_1) was more susceptible for wind distortion and transported from irrigated field than droplet created by relatively larger nozzle size (N_2).

For the same nozzle size, evaporation and wind drift losses (E%) increased as operating pressure increased. This was due to under windy conditions, the distribution of the very small water droplets created by excessive pressures was easily distorted and transported to surrounding areas by wind as a losses.



P_1, P_2, P_3 are operating pressure at 2.5, 3.0 and 3.5 bar; N_1, N_2 are nozzle diameter at 4.4 mm and 4.8 mm respectively.

Figure 4.1. Evaporation & Drift losses Vs Pressure under different wind condition.

The below results(Table 4.1) indicated that evaporation and drift losses increased as operating pressure, wind speed increased and nozzle size decreased. Nozzle size, operating pressure and wind speed are the predominant factors that affect losses from sprinkler system.

Table 4.1. Evaporation & drift losses under various climatic conditions, operating pressure & nozzle size.

No of observation	Nozzle size(mm)	operating pressure (bar)	wind speed (m/sec)	air temperature (0c)	Relative humidity (%)	Evaporation & wind drift losses (%)
1		2.5	3.43	27.2	50	10.29
2	4.4	3	4.11	30.5	32	14.83
3		3.5	5.57	30	43	17.32
4		2.5	2.19	19	90	2.04
5	4.8	3	2.2	19	67	4.33
6		3.5	2.85	30	40	12.17

By considering the riser height as a variable, maximum evaporation and wind drift losses ranged from 6.99% for nozzle size of 4.8 mm and riser height of 2.5 m to 13.65 % for 4.4 nozzle size and 4.0 m riser height in morning wind speed condition, 9.25% for 4.8 mm nozzle size and 2.5 riser height to 19.9 % for 4.4 mm nozzle size and 4.0 m riser height in mid-day wind speed condition, 9.72% for 4.8 mm nozzle size and 2.5 riser height to 17.12% for 4.4 mm nozzle size and 4.0 m riser height in late afternoon wind speed condition, 6.69% for 4.8 mm nozzle size and 2.5 riser height to 13.01% for 4.4 mm nozzle size and 4.0 m riser height in early night wind speed condition, 2.22 % for 4.8 mm nozzle size and 2.5 riser height to 11.56 % for 4.4 mm nozzle size and 4.0 m riser height in late night wind speed condition (Figure 4.2). Details' was presented in appendix table 9-13.

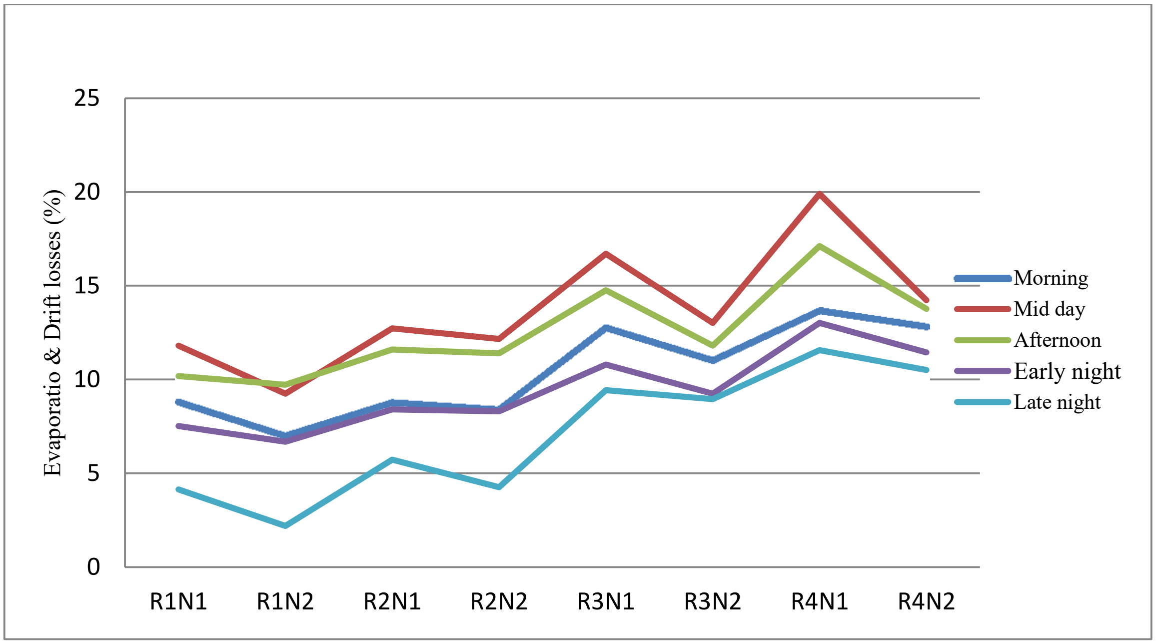


Figure 4.2.Evaporation & Drift losses Vs Riser height under different wind condition.

In general evaporation and wind drift losses increased with increasing riser height and decreased with increasing nozzle size. Abo-Ghobar (2002) reported that riser and nozzle size were the predominant factors affecting evaporation and wind drift losses, and evaporation and drift losses increased with increased riser height, which agreed with this study.

4.2. Operating Pressure and Sprinkler Discharge

4.2.1. System operating pressure

Average measurement results of sprinkler pressure are given in Table 4.2. Taking nozzle size into account, as nozzle size increased from 4.4 to 4.8 m, nozzle pressure increased due to smaller size nozzle would also increase the water pressure. At 2.5 bar of hydrant key pressure, nozzle pressure was increased from 1.98 to 2.01 bars, from 1.95 to 1.98 bars, from 1.91 to 1.95 bars and 1.89 to 1.92 bars for the respective nozzle size of 4.4 and 4.8 mm. At 3.0 bar of hydrant pressure, nozzle pressure was increased from 2.40 to 2.55 bars, from 2.35 to 2.43 bars, from 2.31 to 2.40 bars and from 2.27 to 2.39 bars for nozzle size of 4.4 mm and 4.8 mm, respectively and at 3.5 bar hydrant pressure, the nozzle pressures increased from 2.92 to 2.95 bars, from 2.88

to 2.90 bars, from 2.85 to 2.88 bars and from 2.82 to 2.83 bar for nozzle size of 4.4 and 4.8 mm, respectively.

Taking riser height into account as the riser height increased from 2.5, to 3, 3 to 3.5, 3.5 to 4.0 m, the nozzle pressure was decreased (Table 4.2).

Table 4.2. Average sprinkler pressure for different combinations (bar)

	P_1		P_2		P_3	
	N_1	N_2	N_1	N_2	N_1	N_2
R_1	1.98	2.01	2.40	2.55	2.92	2.95
R_2	1.95	1.98	2.35	2.43	2.88	2.90
R_3	1.91	1.95	2.31	2.40	2.85	2.88
R_4	1.89	1.92	2.27	2.39	2.82	2.83

P_1, P_2, P_3 is operating pressure at 2.5, 3.0 and 3.5 bar; N_1, N_2 is nozzle size at 4.4 and 4.8 mm; R_1, R_2, R_3, R_4 is riser height at 2.5,3, 3.5 and 4.0 m; respectively.

According to Beer and Bhembe, (2008), pressures in the lateral may not vary more than 20% of the average pressure or a variation in discharge of 10%. The results obtained are within the recommended range except for operating pressure of 2.5 bar, riser height of 3.0 m (R_2), 3.5 m (R_3), 4.0 m (R_4) at nozzle size of 4.4 mm and riser height 3.5 m (R_3), 4.0 m (R_4) at nozzle diameter of 4.8 mm and at operating pressure of 3.0 bar, riser height of 3.0 m (R_2), 3.5 m (R_3), 4.0 m (R_4) at nozzle size of 4.4 mm combination which reflected pressure variation of more than 20% (Table 4.3). This magnitude of Pressure variation might be caused by excessive friction loses (head loss) through the pipelines of the lateral as well as the risers and due to topography of study area.

As it is indicated in the Table 4.3 pressure variation decreases as operating pressure increases. This finding agreed with report of Megersa (2004). Pressure variation declined as the operating pressure increased from 2.5 to 3.0 and 3.0 to 3.5 bars. Pressure variation was also an inversely relationship to nozzle sizes which is contrast with Megersa (2004) reported. Pressure variation decreased as the nozzle diameter increased from 4.4mm (N_1) to 4.8 mm (N_2).

Pressure variation increased as riser height increased from 2.5m to 3.0m, from 3.0 to 3.5m, from 3.5m to 4.0 m which show direct relation to riser height. Maximum pressure variation of 24.4%

was observed in operating pressure 2.5 bar, nozzle diameter 4.4 mm and riser height 4.0 m combination.

Table 4.3. Pressure variations calculated from field measurements (%)

	P_1		P_2		P_3	
	N_1	N_2	N_1	N_2	N_1	N_2
R_1	20.08	19.6	20	15	16.57	15.7
R_2	22	20.8	21.6	19	17.71	17.14
R_3	23.6	22	23	19.7	18.57	17.77
R_4	24.4	23.2	24.3	20	19.42	19.14

4.2.2. Application rate

Sprinkler discharge rate has a direct relation to the operating pressure and nozzle size and inverse relation to the riser height (Table 4.4, 4.5 and 4.6). Sprinkler application rate ± 10% recommended by manufacture is acceptable.

However of application rate obtained at combination of operating pressure at 2.5 bar, riser height 2.5 m, 3 m, 3.5 m and 4 m ($P_1N_1R_1$, $P_1N_1R_2$, $P_1N_1R_3$ and $P_1N_1R_4$),at 3.0 bar, riser height 2.5 m, 3.0 m, 3.5 m, and 4 m ($P_2N_1R_1$,$P_2N_1R_2$,$P_2N_1R_3$ and $P_2N_1R_4$) and at 3.5 bar, riser height 2.5 m, 3.0 m, 3.5 m, and 4 m ($P_3N_1R_1$, $P_3N_1R_2$, $P_3N_1R_3$ and $P_3N_1R_4$) at nozzle size 4.4 mm was small as compared to the average design application rate of 4.70 mm/hr. The reason may be clogging of screen filter with sediments which affect sprinkler head (spreader nozzle) discharge by blocking the flow.

On the other hand except the application rate of 3.362 mm/hr obtained at combination of operating pressure 2.5 bar, nozzle diameter 4.8 mm and riser height 4.0 m (P1N2R4) are meet the design application rate of 4.90 mm/hr for nozzle diameter 4.8. This shows that, if we use 4.4 mm nozzle size, the system does not meet the peak requirement of the crop. The average infiltration rate obtained from the field tests was 27 mm/hr. Thus, the sprinkler system could perform without the occurrence of runoff.

Table 4.4. Effect of nozzle size on sprinkler application rate (mm/hr) for combinations of operating pressure, nozzle size and riser height.

	N_1			N_2		
	P_1	P_2	P_3	P_1	P_2	P_3
R_1	3.379	3.534	3.741	4.594	4.894	4.992
R_2	3.356	3.483	3.701	4.526	4.861	4.922
R_3	3.323	3.422	3.676	4.449	4.818	4.842
R_4	3.281	3.353	3.518	4.362	4.666	4.782

Table 4.5. Effect of operating pressure on sprinkler application rate (mm/hr) for combinations of operating pressure, nozzle size and riser height.

	P_1		P_2		P_3	
	N_1	N_2	N_1	N_2	N_1	N_2
R_1	3.379	4.594	3.534	4.894	3.741	4.992
R_2	3.356	4.526	3.483	4.861	3.701	4.922
R_3	3.323	4.449	3.422	4.818	3.676	4.842
R_4	3.281	4.362	3.353	4.666	3.518	4.782

Table 4.6. Effect of riser height on sprinkler application rate (mm/hr) for combinations of operating pressure, nozzle size and riser height.

	R_1		R_2		R_3		R_4	
	N_1	N_2	N_1	N_2	N_1	N_2	N_1	N_2
P_1	3.379	4.594	3.356	4.526	3.323	4.449	3.281	4.362
P_2	3.534	4.894	3.483	4.861	3.422	4.818	3.353	4.666
P_3	3.741	4.992	3.701	4.922	3.676	4.842	3.518	4.782

4.3. Wetted diameter and Jet Break-up index

4.3.1. Wetted diameter

The average wetted diameters measured from different combinations have ranged from 19.5m for the combination of operating pressure 2.5 bar, nozzle size 4.4 mm and riser height 4.0 m in the mid-day wind speed test conditioning ($P_1N_1R_4C_2$) to 27.0 m for the combination of operating pressure 3.5 bar, nozzle size 4.8 mm and riser height 2.5 m at late evening wind speed test condition (Table 4.7).

The wetted diameter increased as operating pressure increased up to optimum. Under excessive high operating pressures, very small water droplets was created. These small droplets was fall nearer the sprinkler and reduced the effective diameter of coverage and possibly reducing the uniformity of water application. Thus, the maximum operating pressure should be limited based on the sprinkler manufacturer's recommendations and existing climate demand of the area to achieve an acceptable diameters of coverage and uniformity of water application.

Table 4.7. Wetted diameters for different test combinations (m)

		N_1				N_2			
		R_1	R_2	R_3	R_4	R_1	R_2	R_3	R_4
	C_1	23.1	22.9	22.8	22.7	24.9	24.5	24.2	23.9
	C_2	22.2	22.3	20.4	19.5	22.8	24.5	22.3	22.1
P_1	C_3	23.5	22.8	22.0	21.3	24.8	24.9	26.4	24.5
	C_4	23.9	23.2	22.5	21.9	25.9	25.5	25.1	24.7
	C_5	24.6	23.5	22.4	22.3	26.9	26.3	25.5	25.9
	Mean	*23.46*	*22.96*	*22.05*	*21.54*	*25.08*	*25.158*	*24.7*	*24.22*
	C_1	25.3	24.9	24.5	23.6	24.9	24.6	24.3	24.1
	C_2	24.7	23.9	23.1	22.3	25.8	25.65	25.4	26.3
P_2	C_3	26	25.7	25.4	25.1	26.9	26.3	25.7	25.1
	C_4	26.8	26.3	25.8	25.3	27.3	26.767	26.13	25.7
	C_5	26.9	26.5	26.13	26.24	27.5	29	26.54	26.1
	Mean	*25.94*	*25.47*	*24.99*	*24.51*	*26.48*	*26.465*	*25.628*	*25.46*
	C_1	26.4	25.27	24.14	23	25.7	25.5	25.3	25.1
	C_2	25.8	22.7	24.4	24.2	26.6	25.7	24.8	23.9
P_3	C_3	25.7	25.5	25.3	25.2	26.9	25.93	24.96	24
	C_4	25.3	25.16	25.01	24.8	27.2	27	26.93	26.8
	C_5	25.4	26.26	25.12	25	27.5	27.36	27.13	26.9
	Mean	*25.72*	*24.98*	*24.79*	*24.44*	*27.87*	*26.298*	*25.826*	*25.34*

As it is indicated in the table 4.7 the wetted diameter increased as nozzle size increased and decreased as riser height increased.

4.3.2. Jet break-up index

The drop size condition of the sprinkler spray was determined from the jet break up index (P_d). The results of the jet break-up indexes are shown in Table 4.8. Based on the range of jet break-up index, the condition of drop size of the sprinkler spray in the study area is found to be good ($P_d > 2.0$) for all combinations. The jet break-up index increased as operating pressure and riser height increased from 2.5 bar to 3.0, from 3.0 bar to 3.5 bar and from 2.5 m to 3.0, from 3.0 to 3.5 m and from 3.5 m to 4.0 m, respectively, and decreased as nozzle size increased from 4.4 mm to 4.8 mm.

Table 4.8. average jet break-up index value for different sprinkler combinations

	N_1				N_2			
	R_1	R_2	R_3	R_4	R_1	R_2	R_3	R_2
P_1	2.37	2.41	2.44	2.48	2.1	2.2	2.24	2.3
P_2	2.55	2.6	2.66	2.73	2.27	2.3	2.33	2.36
P_3	2.64	2.7	2.72	2.75	2.4	2.46	2.49	2.5

The more detail Jet break-up index of combinations of operating pressure (P_n) nozzle diameter (N_n) and riser height (R_n) with five replication presented in appendix Table 14.

4.4. Irrigation Application Efficiency

4.4.1. Potential application efficiency

Application efficiency indicates a measure of system performance attainable under reasonably good management when the desired irrigation is being applied. Potential application efficiency (PAE) in percent is computed from the distribution data the average depth of catch can received and average depth of water applied at a nozzle and presented in Table 4.9.

The result showed a wide range of 51% to 93% (Table 4.9). The highest value of PAE indicated that the average depth of discharge from the sprinkler nozzle compared to the average depth recorded on the surface (catch can) was similar. The lowest PAE was recorded for combination of operating pressure 3.5 bar, nozzle diameter 4.4 mm, riser height 4.0 m and mid-day wind speed condition. The highest PAE was recorded for combination of operating pressure 3.0 bar, nozzle diameter 4.8 mm, riser height 4.0 m and late evening(night) wind speed conditioning.

PAE of 51% means 49% of the applied water was lost between the sprinkler nozzle and the ground surface. This was the effect of highest wind velocity occurred during the test. The average wind speed recorded during the test was 11.35 km/hr for $P_3N_1R_4C_2$ (51%) combination and 7.21 km/hr for $P_2N_2R_4C_5$ (93%) combination.

For all combinations the PAE value obtained during mid-day time test was lower than the values obtained during morning, late afternoon, early evening and late evening time tests. This was because of the wind speed in which it reached at peak during this time and the water applied to the cane was affected by drift losses. Magwenzi (2000) noted that due to wind distortions and other operating factors he found an application efficiency of 49% to 88% for dragline sprinkler.

For sprinkler irrigation the recommended minimum design application efficiency is 70% (Beer and Bhembe, 2008). About 27.5% of PAE results obtained were below the recommended (70%). This was mainly caused by excessive climate demand which mean wind speed, wind direction, surface and air temperature and droplet size which have significant role for the loss of applied water between the sprinkler head and the ground surface.

Table 4.9. Average PAE for different sprinkler combinations test (%)

		N_1				N_2			
		R_1	R_2	R_3	R_4	R_1	R_2	R_3	R_4
	C_1	77.5	78.2	79.7	81.3	81.5	82.2	82.8	83.2
	C_2	63.1	67.5	70	76.1	72.8	73	74	75.6
P_1	C_3	78.1	78.4	79	80.1	75.5	76	70	76
	C_4	80	80.7	81.1	82.4	82.7	83	83.8	85.7
	C_5	81.2	81.9	82.3	83	84	84.5	85.7	86
	C_1	85.1	86.2	87	90.4	82.1	84.7	88	90.7
	C_2	62.4	65	60	61.5	65.8	66.1	67	67.4
P_2	C_3	78.9	76	67	64.3	73.6	70	66.7	76
	C4	86	87.2	89.5	92	86.4	87.4	89.2	91
	C_5	87.6	85	85.8	88	88.3	89.3	90	93.6
	C_1	72	76.7	80.4	85.7	75.4	72.4	73	76.7
	C_2	62	64	67	51	65.2	64.8	63.5	61
P_3	C_3	69	72	73.1	76.4	73	72	71.4	71.2
	C_4	71	71.3	70.8	75	74	73.8	75.8	75.6
	C_5	73	74	73.5	76.7	76	76.4	78	79

Potential application efficiency of low quarter was determined by taking into account on the catch can evaporation during the test. It was determined in order to evaluate how effectively the system can utilize the water supply and what the total losses in the area. Then the total amount of water required to irrigate the field fully was estimated. The rates was used for computing PELQ of sprinkler systems to avoid confusion with AELQ.

The minimum value of PELQ was 25.7% at $P_3N_1R_4C_2$ combination during mid-day test and the maximum was 78.3% at $P_2N_2R_4C_5$ (Table 4.8). The average wind speed recorded during the test was 11.35 km/hr for $P_3N_1R_4C_2$ (25.7%) combination and 7.21 km/hr for $P_2N_2R_4C_5$ (78.3%) combination. Low value of PELQ indicates poor system design. Megersa (2004) reported in his work PELQ values of 63% to 76% of drag line sprinkler at Finchaa. All the values recorded during mid-day time were below 60% because of high weed speed occurred during the test.

Generally, PAE and PELQ increased as operating pressure increased from 2.5 to 3.0 bars except in the mid-day testing condition and decreased as operating pressure increased from 3.0 to 3.5 bars. By considering riser height, PAE and PELQ increased as riser height increased from 2.5m to 3.0,from 3.0m to 3.5m, from 3.5m to 4.0 m except at $P_2N_1C_2$, $P_2N_1C_3$, $P_3N_1C_2$, P_3N1C_3,$P_2N_2C_3$, $P_3N_2C_2$, $P_3N_2C_3$, $P_3N_2C_4$, $P_3N_2C_5$.Again by considering nozzle size, PAE and PELQ increased as nozzle size increased.

Table 4.10 Average PELQ for different sprinkler combinations test (%)

		N_1				N_2			
		R_1	R_2	R_3	R_4	R_1	R_2	R_3	R_4
	C_1	49.3	51.5	52.2	58.1	53.3	55.5	55.3	58
	C_2	34.9	40.8	42.5	50.8	44.6	46.3	46.5	52.3
P_1	C_3	49.9	51.7	51.5	54.8	47.3	49.3	42.5	45.7
	C_4	51.8	54	53.6	57.1	54.5	56.3	56.3	60.4
	C_5	53	55.2	54.8	57.7	55.8	57.8	58.2	60.7
	C_1	56.7	59.5	59.5	65.1	52.9	58	61.5	69.5
	C_2	34.2	38.2	32.5	36.2	37.6	39.4	39.5	49.1
P_2	C_3	50	43.3	39.5	39	45.4	43.3	39.2	67.7
	C_4	57.8	60.5	62	66.7	58.2	60.7	61.7	75.7
	C_5	59.4	58.3	58.3	62.7	60.1	62.6	62.5	78.3
	C_1	43.8	50	52.9	60.4	47.7	45.7	45.5	54
	C_2	33	37.3	39.5	25.7	37	38.1	36	35.7
P_3	C_3	40.8	45.3	45.6	51.1	44.8	45.3	43.9	45.9
	C_4	42.8	44.6	42.5	46.7	45.7	47.1	47.5	50.3
	C_5	44.8	47.3	46	51	47.8	49.7	50.5	53.7

4.4.2. Actual application efficiency of low quarter

Actual application efficiency of low quarter does not indicate the levels of adequacy and uniformity, the actual application efficiency of the low quarter was determined based on the low quarter depth of water infiltrated and stored in the effective root zone. The value of AELQ obtained from all the combinations were below 78.3%. The lowest AELQ was 24.2% for $P_3N_1R_4C_2$ combination and the highest AELQ was 69.1% for $P_2N_2R_1C_5$ combination (Table 4.11).

This implied that 30.9% to 75.8% of the applied water was lost as deep percolation below the effective root zone and/or lost as surface evaporation from the cane field. Megersa (2004) obtained AELQ value ranging from 29% to 32% for luvisol and 46% to 52% for vertisol in his work. The difference between PELQ and AELQ implies poor operation management of the system.

Table 4.11. AELQ for different sprinkler combination test (%)

		N_1				N_2			
		R_1	R_2	R_3	R_4	R_1	R_2	R_3	R_4
P_1	C_1	28.6	31.2	34	30.1	31.2	35.2	37.1	38
	C_2	28.9	30.8	29	27.4	34.1	36.1	37.5	32.3
	C_3	29.2	50	42.5	34.8	35.3	51.7	43.9	44.4
	C_4	32.8	51	49.6	57.1	38.5	52.3	52.2	59.4
	C_5	49	52.2	51.2	59	55.1	57.8	53.3	61.7
P_2	C_1	36.7	45.5	49.5	55.1	62.9	48	51.7	61
	C_2	28	33.2	37.5	36.2	39.6	34.4	39.1	40.2
	C_3	30	43.3	41.5	39	55.4	45.1	49.2	60.7
	C_4	52.8	57.5	59.9	61.1	63.1	59.2	53.4	62.5
	C_5	59.4	57.3	60.5	63	69.1	60.2	57.2	67.4
P_3	C_1	33.7	40	42.9	55	47.4	45.2	45.4	52
	C_2	27.2	34.3	31.5	24.2	37	38.1	35.6	32.1
	C_3	39.8	40.3	44.6	50.1	49.8	41.8	45.6	52.9
	C_4	41.3	44.2	47.5	56.1	51.5	57.4	57.4	58.5
	C_5	44.6	46.7	50	51.4	57.3	59.3	60.8	53.7

4.5. Irrigation Application Uniformity/Water Distribution Uniformity

The effect of operating pressure, riser height, nozzle size and wind speed on the water distribution pattern of sprinkler system was obtained by catching water from block (four sprinklers). The results obtained are presented and discussed in the following subsection.

Effect of operating pressure was their own effect on Christian uniformity coefficient and distribution uniformity. CU and DU was increasing from 2.0 bar to 3.0 bar but decreasing as pressure increased from 3.0 bar to 3.5 bar in the morning, mid- day, late afternoon, early evening and late evening wind condition. The detail was presented in Appendix Table 18 – 27.

The summarized results obtained and presented in table 4.12 and 4.13 shows the average CU, DU, values of a sprinkler parameter test. CU value ranges from 59.5% for $P_1N_1R_1C_2$ combination in the mid-day test to 90.0% for $P_2N_2R_4C_5$ combination in the late night test. DU value ranges from 55% for $P_1N_1R_1C_2$ combination to 87.2% for $P_2N_2R_4C_5$ combination. DU of

55% showed that the low quarter of the area received only 55% of the average. This means that under irrigation was occurred in the test area.

Table 4.12. CU values for different sprinkler parameter combinations test (%)

		N_1				N_2			
		R_1	R_2	R_3	R_4	R_1	R_2	R_3	R_4
P_1	C_1	74.5	75	78	80	83	83.2	83.6	83.7
	C_2	59.5	60.8	64	66	76.9	74.3	72	71.9
	C_3	74.5	77	79.2	81	82	83.1	84.5	85.4
	C_4	78	79.8	82	84	82.5	83.7	84.9	86.2
	C_5	78.6	80.7	83	85	83.2	84	86.8	87.5
P_2	C_1	82.4	82.7	83.4	83.9	87	87.7	88.5	89
	C_2	76.5	77.3	73.1	74.8	77.9	78.1	78.5	78.7
	C_3	77.4	78.7	80.4	82.4	84.7	85.2	86	86.8
	C_4	80	81.6	84.8	86	85.2	86	87.7	88.2
	C_5	82.8	84.3	85.2	87.7	88	88.2	89.6	90
P_3	C_1	76	77.2	77.9	78	76	78	82	84.4
	C_2	73	73.8	74.1	79	78.7	79.2	81.8	82.4
	C_3	74.5	75.7	77	78.1	79.7	80.1	80.7	81
	C_4	76	77.5	79	80	80.5	81	83.2	85
	C_5	79	81.2	83.8	85.2	85.2	85.8	86.2	87

Table 4.13. DU values for different sprinkler combinations test (%)

		N_1				N_2			
		R_1	R_2	R_3	R_4	R_1	R_2	R_3	R_4
P_1	C_1	64.1	65.2	67.3	68.2	69.5	71	74.2	75.2
	C_2	55	56.7	59	60	61.8	62	65.8	66
	C_3	60	63	67.3	69	70.5	74	74.3	75
	C_4	62	64.8	69.1	71.2	74	74.2	75.1	76
	C_5	63	65	70.5	72	75.4	76.5	78.3	79.5
P_2	C_1	71.4	72	73.2	74	74	78	80	82.5
	C_2	62	61.7	60.5	60	63	64	75	67.3
	C_3	67	68.7	70.1	71	73.4	74.4	75.3	75.9
	C_4	69.2	70.3	71	71.8	81	82	84.2	85
	C_5	70	70.8	71.4	73	83	84.7	86.1	87.2
P_3	C_1	65	67	68.7	70.2	66.8	68.7	75.8	78.4
	C_2	62	62.8	63.5	72.7	64.5	66	73	75.8
	C_3	64.8	65.5	66.8	68	71.6	72.6	73.7	74.2
	C_4	65.6	66.8	68.2	70	73	75.8	78.7	80
	C_5	66.8	67.5	69	71	75	77.4	82.6	84

Generally, the uniformity parameters increased as operating pressure increased from 2.5 bar to 3.0 bar but decreased when operating pressure increased from 3.0 to 3.5 bar. Moazed *et al*., (2010) reported that CU increased as operating pressure increased up to the optimum pressure**.**

CU and DU values showed increasing trend when nozzle size increased from 4.4 mm to 4.8 mm. This indicates that small size nozzles are susceptible to climatic parameter specifically to wind condition. Abo-Ghobar (2002) and Shauq (2003) reported that CU increased as nozzle size increased which is agreed to this study. Again when considering the riser height, the uniformity parameters increased as riser height increased from 2.5 m to 3.0 m, from 3.0 m to 3.5m, and from 3.5 m to 4.0 m.

Effect of wind speed on water application uniformity was studied at five levels of morning, mid-day, late afternoon, early night and late night time. Wind speed and direction in the study area showed continual variations i.e from morning to mid-day, mid-day to late afternoon, late afternoon to early night and from early night to late night. Relatively the variation in night time is low as compared to day time. Wind speed showed increasing trend in day time. During the mid-day test of uniformity wind speed reach peak and it affected application of water. Random variation of wind speed and direction, and the effect of nozzle size and operating pressure may be the reason for the variation of CU and DU under different wind speeds condition.

Effect of wind speed on the water application uniformity was also determined at the late night time. Effect of wind speed on water application uniformity was clearly shown that uniformity coefficient was decreased as wind speed increased. Generally, uniformity coefficients were high in late night test because of low wind speed at this time. Dechmi *et al.,* (2003) reported that a significant portion of CU variability was explained by wind speed alone.

As asserted by Merkley and Allen (2004) occasionally wind can help improve uniformity as the randomness of wind turbulence and gusts contribute to smoothening out the distribution pattern ($P_3N_1R_4C_1$ and $P_3N_1R_4C_2$). Wind speed in the mid-day (C_2) was higher than in the morning (C_1) testing condition, but CU in the mid-day (C_2) was slightly higher than morning (C_1) for this combination ($P_3N_1R_4C_1$, $P_3N_1R_4C_2$). This was shown in some combinations in which uniformity increased with some increased of wind speed.

4.6 Statistical analysis of parameters

The analysis of variance (Table 4.15, 4.16, 4.18 and 4.19) showed that there were no significant interactions between pressure*nozzle size, pressure*riser height, pressure*wind condition, nozzle size*riser height, nozzle size*wind condition, riser height*wind condition and pressure*nozzle size*riser height*wind condition on the different performance parameters (PAE, PELQ, CU and DU).

The analysis of variance in Table 4.15 and 4.16 showed that operating pressure was no significant (P>0.05) effect on PELQ and DU. The highest PELQ and DU values were found to be 69% and 72.6% at 3.0 bar and the least were 67.5% at 3.5 bar and 69.3 % at 2.5 bar respectively.

The analysis of variance in Table 4.16 and 4.17 showed that operating pressure was highly significant (p<0.01) effect on PAE and significant ((p<0.05) CU. The highest PAE and CU values were found to be 81% and 81.5 % at 3.0 bar and the least were 61% at 3.5 bar and 70.8% at 2.5 bar respectively.

Table 4.14. Effect of operating pressure on performance parameters.

Operating pressure (bar)	PAE (%)	PELQ (%)	CU%	DU (%)
2.5	63.2[a]	68.3	70.8[a]	69.3
3	74.5[b]	69	81.5[b]	72.6
3.5	61[a]	67.5	71.5[a]	70.2
CV	11.5	12.5	4.7	9.2
Mean	66.2	68.2	74.6	70.7
Standard Deviation	4.18	0.75	5.98	1.7

NB * Means with the same letter are not significantly different.

The mean separation showed that there was significant difference between the treatment means of 2.5 bar and 3.5 bar Vs 3.0 bar at 5% significant levels, but statistically there was no significant difference between the treatment means of 2.5 bar and 3.5 bar at 5% significant levels. This implies that operating the system at 2.5 bar and 3.5 bar pressure had statistically no significant difference on the mean of PAE and CU values. The analysis of variance in Table 4.15 and 4.19 showed that riser height was no significant (p>0.05) effect on PAE and PELQ values.

Table 4.15. ANOVA Table for PELQ

Source	df	SS	Mean Square	F value	P value
Replication	4	83.8335	20.973375	2.18	0.121
Treatment	23	92370.57	4016.1174	68.382	0.96
P	2	313.68519	156.8426	2.04	0.1373
N	1	266.3755	266.3755	3.53	0.0673
R	3	2.8444	0.948	0.031	0.8501
C	4	5728.0984	2879.0492	38.62	<.0001
P*N	2	337.9763	168.98815	2.28	0.1176
P*R	6	225.2697	37.54496	1.62	0.27
P*C	8	387.4825	48.435312	1.32	0.2978
N*R	3	194.6697	64.889	2.6	0.116
N*C	4	116.5885	29.1471	0.79	0.4733
R*C	12	175.3881	14.6156	1.31	0.3184
P*N*R	6	1470.155	245.025	1.168	0.3222
Error	92	15.06678	0.163769		
Total	119	101,714.79	854.74617		

Table 4.16. ANOVA Table for DU

Source	df	SS	Mean Square	F value	P value
Replication	4	93.4714	23.367	1.08	0.3446
Treatment	23	2,985.56	129.80695	16.4	0.9773
P	2	150.00041	75.000205	1.56	0.2333
N	1	790.44711	790.44711	17.4	<.0001
R	3	244.0012	81.33733	5.42	0.0256
C	4	1343.058	335.76	14.88	<.0001
P*N	2	153.4041	76.70205	1.57	0.1984
P*R	6	79.66878	13.278	0.89	0.4282
P*C	8	338.42193	42.3027	1.86	0.1392
N*R	3	1.822481	0.60749	0.06	0.8221
N*C	4	13.48993	3.3725	0.14	0.8532
R*C	12	15.38888	71.2824	0.18	0.921
P*N*R	6	582.6613	97.11022	0.8	0.7047
Error	92	17.0134	0.1849		
Total	119	6,791.92	57.074957		

The highest PAE value was found to be 76.1% at 2.5 m and the least was 73.2% at 4.0 m. The highest PELQ value was 56% at 4.0 m and the least was 53% at 2.5 m.

The analysis of variance in Table 4.16 and 4.18 showed that riser height was significantly ($p<0.01$) effect on CU and DU riser height. The highest values were found to be 83.4% and 76.4% at 4.0 m and the least was 75.6% and 67 % at 2.5 m, respectively.

The mean separation showed that there was significant difference between the treatment means of 2.5 m Vs 3 m, 2.5 m Vs 3.5 m, 2.5m Vs 4.0 m, 3m Vs 3.5 m, 3 m Vs 4.0 m, 3.5 m Vs 4.0 m at 5% significant levels on the mean of CU and DU.

Table 4.17. Effect of riser height on performance parameters

Riser height(m)	PAE (%)	PELQ (%)	CU (%)	DU (%)
2.5	76.1	53	75.6^{a}	67^{a}
3	75.4	55	80.7^{c}	71^{b}
3.5	74.5	55.2	78^{b}	75^{c}
4	73.2	56	83.4^{d}	76.4^{d}
CV	11.5	12.5	4.7	9.2
Mean	74.8	54.8	79.4	72.35
Standard Deviation	1.25	1.28	3.37	4.23

Table 4.18 ANOVA Table for CU

Source	DF	SS	Mean Square	F value	P value
Replication	4	21.399449	5.349862	0.65	0.5542
Treatment	23	2,354.33	102.36217	17	0.981
P	2	58.6322276	29.316114	1.81	0.041
N	1	970.445232	970.44523	59.11	<.0001
R	3	71.8221442	23.940714	0.68	0.0456
C	4	291.3222549	72.830563	17.92	<.0001
P*N	2	36.9074074	18.953704	1.1	0.355
P*R	6	564.223422	94.037236	0.84	0.572
P*C	8	98.0455522	12.255694	1.22	0.889
N*R	3	11.0843342	3.694778	0.63	0.4386
N*C	4	16.7400174	4.1850042	0.48	0.6018
R*C	12	33.6555577	2.8046298	1.09	0.3941
P*N*R	6	180.0566231	30.009436	4.31	0.2491
Error	92	17.88692	0.194423		
Total	119	4,365.89	36.68815		

Table 4.19. ANOVA Table for PAE

Source	DF	SS	Mean Square	F value	P value
Replication	4	199.666711	49.916716	0.92	0.4067
Treatment	23				
P	2	1899.47789	949.73895	9.13	0.0013
N	1	154.744701	154.7447	1.52	0.2392
R	3	144.44421	48.14807	1.34	0.256
C	4	5240.88921	1310.2223	24.71	<.0001
P*N	2	34.712471	17.356236	0.16	0.8591
P*R	6	194.685185	32.44753	10.1	0.4137
P*C	8	722.87787	90.359733	1.67	0.1766
N*R	3	114.37371	90.35973	1.06	0.3133
N*C	4	262.41851	65.60476	1.21	0.3276
R*C	12	450.787534	37.56652	2.14	0.1367
P*N*R	6	2131.56901	355.2607	1.47	0.3125
Error	92	14.9273	0.162253		
Total	119	4,365.89	36.68815		

The analysis of variance in Table 4.15 and 4.19 showed that nozzle diameter was no significant ($p>0.05$) effect on PAE and PELQ. The highest PAE and PELQ values were found to be 72.8% and 58.2% at 4.8 mm and the least were 70.9% and 55.3% at 4.4 mm, respectively.

The analysis of variance in Table 4.16 and 4.18 showed that nozzle diameter were highly significant ($p<0.01$) effect on both CU and DU. The highest values were found to be 83.1% and 73.7% at 4.8 mm and the least was 77.2% and 68.5% at 4.4 mm, respectively.

The mean separation showed that there was significant difference between the treatment means of 4.4 mm Vs 4.8 mm at 5% significant levels.

Table 4.20. Effect of nozzle size on performance parameters

Nozzle size(mm)	PAE (%)	PELQ (%)	CU (%)	DU (%)
4.4	70.9	55.3	77.2^{b}	68.5^{b}
4.8	72.8	58.2	83.1^{a}	73.7^{a}
CV	11.5	12.5	4.7	9.2
Mean	71.85	56.75	80.15	71.1
Standard Deviation	1.34	2.05	4.17	3.67

The analysis of variance in Table 4.16 and 4.18 showed that wind conditions were highly significant ($p<0.01$) effect on both CU and DU). The highest CU and DU values were found to be 85.2% and 81.3% for late night test and the least were 72.8% and 63% for mid-day test, respectively.

The mean separation showed that there was significant difference between the treatment means of early night and late night Vs mid-day test, morning and afternoon Vs mid-day, early night and late night Vs morning and afternoon test at 5% significant levels, but

Statistically there was no significant difference between the treatment means of morning and late afternoon tests, morning and afternoon tests at 5% significant levels. This implies that irrigating during morning and late afternoon time had statistically no significant difference on the means of CU and DU.

Table 4.21. Effect of wind on performance parameters

wind condition	PAE (%)	PELQ (%)	CU (%)	DU (%)
Morning	80.2[c]	52.9[c]	81.2[b]	74[b]
Mid-day	62.2[e]	37.6[e]	72.8[c]	63[c]
Afternoon	77[d]	45.4[d]	80[b]	73.4[b]
Early night	82[b]	58.2[b]	85[a]	80[a]
Late night	83.5[a]	60.1[a]	85.2[a]	81.3[a]
CV	11.5	12.5	4.7	9.2
Mean	76.98	50.84	80.84	74.34
Standard Deviation	8.6	9.34	5.04	7.24

The analysis of variance in Table 4.15 and 4.19 showed that wind conditions were highly significant ($p<0.01$) effect on performance parameters (PAE and PELQ). The highest PAE and PELQ values were found to be 83.5% and 60.1% for early night time test and the least were 62.2% and 37.6% for mid-day test, respectively.

The mean separation showed that there was significant difference between the treatment means of the different wind conditions at 5% significant levels. This implies that irrigating during morning, mid-day, late afternoon, early night and late night time had statistically significant difference on the means of PAE and PELQ.

4.7. System Uniformity

Uniformity parameters calculated from the block test should be adjusted to apply it to the whole system by considering the pressure differences in the system. It was calculated based on the minimum (Pn) and average pressures (Pa) across the lateral which was developed by Keller and Bliesner (2000). The results of the system CU and DU are presented in Table 4.22 and 4.23.

Table 4.22. System CU values for different sprinkler parameter combinations test (%)

		N_1				N_2			
		R_1	R_2	R_3	R_4	R_1	R_2	R_3	R_4
	C_1	71.8	70.3	72.5	79	80.4	78	78.5	79.1
	C_2	57.3	56.5	59.5	61.3	73.8	69.8	67.7	67.8
P_1	C_3	71.3	71.6	73.6	75.3	78.7	78	79.4	80.3
	C_4	74.8	74.2	76.2	78.1	79.2	78.6	79.8	81
	C_5	75.4	75	77.1	79	79.8	78.9	81.6	82.3
	C_1	79	78.5	78.3	79.7	84.4	83	84	85
	C_2	73.4	73.4	69.4	71	75.5	74.1	74.5	82.3

P_2	C_3	74.3	74.7	76	78..3	82.2	80.9	81.7	82.9
	C_4	76.8	77.5	80.5	81.7	82.6	81.7	83.3	84.4
	C_5	79.4	80.2	80.9	83	85.4	83.7	85	86
	C_1	74.5	73.3	74	74.8	73.7	74.8	78.7	81
	C_2	71.5	70.1	70.3	75.8	76.3	76	78.7	79
P_3	C_3	73	71.9	73	74.9	76.5	76.8	76.9	77.7
	C_4	74.4	73.6	75	76	77.2	77.7	79.6	81.6
	C_5	77.4	77.1	79.6	80.9	81.7	81.5	82.7	83.5

Because of the pressure and discharge variation among the whole system of the field, the system CU and DU values were less than the CU and DU obtained actually during the test.

Table 4.23. System DU values for different sprinkler parameter combinations test (%)

		N_1				N_2			
		R_1	R_2	R_3	R_4	R_1	R_2	R_3	R_4
	C_1	60.2	58.6	60.5	61	66	64.6	67.5	68.4
	C_2	51.7	51	53	54	58.7	56	60.7	60
P_1	C_3	56.4	56.7	60	62.1	66.9	67	67.6	68
	C_4	58.1	57.6	62	64	68.4	68	68.3	69
	C_5	59.2	58.5	63	64.8	71.6	69.6	71.3	72.3
	C_1	67.8	66.9	66	68.8	71	72.5	74.4	76.7
	C_2	58.9	57.3	55.1	55.8	60	59.5	69.7	62.5
P_2	C_3	63.6	63.8	63.7	66	70	66.4	68.8	70
	C_4	65.7	65.3	64.4	66.7	77.7	76.26	78	79
	C_5	66.5	65.8	64.9	67.9	79.7	78.7	79	81
	C_1	63	62	63.8	65.9	64	64.5	71.2	73.6
	C_2	60	58	58.6	69.7	61	62	68.6	71.3
P_3	C_3	62.8	60.9	62	63.3	68	68.2	69.2	69.7
	C_4	63.6	62	63	65.1	70	71.3	73.9	75.2
	C_5	64.7	62.7	64.1	66	72	72.7	77.6	78.9

4.8. Adequacy

The common water delivery performance indicator is whether adequate water is reaching the field to meet the required amount of water. Delivery performance ratio (DPR) is the simplest indicator that could be used by irrigation managers to assess performance of operation. It could be used to assess adequacy as it gives information on the amount of water delivered in comparison with the amount of water intended to be delivered at a given location in the field.

4.8.1. Water delivery performance

The ratio of the data generated from the discharge tests to that of the expected sprinkler discharge was used to compute the delivery performance ratio (DPR) of the sprinkler system which is a measure of the system performance. The average delivery performance ratio ranges from 0.75 for $P_1N_1R_4$ combination to 1.22 for $P_3N_2R_1$ combination (Table 4.24).

The adequacy levels of 1.22 indicates the delivery is adequate and at least 22% of excess water was discharged. From table 4.24 it can be seen that water delivery ratio increased as operating pressure as well as nozzle size increased. Water delivery ratio decreased as riser height increased.

Table 4.24. Adequacy of water delivery performance ratio for different sprinkler combinations.

	P_1		P_2		P_3	
	N_1	N_2	N_1	N_2	N_1	N_2
R_1	0.81	1.08	0.85	1.12	0.93	1.22
R_2	0.78	1.06	0.84	11.4	0.91	1.21
R_3	0.77	1.04	0.83	1.1	0.9	1.19
R_4	0.75	1.02	0.81	1.06	0.88	1.17

4.8.2. Water infiltration performance

By assuming the depth of water in the catch can was infiltrated into the soil, adequacy of the water infiltration performance was calculated from the amount of water required for consumptive use (3.2 mm/hr.). It ranges from 0.59 for $P_3N_1R_4C_2$ combination to 1.53 for $P_3N_2R_1C_5$ combination (Table 4.25). The adequacy levels of 0.59 means 59% of the field receives at least the net depth of irrigation and the adequacy levels of 1.53 means the field received at least 53 % of more water discharged than the required.

Table 4.25.Adequacy of water infiltration performance ratio for different sprinkler combination

		N_1				N_2			
		R_1	R_2	R_3	R_4	R_1	R_2	R_3	R_4
	C_1	0.85	0.84	0.83	0.83	1.21	1.25	1.17	1.14
	C_2	0.68	0.70	0.75	0.77	1.07	1.04	0.99	0.97
P_1	C_3	0.81	0.82	0.82	0.83	1.14	1.12	1.10	1.06
	C_4	0.86	0.86	0.88	0.89	1.27	1.22	1.18	1.17
	C_5	0.88	0.86	0.86	0.85	1.31	1.29	1.25	1.22

	C_1	0.89	0.91	0.94	0.96	1.20	1.18	1.14	1.13
	C_2	0.76	0.72	0.65	0.64	1.05	1.01	0.95	0.93
P_2	C_3	0.83	0.80	0.72	0.61	1.19	1.15	1.14	1.12
	C_4	0.91	0.90	0.88	0.87	1.27	1.24	1.21	1.17
	C_5	0.92	0.91	0.90	0.89	1.30	1.29	1.23	1.21
	C_1	1.1	1.09	1.08	1.06	1.40	1.38	1.35	1.33
	C_2	0.87	0.84	0.76	0.59	1.12	1.10	1.02	0.98
P_3	C_3	1.11	1.09	0.86	0.72	1.26	1.25	1.25	1.23
	C_4	1.18	1.16	1.12	1.10	1.51	1.46	1.34	1.25
	C_5	1.21	1.19	1.17	1.15	1.53	1.44	1.31	1.28

As to the water delivery performance ratio, adequacy of water infiltration performance increased as nozzle size increased, and decreased as riser height increased except $P_1N_2C_2R_2$, $P_1N_1C_2R_2$, $P_1N_1C_2R_3$, $P_1N_1C_2R_4$,. $P_1N_1C_3R_4$, $P_1N_1C_4R_2$, $P_1N_1C_4R_3$, $P_1N_1C_4R_4$, $P_2N_1C_1R_2$, $P_2N_1C_1R_3$, $P_2N_1C_1R_4$,and because of the effect of wind speed all the values of adequacy were low in the mid-day test as compared to the morning, late afternoon, early night and late night tests.

4.9. Optimum Set Time for selected combination

Low value of AELQ is an indication of management problem. So by reducing management problems it can be possible to increase the AELQ to PELQ. The best option to reduce this gap is adjusting the sprinkler set time based on the sprinkler discharge rate and the water requirement of sugarcane. The sprinkler discharge rate was taken from the actual field measurement.

The water requirement and irrigation scheduling of sugarcane was determined using CROPWAT 8.0 program for 14 months (425 days) growing length of ratoon crop. Input parameters of climate data are presented in Appendix Table 3. Rain fall input data was added to the program by assuming no rainfall occurred during the crop season and if rainfall occurs during the crop season the effective rainfall will be reduced from the irrigation depth. Since ratoon crop has already an established root, the effective root depth was determined as 55 cm (Megersa, 2004).

The total available moisture content was 120 mm/m which is found by subtracting moisture content at wilting point from field capacity. The total gross irrigation requirement was 3610.5 mm/growth season (appendix figure 2). The average ETo of the area was 5.43 mm/day (appendix figure 1). Total ETc was 2532 mm per cane growth season (appendix figure 2). Actual water use by crop and actual irrigation requirement was 2528.9 mm and 2526.9 mm/growing season respectively. Efficiency of field and moisture deficit at harvest of the area was 88.9% and 46.3 mm respectively. Efficiency of irrigation scheduling was 100% (appendix figure 2). The set duration was determined by dividing the gross irrigation to the sprinkler application rate for the combinations: $P_2N_2R_4$ and $P_2N_2R_4$ Since the gross irrigation is different for crop season months, the set time is also different. The detailed results of optimum set time for all combination are presented in Appendix Tables 15.

Table 4.26. Optimum set time for selected sprinkler combinations (hr).

Combination	Set time(hr) per irri.event's
$P_2N_1R_4$	6.5
$P_2N_2R_4$	4.5

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5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

To conserve limited water resources, great attention must be given to the effect of climate factor and irrigation system parameters on irrigation water application. From this experimental study it can be concluded that, nozzle size, riser height, operating pressure, wind speed and wind condition plays significant role in irrigation water application. From the determined results evaporation and drift losses were low at night and during early morning hours, due to low wind speed. The increase of Evaporation and drift losses from early morning into afternoon and mid-day and decrease at night time was related to wind speed and warming of the air.

Evaporation and drift losses increased as operating pressure and riser height increased and decreased as nozzle size increased. This showed that, nozzle size, operating pressure, riser height and wind speed are the predominant factors that affect losses from sprinkler system.

The swath radius of different combinations increased as nozzle size and operating pressure increased and decreased as wind speed and riser height increased. The sprinkler drop size for different combinations resulted to be good and acceptable performance, which was determined from the jet break up index. The drops from sprinklers do not cause surface runoff or impending water infiltration into the soil.

PAE and PELQ increased as nozzle size increased and operating pressure increased from 2.5 to 3.0 bars except in the mid-day testing condition and decreased as operating pressure increased from 3.0 to 3.5 bars. PAE and PELQ increased as riser height increased except at some combination. The experimental result showed that, PAE, PELQ and AELQ decreased as wind speed increased. All most in all combinations the application efficiency value obtained during day time tests condition was lower than the values obtained during evening tests conditions and better results were obtained in evening tests condition relatively when the wind speed was low.

Application uniformity increased as operating pressure increased from 2.5 bar to 3.0 bar but decreased when operating pressure increased from 3.0 to 3.5 bar. The highest uniformity coefficients were obtained at 3.0 bar operating pressure while the lowest was obtained at 2.5 bar operating pressure. Effect of wind speed on water application uniformity was clearly shown that uniformity coefficient was decreased as wind speed increased and in relation to this better water distribution coefficient was obtained in evening tests than morning, mid-day and late afternoon tests. Uniformity coefficients increased as riser height increased. The uniformity coefficients generally obtained were higher at 4.0 m riser height.

When comparing the means of DU and PELQ, there were no significant differences between the treatments of operating pressures of 2.5, 3.0 and 3.5 bars at 5% significant levels. But there was significant difference between the treatments of operating pressures 2.5, 3.0, 3.5 bars on PAE and CU at 5% significant levels.

When comparing the means of CU and DU, there were significant differences between the different treatment levelss of riser heights and nozzle diameters at 5% significant levels. But there was no significant difference between the different treatment levelss of riser heights and nozzle diameters on PAE and PELQ. When comparing the means of CU, DU, PAE and PELQ, there were highly significant differences between the different treatment levelss of wind conditions at 5% significant levels.

Discharge rate and nozzle pressure measurement results were directly related to operating pressure and nozzle size, and inversely related to riser height. Pressure variation on the lateral resulted in variation within the recommended pressure variation (20%). But the discharge measurement resulted in variation of more than the recommended 10% in most combinations. Filters on the hydrant should be maintained regularly to decrease the discharge variation within the required limit. The sprinkler application rate of different combinations were below the soil infiltration rate and satisfactory without runoff.

The average delivery performance ratio ranges from 0.75 were obtained at 2.5 bar operating pressure to 1.22 at 3.5 bars operating pressure. The adequacy levels of 1.22 indicates the delivery is adequate and at least 22% of excess water was discharged that mean that over irrigated. The results of adequacy analysis indicated that over irrigation was occurred in about 50% of the respective combinations and the rest 50% of the combinations shown under irrigation. The result obtained showed that water delivery ratio increased as operating pressure as well as nozzle size increased. Water delivery ratio decreased as riser height increased.

As to the water delivery performance ratio, adequacy of water infiltration performance increased as nozzle size increased, and decreased as riser height increased except to some combination and because of the effect of wind speed all the values of adequacy were low in the mid-day test as compared to the morning, late afternoon, early night and late night tests.

5.2 Recommendation

Major factors responsible for low irrigation water application efficiency were lack of optimum pressure, low nozzle size and high wind speed. The 2.5 bar operating pressure may not be sufficient for far and uphill fields and 3.5 bar operating pressure may not be economical with respect to cost of pumping and scarce water. So use of 3.0 bar operating pressure is satisfactory. The 4.8 mm nozzle size resulted good achievement to 3.0 and 3.5 bars operating pressures. Riser height of 2.5 m resulted in low water application efficiency as compared to 4.0 m riser height, even if evaporation and drift losses were low.

Based on the results obtained, by taking into account evaporation and drift losses, this study highly recommends sprinkler irrigation with 3.0 bar pressure for 4.4 mm and 4.8 mm nozzle size and 3.5 bar for 4.8 mm with riser height at 4.0 m at evening where wind speed is low based on the adjusted set time to improve water distribution and to efficiently utilize the available water.

This study was conducted on double nozzle sprinkler which mostly practiced by Out Grower Farmer with two levels nozzle size of 4.4 mm, 4.8 mm, riser heights of 2.5 m, 3.0 m, 3.5 m and 4.0 m, and operating pressure 2.5 bars, 3.0 bars, 3.5 bars so further works on nozzle size other than 4.4 mm and 4.8 mm, operating pressure between 3.0 to 3.5 bars should be done to understand the effect on water distribution and quantify more optimum operating pressure.

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7. APPENDICES

7.1 Appendix Table

Appendix Table 1. Combinations of hydrant pressure, nozzle diameter, riser height, wind speed condition and field number.

		Field-1	Field-2	Field-3	Field-4	Field-5	Field-6
		P_1N_1	P_2N_1	P_3N_1	P_1N_2	P_2N_2	P_3N_2
	R_1	$P_1N_1R_1$	$P_2N_1R_1$	$P_3N_1R_1$	$P_1N_2R_1$	$P_2N_2R_1$	$P_3N_2R_1$
C_1	R_2	$P_1N_1R_2$	$P_2N_2R_2$	$P_3N_1R_2$	$P_1N_2R_2$	$P_2N_2R_2$	$P_3N_2R_2$
	R_3	$P_1N_1R_3$	$P_2N_2R_3$	$P_3N_1R_3$	$P_1N_2R_3$	$P_2N_2R_3$	P_3N_2R3
	R_4	$P_1N_1R_4$	$P_2N_2R_4$	$P_3N_1R_4$	$P_1N_2R_4$	$P_2N_2R_4$	$P_3N_2R_4$
	R_1	$P_1N_1R_1$	$P_2N_1R_1$	$P_3N_1R_1$	$P_1N_2R_1$	$P_2N_2R_1$	$P_3N_2R_1$
C_2	R_2	$P_1N_1R_2$	$P_2N_2R_2$	$P_3N_1R_2$	$P_1N_2R_2$	$P_2N_2R_2$	$P_3N_2R_2$
	R_3	$P_1N_1R_3$	$P_2N_2R_3$	$P_3N_1R_3$	$P_1N_2R_3$	$P_2N_2R_3$	P_3N_2R3
	R_4	$P_1N_1R_4$	$P_2N_2R_4$	$P_3N_1R_4$	$P_1N_2R_4$	$P_2N_2R_4$	$P_3N_2R_4$
	R_1	$P_1N_1R_1$	$P_2N_1R_1$	$P_3N_1R_1$	$P_1N_2R_1$	$P_2N_2R_1$	$P_3N_2R_1$
C_3	R_2	$P_1N_1R_2$	$P_2N_2R_2$	$P_3N_1R_2$	$P_1N_2R_2$	$P_2N_2R_2$	$P_3N_2R_2$
	R_3	$P_1N_1R_3$	$P_2N_2R_3$	$P_3N_1R_3$	$P_1N_2R_3$	$P_2N_2R_3$	P_3N_2R3
	R_4	$P_1N_1R_4$	$P_2N_2R_4$	$P_3N_1R_4$	$P_1N_2R_4$	$P_2N_2R_4$	$P_3N_2R_4$
	R_1	$P_1N_1R_1$	$P_2N_1R_1$	$P_3N_1R_1$	$P_1N_2R_1$	$P_2N_2R_1$	$P_3N_2R_1$
C_4	R_2	$P_1N_1R_2$	$P_2N_2R_2$	$P_3N_1R_2$	$P_1N_2R_2$	$P_2N_2R_2$	$P_3N_2R_2$
	R_3	$P_1N_1R_3$	$P_2N_2R_3$	$P_3N_1R_3$	$P_1N_2R_3$	$P_2N_2R_3$	P_3N_2R3
	R_4	$P_1N_1R_4$	$P_2N_2R_4$	$P_3N_1R_4$	$P_1N_2R_4$	$P_2N_2R_4$	$P_3N_2R_4$
	R_1	$P_1N_1R_1$	$P_2N_1R_1$	$P_3N_1R_1$	$P_1N_2R_1$	$P_2N_2R_1$	$P_3N_2R_1$
C_5	R_2	$P_1N_1R_2$	$P_2N_2R_2$	$P_3N_1R_2$	$P_1N_2R_2$	$P_2N_2R_2$	$P_3N_2R_2$
	R_3	$P_1N_1R_3$	$P_2N_2R_3$	$P_3N_1R_3$	$P_1N_2R_3$	$P_2N_2R_3$	P_3N_2R3
	R_4	$P_1N_1R_4$	$P_2N_2R_4$	$P_3N_1R_4$	$P_1N_2R_4$	$P_2N_2R_4$	$P_3N_2R_4$

Where,

P_1, P_2, P_3 are operating pressure at the hydrant 2.5, 3.0, 3.5 bar respectively.

N_1, N_2 are nozzle diameter 4.4 and4.8 mm

R_1 ,R_2 ,R_3, R_3 are riser height at 2.5 m, 3.0 m, 3.5 m, 4.0 m respectively

C_1, C_2, C_3, C_4, C_5 are wind speed condition in the morning, mid-day, late afternoon, early night and late afternoon respectively.

Appendix Table 2. Crop data of 2nd ratoon sugarcane at Tedecha (Source: Wonji research and training center).

Growth stages	Initial	Development	mid	late	Total
Stage length (days)	35	110	210	70	420
Crop coefficient (kc)	0.4	b/n	1.25	0.75	
Rooting depths	0.6	b/n	0.6	0.6	
Critical depletion levelss (p)	0.65	b/n	0.65	0.65	
Yield response factor (Ky)	0.75	0.6	0.5	0.1	1.95

Appendix Table 3. Average meteorological data (1986 to 2016)

Month	T_{max}(°c)	T_{min} (°c)	RF(mm)	RH(%)	U($^m/_s$)	ST(at 5cm)	sunshine(hr)
Jan	28.2	12	15.3	50.7	3	27.4	9
Feb	30	13.4	25.7	50	3.2	28.3	8.9
Mar	30.2	15.3	53.9	49.7	3	29.3	8.4
Apr	30.2	15.5	53.8	51.4	2.7	29.6	8.3
May	30.8	15.6	49.9	50	2.9	30.2	8.9
Jun	29.7	16.2	76.6	53.5	3.2	29.4	8.4
Jul	26.8	15.8	179.2	64.5	3.3	24.4	7
Aug	26.2	15.3	187.5	69	2.5	24.2	7.1
Sep	27.5	14.5	89.2	65.1	1.8	26.8	7.6
Oct	28.9	11.7	41	49.8	2.3	27.6	8.5

Nov	28.5	10.8	9.3	45	2.9	27.8	9.7
Dec	27.8	10.9	10.9	49.8	3.1	26.3	9.7
Mean	28.8	13.9	66.1	54	2.83	25.6	8.45

Where, Tmin. is minimum temperature

Tma. is maximum temperature

RF is rain fall

RH is relative humidity

U is wind speed

ST is soil temperature

Appendix Table 4 Evaporation and Wind Drift Losses (%) at Morning wind speed condition

No of obsn	Nozzle size (mm)	wind condition	operating pressure (bar)	wind speed m/sec	air tempreture (oc)	relative humidity (%)	evaporation and drift losses (%)
1	4.4	Morning	2.5	0.98	23	52	4.035
2			3	0.98	23	52	4.563
3			3.5	0.98	23	52	5.185
4	4.8		2.5	0.98	23	52	3.642
5			3	0.98	23	52	4.135
6			3.5	0.98	23	52	4.922
7	4.4		2.5	1.71	21	72	3.812
8			3	1.71	21	72	4.303
9			3.5	1.71	21	72	4.895
10	4.8		2.5	1.71	21	72	3.437
11			3	1.71	21	72	3.891
12			3.5	1.71	21	72	4.431
13	4.4		2.5	0.93	24	63	3.782
14			3	0.93	24	63	4.194
15			3.5	0.93	24	63	4.763
16	4.8		2.5	0.93	24	63	3.352
17			3	0.93	24	63	3.791
16			3.5	0.93	24	63	4.760
17	4.4		2.5	2.49	23	66	4.842
18			3	2.49	23	66	5.479
19			3.5	2.49	23	66	6.215
20	4.8		2.5	2.49	23	66	4.380
21			3	2.49	23	66	4.959
22			3.5	2.49	23	66	5.630
23	4.4		2.5	1.93	25	60	4.822
24			3	1.93	25	60	5.457
25			3.5	1.93	25	60	6.190
26	4.8		2.5	1.93	25	60	4.362
27			3	1.93	25	60	4.939
28			3.5	1.93	25	60	5.607
29	4.4		2.5	3.05	26	62	5.916
30			3	3.05	26	62	6.682
31			3.5	3.05	26	62	7.561
32	4.8		2.5	3.05	26	62	5.357
33			3	3.05	26	62	6.057
34			3.5	3.05	26	62	6.863
35	4.4		2.5	3.25	24	57	5.576
36			3	3.25	24	57	6.302
37			3.5	3.25	24	57	7.136
38	4.8		2.5	3.25	24	57	5.047
39			3	3.25	24	57	5.709
40			3.5	3.25	24	57	6.473
41	4.4		2.5	1.86	22	58	4.528
42			3	1.86	22	58	5.126
43			3.5	1.86	22	58	5.817
44	4.8		2.5	1.86	22	58	4.095
45			3	1.86	22	58	4.638
46			3.5	1.86	22	58	5.267

Appendix 5. Evaporation and Wind Drift Losses (%) at mid-day wind speed condition

No of obsn	Nozzle diameter (mm)	wind condition	operating pressure (bar)	wind speed m/sec	air empreture (0c)	relative humidity (%)	evaporation and drift losses (%)
1	4.4	mid day	2.5	3.43	27.2	50	10.290
2			3	3.43	27.2	50	11.213
3			3.5	3.43	27.2	50	12.500
4	4.8		2.5	3.43	27.2	50	9.615
5			3	3.43	27.2	50	10.460
6			3.5	3.43	27.2	50	11.429
7	4.4		2.5	2.32	24.5	61	9.280
8			3	2.32	24.5	61	9.750
9			3.5	2.32	24.5	61	11.520
10	4.8		2.5	2.32	24.5	61	8.598
11			3	2.32	24.5	61	9.210
12			3.5	2.32	24.5	61	9.910
13	4.4		2.5	2.95	27	43	10.150
14			3	2.95	27	43	11.060
15			3.5	2.95	27	43	12.090
16	4.8		2.5	2.95	27	43	12.489
17			3	2.95	27	43	10.210
16			3.5	2.95	27	43	11.270
17	4.4		2.5	1.96	28.5	44	9.220
18			3	1.96	28.5	44	10.022
19			3.5	1.96	28.5	44	10.939
20	4.8		2.5	1.96	28.5	44	8.635
21			3	1.96	28.5	44	9.368
22			3.5	1.96	28.5	44	10.210
23	4.4		2.5	5.57	30	43	14.448
24			3	5.57	30	43	15.797
25			3.5	5.57	30	43	17.317
26	4.8		2.5	5.57	30	43	13.448
27			3	5.57	30	43	14.699
28			3.5	5.57	30	43	16.111
29	4.4		2.5	2.85	30	40	10.948
30			3	2.85	30	40	11.941
31			3.5	2.85	30	40	13.070
32	4.8		2.5	2.85	30	40	10.218
33			3	2.85	30	40	11.132
34			3.5	2.85	30	40	12.174
35	4.4		2.5	4.11	30.5	32	13.565
36			3	4.11	30.5	32	14.827
37			3.5	4.11	30.5	32	16.252
38	4.8		2.5	4.11	30.5	32	12.631
39			3	4.11	30.5	32	13.799
40			3.5	4.11	30.5	32	15.121
41	4.4		2.5	2.07	27	41	9.237
42			3	2.07	27	41	10.041
43			3.5	2.07	27	41	10.961
44	4.8		2.5	2.07	27	41	8.690
45			3	2.07	27	41	9.386
46			3.5	2.07	27	41	10.230

Appendix Table 6	ave.Evaporation and Wind Drift Losses (%) at afternoon wind speed condition						
No of obsn	Nozzle diameter (mm)	wind condition	operating pressure (bar)	wind speed m/sec	air tempreture (0c)	relative humidity (%)	evaporation and drift losses (%)
1	4.4	afternoon	2.5	2.92	29	41	7.710
2			3	2.92	29	41	8.680
3			3.5	2.92	29	41	9.770
4	4.8		2.5	2.92	29	41	6.990
5			3	2.92	29	41	7.889
6			3.5	2.92	29	41	8.910
7	4.4		2.5	3.8	26	59	7.880
8			3	3.8	26	59	8.750
9			3.5	3.8	26	59	9.750
10	4.8		2.5	3.8	26	59	7.240
11			3	3.8	26	59	8.040
12			3.5	3.8	26	59	8.960
13	4.4		2.5	2.59	31	34	10.340
14			3	2.59	31	34	11.380
15			3.5	2.59	31	34	12.550
16	4.8		2.5	2.59	31	34	8.790
17			3	2.59	31	34	10.530
16			3.5	2.59	31	34	11.619
17	4.4		2.5	2.66	30	34	9.148
18			3	2.66	30	34	10.162
19			3.5	2.66	30	34	11.315
20	4.8		2.5	2.66	30	34	8.402
21			3	2.66	30	34	9.336
22			3.5	2.66	30	34	10.400
23	4.4		2.5	2.7	31.2	33	7.643
24			3	2.7	31.2	33	8.710
25			3.5	2.7	31.2	33	9.920
26	4.8		2.5	2.7	31.2	33	6.858
27			3	2.7	31.2	33	7.841
28			3.5	2.7	31.2	33	8.960
29	4.4		2.5	3.79	32	36	9.661
30			3	3.79	32	36	10.832
31			3.5	3.79	32	36	12.158
32	4.8		2.5	3.79	32	36	8.796
33			3	3.79	32	36	9.878
34			3.5	3.79	32	36	11.106
35	4.4		2.5	3.4	32.5	30	9.428
36			3	3.4	32.5	30	10.677
37			3.5	3.4	32.5	30	12.087
38	4.8		2.5	3.4	32.5	30	8.505
39			3	3.4	32.5	30	9.660
40			3.5	3.4	32.5	30	10.968
41	4.4		2.5	3.95	30	35	8.878
42			3	3.95	30	35	10.071
43			3.5	3.95	30	35	11.420
44	4.8		2.5	3.95	30	35	7.996
45			3	3.95	30	35	9.099
46			3.5	3.95	30	35	10.350

Appendix table 7.ave.Evaporation and Wind Drift Losses (%) at afternoon wind speed condition

No of obsn	Nozzle diameter (mm)	wind condition	operating pressure (bar)	wind speed m/sec	air empreture (0c)	relative humidity (%)	evaporation and drift losses (%)
1	4.4	early night	2.5	3.69	21	65	4.760
2			3	3.69	21	65	5.500
3			3.5	3.69	21	65	6.360
4	4.8		2.5	3.69	21	65	4.210
5			3	3.69	21	65	4.890
6			3.5	3.69	21	65	5.800
7	4.4		2.5	1.56	18.5	80	3.290
8			3	1.56	18.5	80	3.720
9			3.5	1.56	18.5	80	4.220
10	4.8		2.5	1.56	18.5	80	2.980
11			3	1.56	18.5	80	3.360
12			3.5	1.56	18.5	80	3.820
13	4.4		2.5	2.76	22	60	4.260
14			3	2.76	22	60	5.950
15			3.5	2.76	22	60	6.740
16	4.8		2.5	2.76	22	60	3.760
17			3	2.76	22	60	4.380
18			3.5	2.76	22	60	5.110
19	4.4		2.5	2.03	19.7	50	3.736
20			3	2.03	19.7	50	4.360
21			3.5	2.03	19.7	50	5.081
22	4.8		2.5	2.03	19.7	50	3.284
23			3	2.03	19.7	50	3.851
24			3.5	2.03	19.7	50	4.508
25	4.4		2.5	3.15	19.7	49	4.821
26			3	3.15	19.7	49	5.576
27			3.5	3.15	19.7	49	6.442
28	4.8		2.5	3.15	19.7	49	4.270
29			3	3.15	19.7	49	4.960
30			3.5	3.15	19.7	49	5.754
31	4.4		2.5	4.18	20	55	5.600
32			3	4.18	20	55	6.445
33			3.5	4.18	20	55	6.541
34	4.8		2.5	4.18	20	55	4.982
35			3	4.18	20	55	5.756
36			3.5	4.18	20	55	5.843
37	4.4		2.5	2.93	20	54	4.444
38			3	2.93	20	54	5.155
39			3.5	2.93	20	54	5.971
40	4.8		2.5	2.93	20	54	3.927
41			3	2.93	20	54	4.575
42			3.5	2.93	20	54	5.322
43	4.4		2.5	3.06	19.5	50	4.669
44			3	3.06	19.5	50	5.407
45			3.5	3.06	19.5	50	6.253
46	4.8		2.5	3.06	19.5	50	4.132
47			3	3.06	19.5	50	4.805
48			3.5	3.06	19.5	50	5.580

Appendix table 8. ave.Evaporation and Wind Drift Losses (%) at afternoon wind speed condition

No of obsn	Nozzle diameter (mm)	wind condition	operating pressure (bar)	wind speed m/sec	air tempreture (0c)	relative humidity (%)	evaporation and drift losses (%)
1	4.4	late night	2.5	1.73	19	80	2.420
2			3	1.73	19	80	2.860
3			3.5	1.73	19	80	3.395
4	4.8		2.5	1.73	19	80	2.090
5			3	1.73	19	80	2.490
6			3.5	1.73	19	80	2.970
7	4.4		2.5	2.19	19	90	2.350
8			3	2.19	19	90	2.795
9			3.5	2.19	19	90	3.310
10	4.8		2.5	2.19	19	90	2.040
11			3	2.19	19	90	2.430
12			3.5	2.19	19	90	2.900
13	4.4		2.5	1.94	18	91	3.160
14			3	1.94	18	91	3.590
15			3.5	1.94	18	91	4.120
16	4.8		2.5	1.94	18	91	2.876
17			3	1.94	18	91	3.249
18			3.5	1.94	18	91	3.690
19	4.4		2.5	1.99	18	70	2.897
20			3	1.99	18	70	3.413
21			3.5	1.99	18	70	4.014
22	4.8		2.5	1.99	18	70	2.526
23			3	1.99	18	70	2.992
24			3.5	1.99	18	70	3.536
25	4.4		2.5	2.08	18	71	2.932
26			3	2.08	18	71	3.453
27			3.5	2.08	18	71	4.059
28	4.8		2.5	2.08	18	71	2.558
29			3	2.08	18	71	3.028
30			3.5	2.08	18	71	3.577
31	4.4		2.5	1.82	17.5	77	2.525
32			3	1.82	17.5	77	2.991
33			3.5	1.82	17.5	77	3.535
34	4.8		2.5	1.82	17.5	77	2.191
35			3	1.82	17.5	77	2.611
36			3.5	1.82	17.5	77	3.102
37	4.4		2.5	2.2	19	67	4.227
38			3	2.2	19	67	4.787
39			3.5	2.2	19	67	5.435
40	4.8		2.5	2.2	19	67	3.824
41			3	2.2	19	67	4.330
42			3.5	2.2	19	67	4.919

Appendix Table 9	ave. Evaporation and Wind Drift Losses (%) at Morning wind speed conditior						
No of observati	Nozzle diamete (mm)	wind condition	riser height (m)	wind speed km/hr	air tempreture (0c)	relative humidity (%)	evaporation and drift losses (%)
1	4.4	Morning	2.5	3.528	23	52	8.704
2			3	3.528	23	52	9.394
3			3.5	3.528	23	52	9.926
4			4	3.528	23	52	11.115
5	4.8		2.5	3.528	23	52	8.020
6			3	3.528	23	52	9.016
7			3.5	3.528	21	72	9.540
8			4	3.528	21	72	10.578
9	4.4		2.5	6.156	21	72	9.253
10			3	6.156	21	72	10.519
11			3.5	6.156	21	72	11.722
12			4	6.156	21	72	12.877
13	4.8		2.5	6.156	21	72	8.446
14			3	6.156	21	72	8.955
15			3.5	6.156	21	72	10.206
16			4	6.156	21	72	10.309
17	4.4		2.5	3.348	24	63	7.583
18			3	3.348	24	63	8.772
19			3.5	3.348	24	63	9.039
20			4	3.348	24	63	9.944
21	4.8		2.5	3.348	24	63	6.990
22			3	3.348	24	63	7.327
23			3.5	3.348	24	63	8.395
24			4	3.348	24	63	9.018
25	4.4		2.5	5.964	23	66	8.795
26			3	5.964	23	66	9.135
27			3.5	5.964	23	66	9.409
28			4	5.964	23	66	10.631
29	4.8		2.5	5.964	23	66	7.322
30			3	5.964	23	66	8.644
31			3.5	5.964	23	66	8.062
32			4	5.964	23	66	9.130
33	4.4		2.5	6.948	25	60	8.518
34			3	6.948	25	60	9.812
35			3.5	6.948	25	60	10.050
36			4	6.948	25	60	10.636
37	4.8		2.5	6.948	25	60	7.510
38			3	6.948	25	60	8.336
39			3.5	6.948	25	60	9.532
40			4	6.948	25	60	10.622
41	4.4		2.5	10.98	26	62	8.100
42			3	10.98	26	62	9.509
43			3.5	10.98	26	62	10.826
44			4	10.98	26	62	10.989
45	4.8		2.5	10.98	26	62	7.309
46			3	10.98	26	62	9.002
47			3.5	10.98	26	62	9.961
48			4	10.98	26	62	10.047
49	4.4		2.5	6.948	25	60	8.229
50			3	6.948	25	60	8.628
51			3.5	6.948	25	60	9.959
52			4	6.948	25	60	10.234
53	4.8		2.5	6.948	25	60	7.778
54			3	6.948	25	60	7.916
55			3.5	6.948	25	60	9.018
56			4	6.948	25	60	9.607
57	4.4		2.5	14.73	22	58	8.012
58			3	14.73	22	58	9.969
59			3.5	14.73	22	58	11.340
60			4	14.73	22	58	13.659
61	4.8		2.5	14.73	22	58	7.066
62			3	14.73	22	58	7.942
63			3.5	14.73	22	58	10.752
64			4	14.73	22	58	11.007

Appendix Table 10	ave. Evaporation and Wind Drift Losses (%) at mid day wind speed condition						
No of observatior	Nozzle diameter (mm)	wind condition	riser height (m)	wind speed km/hr	air tempreture (0c)	relative humidity (%)	evaporation & drift losses (%
1	4.4	mid-day	2.5	12.35	27.2	50	10.388
2			3	12.35	27.2	50	14.197
3			3.5	12.35	27.2	50	13.160
4			4	12.35	27.2	50	14.455
5	4.8		2.5	12.35	27.2	50	9.930
6			3	12.35	27.2	50	11.288
7			3.5	12.35	27.2	50	13.013
8			4	12.35	27.2	50	13.818
9	4.4		2.5	8.35	24.5	61	9.609
10			3	8.35	24.5	61	10.590
11			3.5	8.35	24.5	61	12.346
12			4	8.35	24.5	61	13.836
13	4.8		2.5	8.35	24.5	61	9.316
14			3	8.35	24.5	61	10.590
15			3.5	8.35	24.5	61	11.802
16			4	8.35	24.5	61	12.964
17	4.4		2.5	10.62	27	43	10.235
18			3	10.62	27	43	11.635
19			3.5	10.62	27	43	12.967
20			4	10.62	27	43	14.964
21	4.8		2.5	10.62	27	43	9.784
22			3	10.62	27	43	11.122
23			3.5	10.62	27	43	12.395
24			4	10.62	27	43	13.615
25	4.4		2.5	7.06	28.5	44	9.680
26			3	7.06	28.5	44	11.004
27			3.5	7.06	28.5	44	12.264
28			4	7.06	28.5	44	13.400
29	4.8		2.5	7.06	28.5	44	9.254
30			3	7.06	28.5	44	10.519
31			3.5	7.06	28.5	44	11.723
32			4	7.06	28.5	44	12.877
33	4.4		2.5	20.05		43	11.871
34			3	20.05	30	43	12.724
35			3.5	20.05	30	43	14.180
36			4	20.05	30	43	15.575
37	4.8		2.5	20.05	30	43	10.699
38			3	20.05	30	43	12.163
39			3.5	20.05	30	43	13.582
40			4	20.05	30	43	15.069
41	4.4		2.5	10.26	30	40	10.240
42			3	10.26	30	40	11.641
43			3.5	10.26	30	40	12.973
44			4	10.26	30	40	14.250
45	4.8		2.5	10.26	30	40	9.789
46			3	10.26	30	40	11.128
47			3.5	10.26	30	40	12.401
48			4	10.26	30	40	13.622
49	4.4		2.5	14.80	30.5	32	14.352
50			3	14.80	30.5	32	16.314
51			3.5	14.80	30.5	32	18.180
52			4	14.80	30.5	32	19.965
53	4.8		2.5	14.80	30.5	32	10.236
54			3	14.80	30.5	32	11.632
55			3.5	14.80	30.5	32	12.963
56			4	14.80	30.5	32	14.239
57	4.4		2.5	7.45	27	41	9.769
58			3	7.45	27	41	11.098
59			3.5	7.45	27	41	12.368
60			4	7.45	27	41	13.585
61	4.8		2.5	7.45	27	41	9.337
62			3	7.45	27	41	10.662
63			3.5	7.45	27	41	11.883
64			4	7.45	27	41	13.053
			Ave.wind speed=11.35km/hr				

Appendix Table 11	ave. Evaporation and Wind Drift Losses (%) at late afternoon wind speed condition						
No of observation	Nozzle diameter (mm)	wind condition	riser height (m)	wind speed km/hr	air tempreture (0c)	relative humidity (%)	evaporation and drift losses (%)
1	4.4	late afternoon	2.5	10.51	29	41	10.056
2			3	10.51	29	41	11.672
3			3.5	10.51	29	41	12.655
4			4	10.51	29	41	14.261
5	4.8		2.5	10.51	29	41	9.604
6			3	10.51	29	41	11.045
7			3.5	10.51	29	41	11.459
8			4	10.51	29	41	13.626
9	4.4		2.5	13.68	26	59	10.454
10			3	13.68	26	59	11.879
11			3.5	13.68	26	59	13.238
12			4	13.68	26	59	14.540
13	4.8		2.5	13.68	26	59	9.994
14			3	13.68	26	59	11.356
15			3.5	13.68	26	59	12.656
16			4	13.68	26	59	13.801
17	4.4		2.5	9.32	31	34	10.180
18			3	9.32	31	34	11.571
19			3.5	9.32	31	34	12.895
20			4	9.32	31	34	14.165
21	4.8		2.5	9.32	31	34	9.728
22			3	9.32	31	34	11.053
23			3.5	9.32	31	34	12.319
24			4	9.32	31	34	13.531
25	4.4		2.5	9.58	30	34	10.210
26			3	9.58	30	34	11.585
27			3.5	9.58	30	34	12.911
28			4	9.58	30	34	14.182
29	4.8		2.5	9.58	30	34	9.757
30			3	9.58	30	34	11.020
31			3.5	9.58	30	34	12.355
32			4	9.58	30	34	13.490
33	4.4		2.5	9.72	31.2	33	10.248
34			3	9.72	31.2	33	11.643
35			3.5	9.72	31.2	33	12.976
36			4	9.72	31.2	33	14.230
37	4.8		2.5	9.72	31.2	33	9.796
38			3	9.72	31.2	33	11.131
39			3.5	9.72	31.2	33	12.405
40			4	9.72	31.2	33	13.626
41	4.4		2.5	13.64	32	36	11.868
42			3	13.64	32	36	13.353
43			3.5	13.64	32	36	14.768
44			4	13.64	32	36	17.122
45	4.8		2.5	13.64	32	36	9.745
46			3	13.64	32	36	10.800
47			3.5	13.64	32	36	11.807
48			4	13.64	32	36	13.772
49	4.4		2.5	12.24	32.5	30	10.612
50			3	12.24	32.5	30	12.058
51			3.5	12.24	32.5	30	13.438
52			4	12.24	32.5	30	14.761
53	4.8		2.5	12.24	32.5	30	10.156
54			3	12.24	32.5	30	11.539
55			3.5	12.24	32.5	30	12.859
56			4	12.24	32.5	30	14.125
57	4.4		2.5	14.22	30	35	10.766
58			3	14.22	30	35	12.228
59			3.5	14.22	30	35	13.628
60			4	14.22	30	35	14.969
61	4.8		2.5	14.22	30	35	10.291
62			3	14.22	30	35	11.690
63			3.5	14.22	30	35	13.028
64			4	14.22	30	35	14.310

Appendix Table 12	ave. Evaporation and Wind Drift Losses (%) at Morning wind speed conditior						
No of obsn	Nozzle diameter (mm)	wind condition	riser height (m)	wind speed km/hr	air tempretui (0c)	relative humidity (%)	evaporation and drift losses (%)
1	4.4	early night	2.5	13.284	21	65	8.321
2			3	13.284	21	65	9.621
3			3.5	13.284	21	65	10.240
4			4	13.284	21	65	12.740
5	4.8		2.5	13.284	21	65	7.710
6			3	13.284	21	65	9.460
7			3.5	13.284	21	65	9.800
8			4	13.284	21	65	11.220
9	4.4		2.5	5.616	18.5	80	7.524
10			3	5.616	18.5	80	8.750
11			3.5	5.616	18.5	80	10.184
12			4	5.616	18.5	80	11.610
13	4.8		2.5	5.616	18.5	80	6.697
14			3	5.616	18.5	80	8.390
15			3.5	5.616	18.5	80	9.526
16			4	5.616	18.5	80	10.813
17	4.4		2.5	9.936	22	60	8.190
18			3	9.936	22	60	9.750
19			3.5	9.936	22	60	10.971
20			4	9.936	22	60	12.341
21	4.8		2.5	9.936	22	60	7.291
22			3	9.936	22	60	9.185
23			3.5	9.936	22	60	10.172
24			4	9.936	22	60	11.920
25	4.4		2.5	7.308	19	50	9.421
26			3	7.308	19	50	10.665
27			3.5	7.308	19	50	11.932
28			4	7.308	19	50	13.262
29	4.8		2.5	7.308	19	50	8.597
30			3	7.308	19	50	10.207
31			3.5	7.308	19	50	11.525
32			4	7.308	19	50	12.091
33	4.4		2.5	11.34	19.7	42	9.327
34			3	11.34	19.7	42	10.445
35			3.5	11.34	19.7	42	13.004
36			4	11.34	19.7	42	13.013
37	4.8		2.5	11.34	19.7	42	7.954
38			3	11.34	19.7	42	10.121
39			3.5	11.34	19.7	42	11.052
40			4	11.34	19.7	42	12.453
41	4.4		2.5	14.05	17	55	10.125
42			3	15.05	17	55	11.453
43			3.5	15.05	17	55	12.457
44			4	15.05	17	55	13.165
45	4.8		2.5	15.05	17	55	9.246
46			3	15.05	17	55	10.427
47			3.5	15.05	17	55	11.723
48			4	15.05	17	55	12.334
49	4.4		2.5	10.5	20	54	9.232
50			3	10.5	20	54	10.735
51			3.5	10.5	20	54	11.343
52			4	10.5	20	54	11.727
53	4.8		2.5	10.5	20	54	8.108
54			3	10.5	20	54	9.052
55			3.5	10.5	20	54	10.072
56			4	10.5	20	54	11.015
57	4.4		2.5	11.016	19.5	50	8.662
58			3	11.016	19.5	50	10.282
59			3.5	11.016	19.5	50	11.077
60			4	11.016	19.5	50	11.716
61	4.8		2.5	11.016	19.5	50	8.370
62			3	11.016	19.5	50	9.562
63			3.5	11.016	19.5	50	10.103
64			4	11.016	19.5	50	10.923

Appendix Table 13	ave. Evaporation and Wind Drift Losses (%) at Morning wind speed condition						
No of observati	Nozzle diameter (mm)	wind condition	riser height (m)	wind speed km/hr	air tempreture (0c)	relative humidity (%)	evaporation & drift losses (%)
1	4.4	late night	2.5	6.228	19	80	4.552
2			3	6.228	19	80	5.256
3			3.5	6.228	19	80	5.722
4			4	6.228	19	80	7.337
5	4.8		2.5	6.228	19	80	2.901
6			3	6.228	19	80	4.254
7			3.5	6.228	19	80	5.540
8			4	6.228	19	80	6.535
9	4.4		2.5	7.884	19	90	4.144
10			3	7.884	19	90	4.669
11			3.5	7.884	19	90	6.248
12			4	7.884	19	90	7.174
13	4.8		2.5	7.884	19	90	2.229
14			3	7.884	19	90	4.348
15			3.5	7.884	19	90	5.436
16			4	7.884	19	90	6.750
17	4.4		2.5	6.984	18	91	4.180
18			3	6.984	18	91	4.571
19			3.5	6.984	18	91	5.895
20			4	6.984	18	91	6.165
21	4.8		2.5	6.984	18	91	2.728
22			3	6.984	18	91	4.053
23			3.5	6.984	18	91	5.314
24			4	6.984	18	91	6.461
25	4.4		2.5	7.164	18	70	6.221
26			3	7.164	18	70	7.673
27			3.5	7.164	18	70	8.117
28			4	7.164	18	70	10.136
29	4.8		2.5	7.164	18	70	5.556
30			3	7.164	18	70	7.132
31			3.5	7.164	18	70	8.714
32			4	7.164	18	70	9.510
33	4.4		2.5	7.488	18	71	6.310
34			3	7.488	18	71	7.830
35			3.5	7.488	18	71	9.100
36			4	7.488	18	71	10.420
37	4.8		2.5	7.488	18	71	5.820
38			3	7.488	18	71	7.230
39			3.5	7.488	18	71	8.520
40			4	7.488	18	71	9.710
41	4.4		2.5	6.55	17.5	77	5.435
42			3	6.55	17.5	77	6.435
43			3.5	6.55	17.5	77	8.162
44			4	6.55	17.5	77	9.944
45	4.8		2.5	6.55	17.5	77	3.236
46			3	6.55	17.5	77	4.642
47			3.5	6.55	17.5	77	6.963
48			4	6.55	17.5	77	8.437
49	4.4		2.5	7.92	19	67	7.512
50			3	7.92	19	67	8.049
51			3.5	7.92	19	67	9.443
52			4	7.92	19	67	11.562
53	4.8		2.5	7.92	19	67	6.245
54			3	7.92	19	67	7.449
55			3.5	7.92	19	67	8.969
56			4	7.92	19	67	10.513
57	4.4		2.5	7.776	17	70	6.656
58			3	7.776	17	70	8.217
59			3.5	7.776	17	70	9.636
60			4	7.776	17	70	10.958
61	4.8		2.5	7.776	17	70	6.380
62			3	7.776	17	70	7.481
63			3.5	7.776	17	70	8.701
64			4	7.776	17	70	9.414
				ave.=7.21 km/hr			

Appendix Table 14. Jet break-up index value for different sprinkler combinations

		N1				N2			
	trial	R1	R2	R3	R4	R1	R2	R3	R4
P1	1	2.44	2.45	2.462	2.47	2.17	2.187	2.2	2.21
	2	2.65	2.72	2.78	2.85	2.21	2.35	2.42	2.51
	3	2.43	2.45	2.47	2.49	2.18	2.23	2.31	2.37
	4	2.23	2.278	2.324	2.37	2.1	2.15	2.18	2.22
	5	2.13	2.17	2.19	2.22	2	2.11	2.13	2.19
P2	1	2.57	2.587	2.6	2.62	2.28	2.285	2.29	2.29
	2	2.82	2.88	2.94	3	2.37	2.41	2.46	2.51
	3	2.52	2.61	2.77	2.9	2.3	2.4	2.42	2.48
	4	2.45	2.48	2.51	2.57	2.25	2.264	2.29	2.31
	5	2.4	2.45	2.49	2.54	2.16	2.19	2.21	2.23
P3	1	2.68	2.7	2.71	2.74	2.4	2.47	2.49	2.5
	2	2.87	2.88	2.9	2.93	2.51	2.58	2.62	2.67
	3	2.67	2.71	2.763	2.81	2.44	2.46	2.5	2.54
	4	2.51	2.6	2.65	2.72	2.4	2.44	2.46	2.5
	5	2.48	2.5	2.52	2.54	2.32	2.36	2.38	2.41

Appendix table 15. Optimum set time for different sprinkler combinations for ratoon crop (hr.)

	P1		P2		P3	
	N1	N2	N1	N2	N1	N2
R1	6.47	5	6.3	4.4	6.9	4.36
R2	6.51	5.4	6.36	4.43	6.12	4.4
R3	6.55	5.1	6.12	4.46	6.15	4.45
R4	7.6	5.16	6.5	4.55	6.27	4.48

Appendix Table 16. Soil texture analysis test result

S/No	Field No	Sand (%)	Silt (%)	Clay (%)	Textural class
1	202	58	18	24	Sandy clay loam
2	203	58	23	25	Sandy clay loam
3	205	58	18	23	Sandy clay loam
4	206	52	20	28	Sandy clay loam
5	207	56	17	27	Sandy clay loam
6	211	57	19	24	Sandy clay loam

Appendix Table 17. Infiltration analysis test result

Appendix Table 17.1 Soil infiltration rate test 1 results

Time reading hr. min. sec. (local time)	Time difference min	Cumulative time min	Water levels reading before filling (mm)	after filling (mm)	Infiltr-ation (mm)	Cumulative infiltration (mm)	Infiltration rate (mm/min)	Infiltration Rate (mm/hr.)
3:05:00	0	starting =0		100	0	0	0	0
3:07:00	2	2	92	100	8	8	4	240
3:10:00	3	5	89	100	11	19	3.66	219.6
3:15:00	5	10	85	100	15	34	3	180
3:25:00	10	20	75	100	25	59	2.5	150
3:35:00	10	30	80	100	20	79	2	120
3:45:00	10	40	84	100	16	95	1.6	96
4:05:00	20	60	88	100	12	107	0.6	36
4:25:00	20	80	91	100	9	116	0.45	27*
4:45:00	20	100	91	100	9	125	0.45	27*
5:05:00	20	120	91		9	134	0.45	27*

*Basic infiltration rate = 27 mm/hr.

Appendix Table 17.2 Soil infiltration ate test 2 results

Time reading hr. min. sec. (local time)	Time difference Min	Cumulative time min	Water levels reading before filling (mm)	after filling (mm)	Infiltr-ation (mm)	Cumulative infiltration (mm)	Infiltration rate (mm/min)	Infiltration Rate (mm/hr.)
5:30:00	0	starting =0		100	0	0	0	0
5:32:00	2	2	94	100	6	6	3	180
5:35:00	3	5	92	100	8	14	2.6	156
5:40:00	5	10	88	100	12	26	2.4	144
5:50:00	10	20	82	100	18	44	1.8	108
6:00:00	10	30	88	100	12	56	1.2	72
6:10:00	10	40	92	100	8	64	0.8	48
6:30:00	20	60	88	100	12	76	0.6	36
6:50:00	20	80	90	100	10	86	0.5	30*
7:10:00	20	100	90	100	10	96	0.5	30*
7:30:00	20	120	90		10	106	0.5	30*

*Basic infiltration rate = 30mm/hr.

Appendix Table 17.3 Soil infiltration rate test 3 results

Time reading hr. min. sec. (local time)	Time difference Min	Cumulative Time Min	Water levels reading before filling(mm)	after filling(mm)	Infiltr ation (mm)	Cumulative infiltration (mm)	Infiltration rate (mm/min)	Infiltration rate (mm/hr.)
5:00:00	0	starting =0		100	0	0	0	0
5:02:00	2	2	92	100	8	8	4	240
5:05:00	3	5	90	100	10	18	3.3	198
5:10:00	5	10	85	100	16	34	3.2	192
5:20:00	10	20	86	100	14	48	1.4	84
3:30:00	10	30	87	100	13	61	1.3	78
6:40:00	10	40	90	100	10	71	1.1	66
7:00:00	20	60	92	100	8	79	0.4	24*
7:20:00	20	80	92	100	8	87	0.4	24*
7:40:00	20	100	92	100	8	95	0.4	24*

*Basic infiltration rate = 24 mm/hr.

Appendix 18. ava.effect of operating pressure, riser height and nozzle size on Cu in Morning wind condition

	C_1							
	N_1				N_2			
	R_1	R_2	R_3	R_4	R_1	R_2	R_3	R_4
P_1	74.5	75	78	80	83	83.2	83.6	83.7
P_2	82.4	82.7	83.4	83.9	87	87.7	88.5	89
P_3	76	77.2	77.9	78	76	78	82	84.4

Appendix 19. Effect of operating pressure, riser height and nozzle size on Cu in Mid - day wind condition

	C_2							
	N_1				N_2			
	R_1	R_2	R_3	R_4	R_1	R_2	R_3	R_4
P_1	59.5	60.8	64	66	76.9	74.3	72	71.9
P_2	76.5	77.3	73.1	74.8	77.9	78.1	78.5	78.7
P_3	73	73.8	74.1	79	78.7	79.2	81.8	82.4

Appendix 20. Effect of operating pressure, riser height and nozzle size on Cu in late afternoon wind condition

	C_3							
	N_1				N_2			
	R_1	R_2	R_3	R_4	R_1	R_2	R_3	R_4
P_1	74.5	77	79.2	81	82	83.1	84.5	85.4
P_2	77.4	78.7	80.4	82.4	84.7	85.2	86	86.8
P_3	74.5	75.7	77	78.1	79.7	80.1	80.7	81

Appendix 21. Effect of operating pressure, riser and nozzle size on Cu in early evening wind condition

	C_4							
	N_1				N_2			
	R_1	R_2	R_3	R_4	R_1	R_2	R_3	R_4
P_1	78	79.8	82	84	82.5	83.7	84.9	86.2
P_2	80	81.6	84.8	86	85.2	86	87.7	88.2
P_3	76	77.5	79	80	80.5	81	83.2	85

Appendix 22. Effect of operating pressure, riser and nozzle size on Cu in late evening wind condition

	C_5							
	N_1				N_2			
	R_1	R_2	R_3	R_4	R_1	R_2	R_3	R_4
P_1	78.6	80.7	83	85	83.2	84	86.8	87.5
P_2	82.8	84.3	85.2	87.7	88	88.2	89.6	90
P_3	79	81.2	83.8	85.2	85.2	85.8	86.2	87

Appendix 23. Effect of riser height, operating pressure and nozzle size on Du in Morning wind condition

	C_1							
	N_1				N_2			
	R_1	R_2	R_3	R_4	R_1	R_2	R_3	R_4
P_1	64.1	65.2	67.3	68.2	69.5	71	74.2	75.2
P_2	71.4	72	73.2	74	74	78	80	82.5
P_3	65	67	68.7	70.2	66.8	68.7	75.8	78.4

Appendix 24. Effect of riser height, operating pressure and nozzle size on Du in mid day wind condition

	C_2							
	N_1				N_2			
	R_1	R_2	R_3	R_4	R_1	R_2	R_3	R_4
P_1	55	56.7	59	60	61.8	62	65.8	66
P_2	62	61.7	60.5	60	63	64	75	67.3
P_3	62	62.8	63.5	72.7	64.5	66	73	75.8

Appendix 25. Effect of riser height, operating pressure and nozzle size on Du in late afternoon wind condition

	C_3							
	N_1				N_2			
	R_1	R_2	R_3	R_4	R_1	R_2	R_3	R_4
P_1	60	63	67.3	69	70.5	74	74.3	75
P_2	67	68.7	70.1	71	73.4	74.4	75.3	75.9
P_3	64.8	65.5	66.8	68	71.6	72.6	73.7	74.2

Appendix 26. Effect of riser height, operating pressure and nozzle size on Du in early night wind condition

	C_4							
	N_1				N_2			
	R_1	R_2	R_3	R_4	R_1	R_2	R_3	R_4
P_1	62	64.8	69.1	71.2	74	74.2	75.1	76
P_2	69.2	70.3	71	71.8	81	82	84.2	85
P_3	65.6	66.8	68.2	70	73	75.8	78.7	80

Appendix 27. Effect of riser height, operating pressure and nozzle size on Du in late evening wind condition

	C_5							
	N_1				N_2			
	R_1	R_2	R_3	R_4	R_1	R_2	R_3	R_4
P_1	63	65	70.5	72	75.4	76.5	78.3	79.5
P_2	70	70.8	71.4	73	83	84.7	86.1	87.2
P_3	66.8	67.5	69	71	75	77.4	82.6	84

7.2 Appendix Figures

Monthly ETo Penman-Monteith - C:\Users\Alx\Desktop\ETo of tedecha LSIS.PEM

Country: Ethiopia | Station: Tedecha LSI scheme

Altitude: 1466 m. | Latitude: 8.24 °N | Longitude: 39.23 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	12.0	28.0	50	259	9.0	21.0	5.28
February	13.4	30.0	50	276	8.9	22.0	5.89
March	15.3	30.0	49	259	8.4	22.3	6.00
April	15.5	30.0	51	233	8.3	22.3	5.80
May	15.6	31.0	50	250	8.9	22.6	6.09
June	16.2	30.0	53	276	8.4	21.4	5.88
July	15.8	27.0	64	285	7.0	19.5	4.88
August	15.3	26.0	69	216	7.1	20.1	4.40
September	14.5	28.0	65	155	7.6	21.0	4.57
October	11.7	29.0	49	198	8.5	21.6	5.29
November	10.8	29.0	45	250	9.7	22.1	5.69
December	10.9	28.0	50	267	9.7	21.4	5.35
Average	**13.9**	**28.8**	**54**	**244**	**8.5**	**21.4**	**5.43**

Appendix Figure 1. CROPWAT 8.0 program ET_o result.

Crop Water Requirements

ETo station: Tedecha LSI scheme | Crop: sugar cane

Rain station: Tedecha LSIS | Planting date: 01/07

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jul	1	Init	1.14	5.94	59.4	0.0	59.3
Jul	2	Init	1.07	5.21	52.1	0.0	52.0
Jul	3	Init	0.99	4.68	51.5	0.0	51.5
Aug	1	Deve	0.92	4.18	41.8	0.0	41.8
Aug	2	Deve	0.85	3.72	37.2	0.0	37.2
Aug	3	Deve	0.78	3.47	38.1	0.0	31.2
Sep	1	Deve	0.65	2.94	29.4	0.0	29.3
Sep	2	Deve	0.73	3.33	33.3	0.0	33.2
Sep	3	Deve	0.81	3.87	38.7	0.0	38.7
Oct	1	Deve	0.88	4.46	44.6	0.0	44.5
Oct	2	Deve	0.96	5.08	50.8	0.0	50.7
Oct	3	Deve	1.04	5.64	62.1	0.0	62.1
Nov	1	Deve	1.12	6.23	62.3	0.0	62.3
Nov	2	Deve	1.20	6.82	68.2	0.0	68.2
Nov	3	Mid	1.25	6.96	69.6	0.0	69.6
Dec	1	Mid	1.25	6.83	68.3	0.0	68.2
Dec	2	Mid	1.25	6.68	66.8	0.0	66.8
Dec	3	Mid	1.25	6.66	73.2	0.0	73.2
Jan	1	Mid	1.25	6.63	66.3	0.0	66.3
Jan	2	Mid	1.25	6.60	66.0	0.0	66.0
Jan	3	Mid	1.25	6.86	75.4	0.0	75.4
Feb	1	Mid	1.25	7.11	71.1	0.1	71.0
Feb	2	Mid	1.25	7.36	73.6	0.1	73.6
Feb	3	Mid	1.25	7.41	59.3	0.1	59.2
Mar	1	Mid	1.25	7.46	74.6	0.1	74.5
Mar	2	Mid	1.25	7.51	75.1	0.1	75.0
Mar	3	Mid	1.25	7.42	81.6	0.1	81.5
Apr	1	Mid	1.25	7.33	73.3	0.1	73.3
Apr	2	Mid	1.25	7.25	72.5	0.0	72.5
Apr	3	Mid	1.25	7.37	73.7	0.1	73.6
May	1	Mid	1.25	7.49	74.9	0.1	74.8
May	2	Mid	1.25	7.61	76.1	0.1	76.0
May	3	Mid	1.25	7.52	82.8	0.1	82.7
Jun	1	Mid	1.25	7.44	74.4	0.1	74.3
Jun	2	Mid	1.25	7.35	73.5	0.0	73.5
Jun	3	Late	1.21	6.72	67.2	0.0	67.1
Jul	1	Late	1.14	5.94	59.4	0.0	59.3
Jul	2	Late	1.07	5.21	52.1	0.0	52.0
Jul	3	Late	0.99	4.68	51.5	0.0	51.5
Aug	1	Late	0.92	4.18	41.8	0.0	41.8
Aug	2	Late	0.85	3.72	37.2	0.0	37.2
Aug	3	Late	0.78	3.47	31.2	0.0	31.2
					2532.0	**1.9**	**2523.2**

Appendix Figure 2. CROPWAT 8.0 CWR result.

Crop irrigation schedule

ETo station: Tedecha LSI scheme | Crop: sugar cane | Planting date: 01/07 | Yield red.

Rain station: Tedecha LSIS | Soil: sandy clay loam | Harvest date: 29/08 | 0.0 %

Table format
- (•) Irrigation schedule
- ( ) Daily soil moisture balance

Timing: Irrigate at critical depletion

Application: Refill soil to field capacity

Field eff. 70 %

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
1 Jul	1	Init	0.0	1.00	100	73	52.7	0.0	0.0	75.3	8.72
9 Jul	9	Init	0.0	1.00	100	66	47.5	0.0	0.0	67.8	0.98
18 Jul	18	Init	0.0	1.00	100	66	47.6	0.0	0.0	67.9	0.87
28 Jul	28	Init	0.0	1.00	100	66	47.8	0.0	0.0	68.3	0.79
8 Aug	39	Dev	0.0	1.00	100	66	47.5	0.0	0.0	67.8	0.71
21 Aug	52	Dev	0.0	1.00	100	68	49.0	0.0	0.0	70.0	0.62
5 Sep	67	Dev	0.0	1.00	100	68	49.3	0.0	0.0	70.4	0.54
20 Sep	82	Dev	0.0	1.00	100	67	47.9	0.0	0.0	68.4	0.53
2 Oct	94	Dev	0.0	1.00	100	66	47.6	0.0	0.0	68.0	0.66
13 Oct	105	Dev	0.0	1.00	100	71	50.9	0.0	0.0	72.6	0.76
22 Oct	114	Dev	0.0	1.00	100	65	46.8	0.0	0.0	66.9	0.86
31 Oct	123	Dev	0.0	1.00	100	71	50.8	0.0	0.0	72.6	0.93
8 Nov	131	Dev	0.0	1.00	100	69	49.8	0.0	0.0	71.2	1.03
16 Nov	139	Dev	0.0	1.00	100	74	53.4	0.0	0.0	76.3	1.10
23 Nov	146	Mid	0.0	1.00	100	67	48.2	0.0	0.0	68.8	1.14
30 Nov	153	Mid	0.0	1.00	100	68	48.7	0.0	0.0	69.6	1.15
7 Dec	160	Mid	0.0	1.00	100	66	47.7	0.0	0.0	68.2	1.13

7 Dec	160	Mid	0.0	1.00	100	66	47.7	0.0	0.0	68.2	1.13
14 Dec	167	Mid	0.0	1.00	100	66	47.2	0.0	0.0	67.4	1.11
22 Dec	175	Mid	0.0	1.00	100	74	53.4	0.0	0.0	76.3	1.10
30 Dec	183	Mid	0.0	1.00	100	74	53.2	0.0	0.0	76.0	1.10
7 Jan	191	Mid	0.0	1.00	100	74	53.0	0.0	0.0	75.7	1.10
15 Jan	199	Mid	0.0	1.00	100	73	52.9	0.0	0.0	75.5	1.09
23 Jan	207	Mid	0.0	1.00	100	74	53.5	0.0	0.0	76.5	1.11
30 Jan	214	Mid	0.0	1.00	100	67	48.0	0.0	0.0	68.5	1.13
6 Feb	221	Mid	0.0	1.00	100	69	49.5	0.0	0.0	70.7	1.17
13 Feb	228	Mid	0.0	1.00	100	70	50.5	0.0	0.0	72.1	1.19
20 Feb	235	Mid	0.0	1.00	100	72	51.5	0.0	0.0	73.6	1.22
27 Feb	242	Mid	0.0	1.00	100	72	51.8	0.0	0.0	74.0	1.22
6 Mar	249	Mid	0.0	1.00	100	72	52.1	0.0	0.0	74.4	1.23
13 Mar	256	Mid	0.0	1.00	100	73	52.3	0.0	0.0	74.7	1.24
20 Mar	263	Mid	0.0	1.00	100	73	52.5	0.0	0.0	75.0	1.24
27 Mar	270	Mid	0.0	1.00	100	72	51.9	0.0	0.0	74.1	1.23
3 Apr	277	Mid	0.0	1.00	100	72	51.7	0.0	0.0	73.8	1.22

10 Apr	284	Mid	0.0	1.00	100	71	51.3	0.0	0.0	73.3	1.21
17 Apr	291	Mid	0.0	1.00	100	70	50.7	0.0	0.0	72.4	1.20
24 Apr	298	Mid	0.0	1.00	100	71	51.2	0.0	0.0	73.1	1.21
1 May	305	Mid	0.0	1.00	100	72	51.7	0.0	0.0	73.8	1.22
8 May	312	Mid	0.0	1.00	100	73	52.3	0.0	0.0	74.8	1.24
15 May	319	Mid	0.0	1.00	100	74	53.0	0.0	0.0	75.7	1.25
22 May	326	Mid	0.0	1.00	100	74	53.0	0.0	0.0	75.8	1.25
29 May	333	Mid	0.0	1.00	100	73	52.6	0.0	0.0	75.2	1.24
5 Jun	340	Mid	0.0	1.00	100	73	52.2	0.0	0.0	74.6	1.23
12 Jun	347	Mid	0.0	1.00	100	72	51.9	0.0	0.0	74.1	1.23
19 Jun	354	Mid	0.0	1.00	100	71	51.5	0.0	0.0	73.5	1.22
26 Jun	361	End	0.0	1.00	100	66	47.6	0.0	0.0	68.1	1.13
4 Jul	369	End	0.0	1.00	100	70	50.6	0.0	0.0	72.3	1.05
13 Jul	378	End	0.0	1.00	100	71	51.2	0.0	0.0	73.2	0.94
23 Jul	388	End	0.0	1.00	100	70	50.5	0.0	0.0	72.1	0.83
3 Aug	399	End	0.0	1.00	100	69	50.0	0.0	0.0	71.4	0.75
15 Aug	411	End	0.0	1.00	100	66	47.9	0.0	0.0	68.4	0.66
29 Aug	End	End	0.0	1.00	0	64					

Totals

Total gross irrigation	3610.5 mm	Total rainfall	1.9 mm
Total net irrigation	2527.4 mm	Effective rainfall	1.7 mm
Total irrigation losses	0.0 mm	Total rain loss	0.2 mm
Actual water use by crop	2528.5 mm	Moist deficit at harvest	46.3 mm
Potential water use by crop	2528.5 mm	Actual irrigation requirement	2526.9mm
Efficiency irrigation schedule	100.0 %	Efficiency rain	88.9 %
Deficiency irrigation schedule	0.0 %		

Yield reductions

Stagelabel	A	B	C	D	Season	
Reductions in ETc	0.0	0.0	0.0	0.0	0.0	%
Yield response factor	0.75	0.60	0.50	0.10	1.95	
Yield reduction	0.0	0.0	0.0	0.0		%
Cumulative yield reduction	0.0	0.0	0.0	0.0	0.0	%

Appendix Figure 3.CROPWAT 8.0 irrigation scheduling out put

7.3 appendix form

Sprinkler Evaluation Data Sheet

Location………….Field No………. Field Area (ha)……………Observer………………..

Date….........Crop Type ………………………..Growth Stage…………………………….

Type of Sprinkler System……………………..Hydrant Pressure(bar)………………………

Riser Height (m)……… Lateral Pipe Diameter (cm)….........Nozzle Size (mm)…………

Test Data

Weather: Temperature………………..… Humidity…..…………. Cloudiness………………….

Wind Velocity: Begin………………………………….. Finish……………………………………

Wind Direction: Begin………………………..…..........Finish……..................................

Lateral Spacing……..………………………..…… Gauge Spacing ……………........x…………………..

Sprinkler Number on the Lateral……………………………………………………………………….

Time of Test: Begin…………… Finish………………, Duration, hr.…………. Min.……………..

Evaporation Gauge Depth: Begin……….… Finish……….….. Loss….………... Rate..........

Comments………………………………………………………………………………………………
……
……
………………………………………………

Catch Can Record Sheet for Sprinkler

Catch can ID	*Equivalent depth, mm*		*Catch can ID*	*Equivalent depth, mm*
1			19	
2			20	
3			21	
4			22	
5			23	
6			24	
7			25	
8			26	
9			27	
10			28	
11			29	
12			30	
13			31	
14			32	
15			33	
16			34	
17			35	
18			36	

Location:-___________________________

Hydrants pressure :- *(2.5bar, 3.0 bar, and 3.5bar)*

Riser height: - *(2.5 m, 3.0 m, 3.5 m,4.0 m)*

Wind condition: - *morning (___________), mid- day (__________________________)*

afternoon (______________________)

early night (______________), late night (_______________________)

Wind speed:-*beginning (___________________), end (_________________________)*

Data collector:-___________________________

7.4 Appendix picture

Appendix picture .1 Field preparation and grid formation.

Appendix Picture 2. Water depth reading from catch can.

Appendix Picture 3. Pressure adjustment, measurement at the hydrant and riser valve using pressure gauge.