PERFORMANCE EVALUATION OF FIELD WATER APPLICATION AT TENDAHO SUGAR PROJECT, ETHIOPIA

MSc THESIS

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DECLARATION

I hereby declare that this MSc dissertation 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.

Name: ____

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ADVISORS' THESIS SUBMISSION APPROVAL

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This is to certify that the thesis entitled **"Performance Evaluation of Field Water Application at Tendaho Sugar Project, Ethiopia"** submitted in partial fulfillment of the requirements for the degree of Master's with specialization in Irrigation and Drainage Engineering, the Graduate Program of the Water Resource and Irrigation Engineering Department, and has been carried out by **Tadesse Gobena Shonka, ID. No: RMSc/150/06,** under my supervision. Therefore I recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department for defense.

________________________	______________________	_____________________
Name of Principal advisor	Signature	Date
________________________	______________________	_____________________
Department Head	Signature	Date

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ACRONYMS

AMD	Allowable Management Depletion
AW	Soil available water capacity
BCL	Billion Cubic Liter
Bd	Bulk Density
Cu	Christensen's Coefficient Of Uniformity
Coef.var	Coefficient Of Variation
D_{app}	Application Depth (Irrigation depth)
Dp	Deep Percolation
Du	Distribution Uniformity
DUlq	Low-Quarter Distribution Uniformity
Ea	Application Efficiency
Ec	Conveyance Efficiency
Es	Storage Efficiency
ETc	Crop Evapotranspiration
ETo	Reference Evapotranspiration
FAO	Food And Agriculture Organization
Fc	Field Capacity
FC	Field Code
GIS	Geographical Information System
ha	Hectare
HDPE	High Density Polyethylene
Kc	Crop Coefficient
MAD	Management Allowable Depletion
PWP	Permanent Wilting Point
SCS	Soil Conservation Service
SIRMOD	Surface Irrigation Simulation, Evaluation And Design Model
St.dev	Standard Deviation
SMD	Soil Moisture Deficit
TAM	Total Available Moisture
TSP	Tendaho Sugar Project
USDA	United State Department Of Agriculture
WPCS	Water and Power Consultancy Services
WWDSE	Water Works Design And Supervision Enterprise

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ABSTRACTS

Sugarcane is fully irrigated crop in Ethiopia. But, there is little information on the field water application performances of sugar estate farms. Open canals are the main systems for supplying irrigation water in these farms. However, most of these schemes are frequently criticized for their low conveyance and field water application efficiencies. Under the water scarce situation, improving the canals conveyance efficiency and field water application can offers an opportunity to realize field level water savings. This study was done a purpose of identifying and understanding the current level of field water application efficiencies of Tendaho sugarcane irrigation scheme using appropriate on-field irrigation performance indicators. Primary/direct field data collection and some secondary data were used to undertake planned objectives. Canal conveyance evaluation was done for tertiary canals based priority of dominant conveyance defects observed in the sugar estate. Field water application evaluations were done during the normal irrigation practice of the sugar estate considering: application efficiency, storage efficiency, and deep percolation losses. The relationships between coefficient of uniformity and distribution uniformity have also described based on opportunity time for each quarters using the linear equation. Tertiary conveyance was evaluated by using volume flow measuring method using Parshall flumes set at inlet and outlet of representative canals. From results, the mean conveyance efficiency of tertiary canal was 59.589% with high amount of water losses. From field evaluation, most of field irrigation activities were not carried out on timely schedules. These resulted in overall mean on-field water application efficiency of 56.57%, 70.30% storage efficiency and 91.93% distribution uniformity at target application depth with the overall system efficiency of to 30.81%. Other factors found to affect irrigation efficiency are cut-off time, inflow rates, soil type, and furrow shapes. The results of irrigation scheduling have showed smaller irrigation intervals. To improve irrigation scheduling different net depths of application for each soil has proposed based on soil, crop property and climatic condition of the area. Finally, the inflow rate and cut-off times of two soils are proposed based on field obtained evidences. The inflow rate of 5l/sec and cut-off time of 45minute were recommended as best decision variables to be considered.

Key words: Field water application efficiencies, tertiary canal conveyance, irrigation scheduling, inflow rate cut-off time.

DEDICATION

I dedicated this thesis inscription to my Mother Lucho Butu, to my Father, and to Mirtinesh H/Yesus.

1. INTRODUCTION

1.1 Backgrounds

Irrigation is generally defined as the application of water to the soil for the purpose of supplying moisture essential for plant growth. However, a broader and more inclusive definition is that irrigation is the application of water to the soil for any number of the following purposes; to add water to the soil to supply the moisture essential for plant growth, to provide crop insurance against short duration droughts, to cool the soil and atmosphere, to reduce the hazard of frost in cold area, to soften tillage pans and clods and to washout or dilute salts in the soil (Tadesse Nagi., et al., 2009).

Surface irrigation refers to water application systems in which water is applied and conveyed over the field surface by gravitational force (Koech et al., 2010). In coming futures, as the competition for water resources quickens and global population growth continues to escalate, surface irrigation will have to struggle with the difficult assignment of producing more food and fiber with less resources. Obviously, if the surface irrigation is to remain a sustainable and positive social and economic force in the 21st century, it needs to evolve into an efficient, cost effective, and environmentally kind technology (Jurriens et al., 2001).

Relatively conservative estimate is that 40% or more of the water diverted for irrigation is wasted at farm level through either deep percolation or surface runoff (Walker, 1989). Efficient management of irrigation water is more important, as the new sources of irrigation water supplies become scarce and new irrigation development requires huge investment. Thus, optimum utilization is becoming increasingly important for the maximum beneficial use.

Tendaho sugar estate, the target area of the study is located at North-East of Ethiopia; in Afar Regional State, in Zone 1, at 588 km from capital city, Addis Ababa; on completion the factory will be the only huge factory both in the country and African continent. To supply water continuously to cane farming, and make irrigable land, a dam (Tendaho Dam) with a capacity of holding 1.8BCL water diverted from Awash River with a main canal discharge of 78000m^3/sec.

The sugar estate is running fully surface irrigation system of furrow irrigation method for sugarcane plantation. Its total area of cane plantation is 50,000ha. The factory, at its full operation has a capacity to create a job opportunity close to 40-50 thousands citizens and, upon reaching its maximum production capacity, it will contribute from 65-70megawatts to the national grid covering its own consumption (WWDSE, 2005).

The performance of field water application of the sugar estate was not yet evaluated so far. Therefore, the actual performance of field water application of the sugar estate is not known. The problems with field water application of the sugar estate are mainly related to water conveyance systems, and field water applications managements. Normally, surface irrigated agricultures face a number of difficult problems. One of the major concerns is generally poor efficiency and uniformity with which water resources have been used for irrigation. A large part of low performance may be due to inadequate water management at a system and a field level.

In this paper, the study of field water application system was started from tertiary conveyance system which conveys irrigation water to the field feeder ditches. In the area, the main problems relating to field water application system were starts from tertiary canals; at gate (inlet and outlet) which was used to be closed with a sheet metal, but now totally closed with mud filled in the sucks or mud alone at every tertiary off takes. The closing material does not fit to the groves due to repeated opening and closing of the gates without routine maintenance; the muds was also easily washed out which would result in passing unwanted or leaking water to commercial fields which was not need to be irrigated.

According to the estate irrigation practice, after the water has reached the field ready to be irrigated, it will distribute onto the field by a variety of means, both simple and elaborately constructed. Most fields have a gated pipe (hydroflumes) running along the width of the field from which the flow is distributed into the field. A furrow systems use outlets which can be directed to each furrows. In this system, the problems of field water application are mainly observed due to advance and recession’s times, furrow shaping, furrow slope and water managements. In the study area, most fields almost flooded where others irrigated insufficiently. These combined problems are causing inefficient irrigation water use, yield reduction, and similarly this excess use of irrigation water is favoring the rise of ground water table and formation of salinization in the sugar estate farms.

Efficient water use mostly related to irrigation scheduling. The most fundamental requirement of scheduling is the determination of crop evapotranspiration, ETc. According to Allen et al. (1998), evapotranspiration is not easy to measure, because specific devices and accurate measurements of various physical parameters or the soil water balance in Lysimeters are required to determine evapotranspiration. The crop coefficient (Kc) versus reference evapotranspiration (ETo) method is a practical and reliable technique for estimating ETc, and it is being widely used. Besides the accuracy and reliability, the advantage of this method is related to the fact that is inexpensive, requiring only meteorological data to estimate ETo which is then multiplied by a crop coefficient to represent the relative rate of ETc under a specific condition (Allen et al., 1998).

The phases of a surface irrigation event are advance, wetting, depletion and recession. Data from an evaluation of the advance phase are generally the most important in terms of the information they generate. During field works, points in the field are located with paints or stakes at regular intervals. Two flumes, one placed at the inlet of the furrow and the other at the outlet (if run-off is there) are used to measure the discharge hydrograph into the furrow and the runoff hydrograph from the furrow. The time for the advancing front to reach each stake is noted during the advance phase and when it leaves the stakes during the recession phase. The depletion phase begins at the time of cutoff through when the water surface elevation declines and ends when any portion of the ground surface is bare of water in which case the recession phase ends.

1.2 Definition of the Problems

Irrigation is an art that has been practiced for centuries. By carefully handling the flow of water and observing the resulting yields, growers gradually arrived at certain operational standards. These standards had only regional and sometimes just local significance. They were aimed at either maximum crop production under the given conditions or at an acceptable amount of labor. With more and more land being brought under irrigation, many of these empirical standards were simply copied even when the physical and social conditions in the newly developed regions differed considerably from those in existing projects where they had proved their value. As a result, the effect of irrigation on the yields of the crops, or the labor required for irrigation, can differ greatly from one area to another. Even if these differences in physical and social conditions are well understood, the designers of new projects are still facing the problem of not being able to present a better plan because of a lack of objective standards.

Scarcity of water has becoming the major issue in the world across all countries. Not only does the unwise use of water resulting in wastage make it an important issue, but so is the need to use it for other sectors, and to protect the resource. The main purpose of an irrigation system is to deliver water in a specified quantity for irrigation. Considerable emphasis should be placed on the measurement and control of water, both in storage and in transit through the systems, to minimize losses.

There are three physical characteristics which govern any irrigation operation, in terms of both quantity and time:

- The evapotranspiration by the crops cultivated and its changes during growing season
- The moisture retention of the soils: between field capacity and a preselected depletion limit (the lowest acceptable moisture content that does not significantly affect yields);
- The infiltration rate of the relevant soils.

So far in Tendaho sugar estate; there was no previously done research on the performance evaluation of field water application of the surface irrigation system of furrow irrigation method. As a result, the actual performance of field water application of furrow irrigation of the study area and the level of achievement of the factory’s farm is not known. Relating to irrigation activities, there are visible structural and water application defects in this sugar estate. To be in the rage of study scope, the evaluation has started from tertiary conveyance system to the field water application levels. Therefore, this study was implemented with broad objective to estimate field water application efficiencies, evaluating tertiary conveyance and irrigation scheduling, and with the aim spatially supporting the sugar corporation’s goals by providing potential recommendations for good land and water resource management which will increases production and profitability of the organization resulting in decrease of operation cost.

1.3 Research Objectives

The main objective of the thesis was evaluating the performance of field water application of Tendaho sugar estate in terms of application efficiency, storage efficiency and distribution uniformity of the furrow irrigation systems.

Specific objectives:

- To evaluate the performance of water conveyance of tertiary systems
- To assess the performance of field water application of furrow irrigation system
- To improve the existing irrigation scheduling of system to maintain its sustainability.
- To determine optimum decision variables; inflow rate and cut-off time

1.4 Significance of the Study

Effective performance evaluation of field water application of the schemes is the most appropriate tools for abundant save of resources and using them in proper ways; and most likely to increase livelihood of the country. The output of a given irrigation scheme's objective is achieved if the performance characteristic of that given system is well maintained. This study was important in identifying and understanding the current level of the Tendaho irrigation scheme using performance indicators for conveyances and field water application systems, and evaluation of existing irrigation schedules. The information could therefore important for the sugar estate and provides relevant facts that can be integrated to the sugar project circle through the farm.

1.5 Scope of the Study

The scope of this research was to assess the field water application performance (uniformity and efficiency) starting from tertiary conveyance system to on-farm level using performance parameters such as application efficiency, storage efficiency and distribution uniformity, and other appropriate performance pointers. Finally, it's to draw out relevant recommendations from results for further improvements.

2. LITERATURE REVIEWS

Irrigation is the supply of water to agricultural crops by artificial means, and is required to permit farming in arid regions and to balance the effect of drought in semi-arid regions; even in areas where total seasonal rainfall is adequate on average and where it poorly distributed during the year and variable from year to year. Where traditional rain-fed farming is a high-risk enterprise, irrigation can help to ensure stable agricultural production (FAO, 1997).

According to USDA (1999), irrigation application methods are categorized under two broad system types: gravity or surface, and pressurized systems. Surface irrigation is the process of introducing a stream of water at the head of the field and allowing gravity and hydrostatic pressure to spread the flow over the surface throughout the field. In second method, pressure irrigation method, the water is given to soil by using closed pipe systems with an additional energy or a drawing effect. Pressure methods can be categorized as overhead (spray) irrigation with water delivered through nozzles, or drip irrigation with water delivered through tubes and emitters.

2.1 Surface Irrigation System and Processes

According to Jurreins, et al. (2001), the process of surface irrigation is characterized by four phases: advance, storage, depletion, and recession. As water is applied to the top end of the field, it will flow or advance over the field length. The advance phase refers to that length of time as water is applied to the upstream end of the field and flows or advances over the field length. After the water reaches the end of the field, it will either run-off or start to pond. The period of time between the end of the advance phase and the shut-off of the inflow is termed the wetting or storage phase. As the inflow ceases, the water will continue to infiltrate and runoff until the entire field is drained. The depletion phase is that short period of time after cut-off when the length of the field is still submerged. The recession phase describes the time period while the water front is retreating towards the downstream end of the field. The depth of water applied to any point in the field is a function of the opportunity time, the length of time for which water is present on the soil surface.

2.1.1 Furrow Irrigation

Furrow irrigation is conducted by creating small parallel channels along the field length in the direction of predominant slope. Water is applied to the upstream end of each furrow and flows down the field under the influence of gravity. Water may be supplied using gated pipe, siphon and head ditch or bank-less systems. The speed of water movement is determined by many factors such as slope, surface roughness and furrow shape but most importantly by the inflow rate and soil infiltration rate. The spacing between adjacent furrows is governed by the crop species.

Plate 1 Furrow irrigation method in Tendaho sugar factory farm

Furrow irrigation of sugarcane is popular for the following reasons: water is applied by gravity, wind has no effect on application efficiency, it is a simple and cheap system to install and operate, it can be adapted to a wide range of soil types, and it can use a variety of water delivery methods at the head of the furrow (Glyn James, 2004). On the negative side, surface irrigation systems are typically less efficient in applying water than either sprinkle or trickle systems, and it tends to cause waterlogging and salinity problems. The need to use the field surface as a conveyance and distribution facility requires that fields be well graded. Land leveling costs are high, so the surface irrigation practice tends to be limited to land already having small, even slopes (Walker, 2003).

2.1.2 Flexible Gated Pipe

Gated pipes are an option used instead of feeder ditches in furrow irrigation method. It is an improvement on furrow irrigation, in which the conventional head ditch and siphons are replaced by an aboveground pipe. Gated pipes used for distributing water into irrigation furrows can either be rigid (plastic or aluminum) or flexible (polyethylene) with outlets aligned to each furrow shots normally spaced according to the crop row spacing. Rigid gated pipes are rarely used in the irrigation sector mainly because of difficulty experienced in transportation. Flexible gated pipes are widely used in the sugar industry (Smith and Gillies, 2010). Flexible gated pipe is relatively low cost, easily transportable and requires little storage space.

Plate 2 Hydroflumes/gated pipe - irrigation method in Tendaho sugar project

Hassan (1998) stated that gated pipe has made furrow irrigation more efficient and easy to operate and maintain. It is one of the ways to improve the efficiency of surface irrigation. This system has attained an application efficiency of 90% for a recycling system (Tilly and Chapman, 1999). According to Hassan (1998), gated pipe can result in a 35 to 60% reduction in water and labor costs. Gated pipe provides a more equal distribution of water into each furrow (by setting the gates precisely) and eliminates seepage and evaporative losses which occur in unlined irrigation ditches. Omara (1997), found that the irrigation application efficiency and irrigation distribution efficiency increased to 72.5% and 92%, respectively by using gated pipe system through furrow irrigation.

2.1.3 Evaluation of Surface Irrigation Systems

Evaluation can be defined as follow-up, understand and pass judgment on a given situation (Chaponnière et al, 2012). System evaluation is necessary to provide direction to management for either continuing existing practices or making essential improvements. The purpose of an evaluation is to ensure that the system functions as described in the design report and whether the system was installed according to plan (Koegelenberg and Breedt, 2003). Irrigation system evaluation techniques are undertaken to evaluate the existing operational and management conditions, and to help determine the potential for more economical and efficient operation (Merriam et al., 1973). System evaluation is necessary to provide direction to management for either continuing existing practices or making essential improvements. The process of efficient water management is to determine and control the rate, amount, timing and distribution of irrigation water so that the crop water requirements are met in a planned and effective manner (Reinders, 1996).

2.1.4 Performance of Surface Irrigation systems

The performance of a system can be defined as its efficiency, understood as the relation between actual results versus the expected results of the system (inputs and outputs). The purpose of performance evaluation is to achieve an efficient and effective use of resources by providing relevant feedback to the scheme management at all levels. Poor design and lack of suitable criteria for irrigation systems are generally responsible for uneven irrigation, leading to wastage of water, waterlogging and salinity problems (Maheshwari, 1993a).

2.1.5 Reasons for Performance Assessment

There are several cases for carrying out performance assessment of irrigation scheme (Walker, 1987)

- When we know something is wrong and we wish to find out what is causing it
- When we want, as part of management, to know how we are doing and can improve it
- When a researcher, using the case study approach, seeks to understand the detailed workings of an irrigation scheme in order to draw generalized inferences.

The need to develop comprehensive methodologies to evaluate the performance of irrigation schemes has long been recognized. The concluding remarks of a workshop on irrigation water management held at the International Rice Research Institute (IRRI) in 1979 stated that: "What is most needed is an established methodology to determine the efficiency of an irrigation system in physical, economic, and social terms as well as in terms of water use and to show how the efficiency can be improved..." (IRRI, 1980)

Bhuiyan (1981) states that: "There is a need for more research work to develop appropriate system evaluation criteria that could be used for systematic but rapid identification of irrigation systems weaknesses and strengths, and also for the better evaluation of management improvement efforts."

Against this background, there have been several attempts over the past three decades to address this problem. The interest in the subject of 'irrigation performance' further gained momentum in the 1980s, and has presently become one of the top issues of discussion in irrigation circles. This is evident in the many national and international activities undertaken on the subject in the past decades. In 1983, FAO organized an Expert Consultation on Irrigation System Performance in an early effort to develop guidelines and methodologies for assessing irrigation systems performance and for identifying their problems and solutions .In June 1989, the International Commission on Irrigation and Drainage (ICID) widened the task of its Working Group on 'Irrigation Efficiencies' to 'Irrigation Performance Assessment.' This marked a move away from viewing performance as purely technical (i.e. losses in canals) to broader issues.

2.2 Performance Evaluation of Tertiary Conveyance System

According to Fairweather et al, (2003), conveyance losses are defined as the losses that occur from the time water is released from the reservoir to when it is delivered to the farm gate. It includes evaporation, transpiration, seepage losses and other leakages such as filling losses. These losses can be divided into unavoidable losses and avoidable losses. Unavoidable losses are include the major system losses in open farm water distribution systems; evaporation and seepage losses and they may be as high as 50 % of total volume available. Avoidable losses include operational losses resulting from improper management with one of the most critical faults being incorrect run times varying climatic and demand conditions, which can account up to 9-17%.

According to James (1988), the performance of a farm irrigation system is determined by the efficiency with which water is diverted, conveyed, and applied, and by the adequacy and uniformity of application in each field on the farm. Mishra and Ahmed (1990), also said that irrigation efficiency indicates how efficiently the available water supply is being used based on different methods of evaluation. The objective of these efficiency concepts is to show where improvements can be made, which will result in increased irrigation efficient.

2.2.1 Conveyance and Measurement Structures

The water conveyance systems are those structures to convey water to the field by receiving water from diversion headwork. The conveyance systems can be earthen ditches or laterals, of buried pipe, or a lined ditch. Tendaho sugar project is using completely earthen ditch of tertiary conveyance system. Since it is the unlined type conveyance systems, obviously the performance of the conveying structure is not similar throughout operations. Erosion of side walls, poor slope of canals and vegetation growth are the main problems of poor efficiency of these systems.

The delivery of water from the canal turnout to the field inlet requires conveyance and control structures found in major canal networks. The conveyance structures are usually an earthen ditch or sideways, a buried pipe, or a lined ditch. Pipe materials are usually plastic (PVC), concrete, clay, or asbestos cement, but may be as simple as a wooden square or rectangular construction.

The control of water within conveyance system involves flow measurement, sediment and debris removal, divisions, checks, drops, energy dissipaters, and water-level controls. More common flow-measuring structures for open channels are weirs, flumes and orifices (FAO, 1989b)

Plate 3 Typical flow measuring devices used in surface irrigation systems

2.2.2 Losses of Water in Canals

During the passage of water from main canal to the outlet at the head of the watercourse, water may be lost either by evaporation from the surface or by the seepage through the peripheries of the channels. These losses are sometimes very high, of the order of 25 to 50% of the water diverted into the main canal (Garg, 2005). According to Reid et al., (1986) in Implementation Guidelines for Water Conservation and Water Demand Management in Agriculture, approximately 0.3% of the total stream is lost due to evaporation.

The conveyance efficiency (Ec) mainly depends on the following indicators; the length of the canals, the soil type or permeability of the canal banks and the condition of the canals. It is defined as the ratio between the water that reaches a farm and that diverted from the irrigation water source (Boss, 1997).and it is defined as:

$$Ec = 100 \left(Vf / Vt \right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 2.1$$

Where, Ec = is the conveyance efficiency (%), V_f = is the volume of water that reaches the farm or field (m^3), and V_t = is the volume of water diverted (m^3) from the source.

Factors affecting conveyance efficiency among others are; size of the irrigated hectares, size of rotational unit, number and types of crops requiring adjustments in the supply, evaporation, canal lining and technical and managerial facilities of water control.

2.3 Performance Evaluation of Field Water Application of Furrow Irrigation

The evaluation of surface irrigation at a field level is an important aspect of both design and management. Field measurements are necessary to characterize the irrigation system in terms of its most important parameters, to identify problems in its function, and to develop alternative means for improving the system. System characterization necessitates a series of basic field measurements before, during, and after the irrigation events. In some cases, there are alternative methods and equipment for accomplishing the same ends (FAO, 1989b)

2.3.1 Technical Parameters to Evaluate Furrow Irrigation System

2.3.1.1 Irrigation Water Use Efficiency

Irrigation water use efficiency is a measure of the effectiveness of an irrigation system to deliver water to a field, or the effectiveness of an irrigation system to increase crop yields. It is the ratio between the volume used by plants throughout the evapotranspiration process and the volume that reaches the irrigation plots and indicates how efficiently the available water supply is being used, based on different methods of evaluation (Wolters and Bos, 1989; Fairweather et al., 2003).

According to Molden et al (1998), much of the work to date in irrigation performance assessment has been focused on internal processes of irrigation systems. Many internal process indicators relate performance to management targets such as timing, duration, and flow rate of water; area irrigated; and cropping patterns. A major purpose of this type of assessment is to assist irrigation managers to improve water delivery service to point of use.

2.3.1.1.1 On-farm Application Efficiency

Application efficiency refers to the amount of water needed for crop production compared with the amount applied to the field and depends on system uniformity and management. It is the ratio of the amount of irrigation water beneficially used to the amount of applied water. It can be defined as the ratio of the volumes (depth) of water used by the plant to the volume (depth) of water applied to the field (Zerihun et al., 1997).

$$Ea = \frac{Var}{Vap} \quad \text{……………………………..……………………………………….2.3}$$

Where, Ea = Application efficiency (%), Var = volume of water used by the plant (m^3), Vap = volume of water applied to a field (m^3). The field application efficiency (Ea) mainly depends on the irrigation method and the level of grower discipline. It relates to the actual use of water by the crop in relation to the water applied to the field.

Well designed and managed surface irrigation systems may have application efficiencies of up to 90% (Anthony, 1995); many commercial systems have been found to be operating with highly variable efficiencies at significantly lower levels. For example, commercial furrow application efficiencies in the Australian sugar industry have been found to range from 14-90% for single irrigations and from 31-62% for seasonal applications (Raine and Bakker, 1996). Similarly, application efficiencies of 54.7-92% have been found in Kenyan sugarcane industry (Muturi et al., 2006) and application efficiencies of 30-50% have been found on cotton farms and 40-80% on vane yards (Smith, 1988).

Smith et al., (2005) conducted an analysis of 79 furrow irrigation events under normal grower management and demonstrated potential efficiency gains of an average 20%. This improvement in performance could be achieved through an increase of the furrow flow rate to 6 l/sec and reducing the irrigation time accordingly but with no significant modification to the field design or management. Holzapfel et al., (2009) reported that water application efficiency increases its value while the furrow length is increased, whereas its value decreases when either the inflow or cutoff time increases. Thus, it can be deduced that a furrow irrigation using a large inflow, a small furrow length, and a long cutoff time losses more water than using a large furrow length, a small inflow, and a small cutoff time.

Habib (2004), have conducted performance evaluation and sensitivity analysis for furrow irrigation at Metehara Sugar Estate of Ethiopia. The sensitivity experiment attempts to quantify the performance parameters of different furrow length and inflow rate combinations. He examined two furrow lengths (50 and 100 m) and four inflow rates (2, 3, 4 and 5 l/s). He concluded that application efficiency and uniformity coefficient were more sensitive to furrow length than inflow rate. On the other hand, distribution uniformity and storage efficiency were more sensitive to inflow rate than furrow length. The mean application efficiency, distribution uniformity, uniformity coefficient and storage efficiencies were 74.1, 73.4, 77 and 96.7 % 50 m furrow length while 76.2, 74.3, 81.2 and 98.4% for 100 m furrow length respectively. Almost all performance parameter increased by doubling the furrow length from 50 m to 100 m.

2.3.1.1.2 Storage Efficiency

The requirement efficiency is an indicator of how well the irrigation meets its objective of refilling the root zone. The value of Es is important when either the irrigations tend to leave major portions of the field under-irrigated or where under-irrigation is purposely practiced to use precipitation as it occurs and storage efficiency become important when water supplies are limited (FAO, 1989b).

Jurriens et al. (2001), expresses adequacy of irrigation turn in terms of storage efficiency and the purpose of an irrigation turn is to meet at least the required water depth over the entire length of the field. Conceptually, the adequacy of irrigation depends on how much water is stored within the crop root zone, losses percolating below the root zone, losses occurring as surface run off, and the remaining deficit or under irrigation within the soil profile following irrigation.

The water requirement efficiency (Es) measures the effectiveness of the quantity of water stored in the root zone after irrigation (Zerihun et al., 2001): is presented here as:

$$Es = \frac{Var}{Vps} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. \; 2.4$$

Where, Es = Storage efficiency (%), Var = volume of water added to root zone storage (volume stored in root zone) (m^3), Vps = Potential soil moisture storage volume (SMD) (m^3)

According to Mishra and Ahmed (1990), the water requirement efficiency, Es, is also commonly referred to as the storage efficiency. The requirement efficiency is an indicator of how well the irrigation meets its objective of refilling the root zone. The value of Es is important when either the irrigations tend to leave major portions of the field under irrigated or where under-irrigation is purposely practiced to use precipitation as it occurs. This parameter is the most directly related to the crop yield since it will reflect the degree of soil moisture stress.

2.3.1.1.3 Deep Percolation Ratio

When water is diverted into any water application system such as furrows, part of the water infiltrate into the soil for consumptive use by the crop, while the rest is lost as deep percolation and runoff. SIRMOD III manual (2001) defines deep percolation fraction as the ratio of the volume of water percolated below the bottom of the root zone as the subject area to the total volume admitted into the subject area and defined as:

$$Dp = \frac{Vdp}{Vwa} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 2.5$$

Where, Dp = Deep percolation ratio, Vdp = volume of deep percolation (m^3), Vwa = volume of water added to a field (m^3).

High deep percolation losses aggravate waterlogging and salinity problems, and leach valuable crop nutrients from the root zone. Depending on the chemical nature of the groundwater basin, deep percolation can cause a major water quality problem of a regional nature. Deep percolation results when water is applied too long to the field and/or the variation of intake opportunity time is too large (inflow rates are too small). These two problems can be remedied by adjusting the time of cutoff and in inflow rate.

2.3.1.1.4 Run-off Fraction

Run-off, RO measures the relative proportion of the losses at the tribute to that of the total volume of the water delivered to the head end of the subject area (Walker and Skogeboe, 1987), and formulated by:

$$RO = 1 - Ea - Dp \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 2.6$$

Where, RO = run-off fraction, Ea = application efficiency and Dp = deep percolation ratio

Runoff losses pose additional threats to irrigation systems and regional water resources. Erosion of the topsoil on a field is generally the major problem associated with runoff. The sediments can then obstruct conveyance and control structures downstream, including dams and regulation structures. Runoff losses can be reduced by adjusting the inflow, by collecting and recycling the tail-water, and by reducing the inflow after the advance has been completed (SIRMOD III Manual, 2001).

2.3.1.2 Irrigation Water Uniformity

According to Pereira and Luis (1999), several parameters are used as indicators of the uniformity of water application to a field. The most commonly used index are: the Coefficient of Uniformity (CU), Distribution Uniformity (DU), and the Statistical Uniformity coefficient (SU).

2.3.1.2.1 Coefficient of Uniformity

Christensen (1942) defined the coefficient of uniformity, Cu as the ratio of the difference between the average amount applied and the average deviation from the average amount applied to the average amount applied. It is given by:

$$\mathrm{Cu} = 100\left[1 - \frac{\sum_{i=1}^{n}\left|Zi - \overline{Z}\right|}{N * \overline{Z}}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.7$$

Where: Z_i-infiltrated amount at point i [m^3/m], $\overline{Z}$ - average infiltrated amount [m^3/m], N-Number of points used in the computation of Cu.

2.3.1.2.2 Distribution Uniformity

Distribution uniformity, DU, is a measure of how evenly water infiltrates across a field. It gives an indication of the magnitude of the uneven distribution and can be defined as the percent of average application amount in the lowest quarter of the field (Rogers et al., 1997). The lowest quarter fraction, d_{lq} (mm), has been used by the United States Department of Agriculture (USDA) since the 1940s and has proved to be useful in irrigated agriculture and is defined by the following (Burt et al., 1997):

$$\mathrm{Dlq} = \frac{\text{Volume accumulated in 1/4 total area of elements with smallest depths}}{\text{Total area of 1/4 of the total area of elements}} \ldots\ldots\ldots\ldots. 2.8$$

The low-quarter distribution uniformity, DUlq, can be defined as;

$$\mathrm{DUlq} = \frac{d_{lq}}{d_{avg}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.9$$

Where, d_{lq} = minimum infiltrate amount over the length of run (mm), d_{avg} = Average depth of infiltrate water over the length of run of subjected area (mm)

2.3.1.2.3 Factors That Affects the Uniformity

The uniformity of each type of irrigation system is influenced by different factors which are detailed by Pereira (1999) and Burt et al., (1997).

Table 1 Factors that affect uniformity in furrow irrigation systems (after Burt et al., 1997)

Uniformity component	Factors causing non-uniformity
Opportunity-time differences down a furrow	Flow rate and duration Slope and roughness Furrow cross-sectional shape
Opportunity-time differences between furrows	Furrow length Different day or night irrigation set times Wheel row compaction or no wheel compaction (infiltration rate problem) Different furrow flow rates
Different infiltration characteristics for individual furrows	Different degree of compaction due to tractor tires and tillage
Different infiltration characteristics across the field	Different soil types Texture differences of soils
Other opportunity time differences throughout a field	Non-uniform land preparation
Difference in day and night intake rates	Viscosity changes due to temperature changes
Infiltration rate differences due to differences in wetted perimeter	Slope changes or restriction to flow along the furrow

2.3.2 Determination of Decision Variables: Inflow Rate Cut Off Times

The main design and management variables are the unit flow rate (Q) and the time of cutoff (t_{co}), and to a lesser extent the border or furrow length (L). The geometry of the parcel and the location of the water point source, however, impede that the length is a variable (Jurriens, 2001).

According to Panoras et al. (1996), who have dealt with furrow irrigation, the changeable parameters in furrow irrigation variables are the inflow rate and the length of the furrow. It is one of the key variables in influencing the outcomes of an irrigation event; it affects the rate of advance to a significant degree and recession in an indirect way. It affects recession only when the infiltration perimeter and volume stored at the surface depends on inflow. It has a significant effect on uniformity, efficiency and adequacy of irrigation.

Cut-off time, t_{co} is the time at which the supply is turned off, measured from the onset of irrigation. Cut-off time has no impact on advance as long as the latter is taken equal or larger than the advance time. However, it has an influence on recession. The most important effect of cut-off time is reflected on the amount of losses, deep percolation and surface run-off, and hence efficiency as well as adequacy of irrigation. For any given factor level combinations the selection of an appropriate value of t_{co} is made on the basis of the target application depth and acceptable level of deficit (Jurriens et al., 2001). Cutting the inflow too soon will result in an insufficient depth of application, poor uniformity and the real possibility of the advance not reaching the bottom end of the field. If the cut-off is too late, the depth of application may be excessive with large losses of water in the form of deep percolation below the root zone and run-off from the end of the field.

The infiltration characteristic is the dominant factor of all the above variables affecting the performance of surface irrigation systems; and the variability of this parameter further complicates the situation for the growers to irrigate efficiently (Solomon Assefa, 2011).

The soil's infiltration rate which is a field parameter is a measure of how fast water is soaking into the soil. Infiltration rates are described in terms of "inches per hour". Using Kostiakov-Lewis equation, the infiltration depth of fields was determined as follows:

$$Z = K\,t^{a} + f_{o}\,t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.12$$

$$a = \frac{\ln\left[\left(Z_1 - fo * t_1\right)/\left(Z_2 - fo * t_2\right)\right]}{\ln\left(t_1/t_2\right)} \qquad\qquad k = \frac{\left(Z_2 - fo * t_2\right)}{t_2^{\,a}}$$

Where, Z_1= initial infiltrated water depth (mm); Z_2= average infiltrated water depth (mm); k= intake constant (mm/min^{a}); a= intake power (-); f_o= final intake rate (mm/min); τ =the design intake opportunity time min), t_1=corresponding time (min) to the infiltrate Z_1; and t_2= intake opportunity time (min)

Melaku (2006) has evaluated the performances of Bato Degaga surface irrigation system. He investigated three levels of furrow flow rate 0.3, 0.4 and 0.5lit/sec and three levels of furrow lengths 24, 35 and 50 m in split plot design. He found that average application efficiency of 28.9, 33.6 and 40.46% for furrow lengths of 24, 35 and 50 m respectively. Regarding flow rates the average values application efficiencies became 32.9, 32.8 and 36.9% for the flow rates of 0.3, 0.4 and 0.5lit/sec, respectively. As to the irrigation adequacy he found that 93.35, 86.9 and 99.2% for the 24, 35 and 50 m furrow length respectively. For all test flow rates 100% adequacy was achieved. The distribution uniformity was 32.64, 39.6 and 35 % for furrow lengths of 24, 35 and 50m respectively and 25.3,37 and 44.8% for the flow rates of 0.3, 0.4 and 0.5 lit/sec respectively.

Teshome (2007) has conducted a study on infiltration characteristic of furrow irrigation by assessing the effect of decision variables and designing parameters such as inflow rate, furrow length and cut off time. The study was conducted at Arba Minch University research farm on dominantly sandy clay loam soil of plot size of 300 m length and 25 m width with slope of 0.45%. He found that highest application efficiency of 65.1, 65.1, 61.1, 63, 61.6 and 47.6% for the inflow rates of 0.8, 1.2, 1.2, 1.8, 2.6 and 3 lit/sec; for the furrow lengths of 50, 75, 100, 125, 175 and 200 m, respectively. These flow rates were found to be the best combination which balances the losses due to deep percolation and run off.

2.4 Irrigation Scheduling

Effective, efficient irrigations are the result of knowing "When" to irrigate, "How much" to irrigate, and "How" to irrigate. When to irrigate is an agronomic decision, based on how you want the crop to develop. How much to irrigate depends on soil moisture deficit (SMD) in the current effective root zone. You must know how much water is needed to take the soil back to field capacity.

There are varieties of scheduling methods; according to FAO (1989a), three alternative methods are suggested: Plant observation method, Estimation method, and Simple calculation methods. The plant observation method is normally used by farmers in the field to estimate "when to irrigate", and it's based on observing changes in plant characteristics, such as change in color of plants, curling of the leaves, and ultimately plant wilting. In the estimation method, a table is provided with irrigation schedules for the major field crops grown under various climatic conditions. The simple calculation method is based on the estimated depth of the irrigation application, and the calculated irrigation water need for the crop during the growing season.

2.4.1 Crop Evapotranspiration – Concepts

According to Allen et al. (1998), evaporation is the process whereby liquid water is converted to water vapor and removed from the evaporating surface; vapor removal. Water evaporates from a variety of surfaces, such as lakes, rivers, pavements, soils and wet vegetation. Transpiration, in turn, is the transfer of water from plants through their aerial parts. Water transfer from plant to atmosphere occurs mainly through the stomata through which they pass more than 90% water transpired.

The most popular method for crop evapotranspiration estimate is the use crop coefficient (Kc), which is defined as the ratio between a crop and ETo (Allen et al., 2011). The Kc method has the advantage of being inexpensive, since it requires only daily weather data to estimate the reference evapotranspiration which is multiplied by Kc dimensionless value. The Kc value depends on crop growth stage.

2.4.2 Crop Coefficient

The Kc concept was introduced by Jensen (1983) and is widely discussed and refined by the FAO in its Bulletin-56 (Irrigation and Drainage Paper, Allen et al., 1998). In the crop coefficient approach, crop evapotranspiration is obtained by multiplying the reference evapotranspiration, ETo (mm/day), by a crop coefficient, Kc according to Equation 2.8

$$ETc = Kc * ETo \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 2.10$$

Where, ETc is a crop evapotranspiration (mm/day), Kc is dimensionless and ETo is a reference evapotranspiration (mm/day). The FAO-56 reported Kc values for the initial, middle and end growth stages, $Kc\text{-}_{init}$, $Kc\text{-}_{mid}$ and $Kc\text{-}_{end}$, respectively, for many crops.

2.4.3 Irrigation Scheduling in Sugarcane Based On Soil Water Balance Approach

The principle of the water balance method is shown in Figure 1. The objective is to obtain a balance of incoming and outgoing soil water so that adequate available water is maintained for the plant. Inputs include incoming water in any form whether rainfall or irrigation. Outputs include any type of water removal. Water removal is more commonly referred to as evapotranspiration (Harrison, 2012).

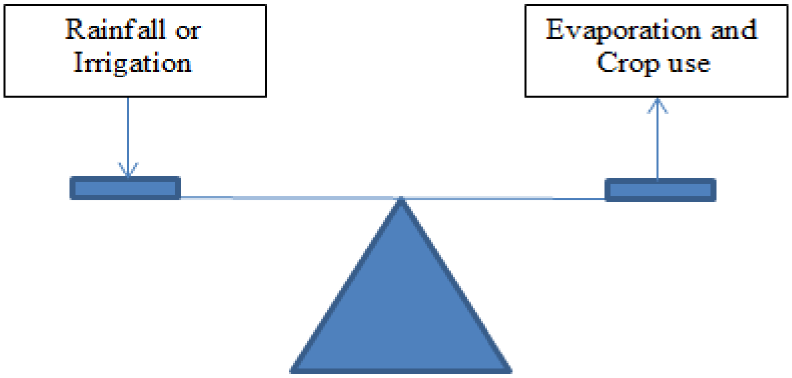

Figure 1 Water balance method

2.4.4 Determining Irrigation Need

Since irrigation scheduling by the water balance approach is based on keeping a balance of soil water content, the irrigation criterion is the percent of water depleted from the soil water available to plants. Two parameters determine the total soil water available to plants. The first parameter is the soil water-holding capacity, which is the amount of water measured in (mm/m) held in the soil by capillary forces. The second parameter is the effective root zone of the crop, which is the soil depth of the roots. The management allowable depletion (MAD) is the percent of available soil water that is allowed to be depleted before irrigation is applied. Irrigation is needed when the allowed amount of water is depleted from the root zone. Depletion beyond allowable amount stresses plants and reduces crop yield (Broner, 2005).

2.4.4.1 Estimating Soil Water Content

The water content in the effective root zone is estimated by using the water balance equation (Broner 2005);

$$WC_t = WC_{t-1} + Ir + R - ETa - DP \quad \text{……..……………………………………}2.11$$

Where, WC_t = Soil water content today (mm), WCt-1 = Soil water content yesterday (mm), Ir = Irrigation depth since yesterday (mm), R = Rain since yesterday (mm), Eta = Actual ET (mm), and DP= Deep percolation (mm).

2.4.4.2 Water Requirement of Sugarcane

FAO (2010) indicated that adequate soil moisture throughout the crop-growing season is important for obtaining maximum yields as vegetative growth is directly proportional to the water transpired. According to the same report, water requirement of sugarcane depends on the agro-ecological conditions, cultivation practices adopted and crop cycle (12-24 months) and it varies about 1300 mm to 2500 mm evenly distributed over the growing season.

(Abdel Wahab, 2005), reported that the water required by sugarcane increased gradually with plant growth stage, and the quantities of irrigation water required in the crop root zone amounted to 17220 and 20570 m^3/ha/season for ratoons and plant cane, respectively. Net irrigation requirement is drived from field balance equation (Netafim, 2009)

$$NIR = ETc - (Pe + Ge + Wb) + LR \quad \ldots\ldots 2.12$$

Where, NIR= is net irrigation requirement, ETc= crop water requirement, Pe= effective dependable rainfall (mm), Ge= ground water contribution from water table (mm), Wb= water stored in the soil at the beginning of each periods (mm), and LR= leaching requirement

2.4.4.3 Irrigation Interval of Sugarcanes

According to Michel and Pierre (2009), irrigation is a major factor in sugarcane production; indeed, it is one of the most water demanding crops after rice. It is frequently criticized for its high water consumption. Frequency and depth of irrigation should vary with growth periods of the cane (Michel, 2008; FAO, 2010). During the early vegetative period the tillering is in direct proportion to the frequency of irrigation. During stem elongation and early yield formation irrigation interval can be extended but depth of water should be increased. The response of sugarcane to irrigation is greater during the vegetative and early yield formation periods than during the latter part of the yield formation period when active leaf area is declining and the crop is less able to respond to sunshine. During the ripening period, irrigation intervals are extended or irrigation is stopped when it is necessary to bring the crop to maturity by reducing the rate of vegetative growth, dehydrating the cane and forcing the conversion of total sugar to recoverable sucrose.

Irrigation frequency is defined as the frequency of applying water to a particular crop at a certain stage of growth and is expressed in days. According to Mishra and Ahmed (1990), irrigation interval is calculated by the formula:

$$\text{Irrigation interval} = \left(\mathrm{AMD}/\mathrm{ETc}\right) = \left(\mathrm{TAW} * \rho * \mathrm{Drz}\right)/\mathrm{ETc} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 2.14$$

Where, AMD = allowable soil moisture depletion, cm; ETc = daily water use or CWR (cm/day), TAW-total available soil moisture (Fc-PWP) (mm/m), ρ-allowable depletion (decimal), Drz-effective root zone depth (m),

2.4.4.4 Depth of Irrigation Application

Depth of irrigation application is the depth of water that can be stored within the root zone between field capacity and the allowable level the soil water can be depleted for a given crop, soil and climate. It is equal to the readily available soil water over the root zone (James, 1988).

The moisture deficit (d) in the effective root zone is found out by determining the field capacity moisture contents and bulk densities of each layers of the soil (Mishra and Ahmed, 1990).

$$d = \sum_{i=1}^{n} \frac{(\mathrm{Fci} - \mathrm{PWi})}{100} * \mathrm{Bdi} * \mathrm{Di} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 2.12$$

Where: Fc_i = field capacity of the i^{th} layer on oven dry weight basis, %; PW_i = moisture content before irrigation in the i^{th} layer of the soil, %; Bd_i = bulk density of the soil in the i^{th} layer, D_i = depth of i^{th} soil layer within the root zone, cm and, n = number of layers in the root zone.

Previous studies of Habib (2004) and Solomon (2010) has considered the maximum rooting depth of 1.0 meter for Metahara sugar estate to calculate water application depths in each soil types of the estate. Similarly, in their study the maximum rooting depth of 1m and the optimum factor of depletions for sugarcane was in between 0.50 to 0.65 was used which was also proposed by Booker Tate (2009) for Metahara sugar estate soils, and are in agreement with recommended 0.55 by Rao (1990) and 0.65 by FAO (1979).

2.4.4.5 Irrigation Speed

Irrigation speed is the time (hours or days) taken to irrigate a given area (ha or m^2) of irrigation field. Knowing the time required to irrigate a specific field or irrigation speed of a scheme, helps to determine the number of irrigators to be engaged in, the amount of water to be released at a specific period, to monitor irrigation calendar and in general to asses or monitor the performance of the irrigation system as a whole. Time of irrigation is defined as Muhammad (2012):

$$T = 27.78Ad/Q \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 2.13$$

Where, Q = Discharge (lps), T = Time (hrs), A = Area (ha) and d = Depth of water (cm)

Solomon Mulugeta (2010), has also conducted study on Evaluation of Irrigation Scheduling and Field Application Performance of Hydroflumes Furrow Irrigation at Metahara Sugar Estate with the objectives of evaluating the performance of irrigation scheduling being used for full irrigation strategy, evaluating field application of hydroflumes under current practices, determining irrigation scheduling for sugarcane under current soil and climatic condition for each cropping stages, and determining optimum cut-off time for selected flow rate using SIRMOD III simulation model for each soil types. He has used four major soils with furrow length of 100m and 200m; and obtained the following results: mean application efficiency of 80.58 % for 100m furrow length and 59.56% application efficiency for 200m furrow lengths. But, after optimization both furrow length were attained application efficiency greater than 91% for all soil types at 5 l/sec inflow rate and cutoff time in between 44 to 54 minutes for 100m furrow length and 92 to 118 minutes for 200m furrow length. Similarly, the author has also proposed the irrigation interval of the four soils from which almost relatively similar (9-11) days for 0 to 3 months growth stages, and to the maximum of once per month for last growth stages.

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3. RESEARCH METHODOLOGY

3.1 Description of the Study Area

3.1.1 Location

Tendaho Sugar factory is located between latitude 11^0 30’- 11^0 50’ N, and Longitude 40^0 45’- 41^0 03’ E in Eastern Afar Regional State, in Zone 1; with its command area encircling part of Millie, Dubti, Asaiyta and AfamboWoreda. The sugarcane farm of the factory lies on both banks of Awash River between the proposed Dam near Tendaho and the junction of river Awash with Gamari and Afambo lakes. The altitude of the study area ranges from 340 to 365 m a.s.l. The net command area of the sugar estate is 50,000 ha. The entire command area lies in the deltaic alluvial plains. The slope is very mild from 0.05 to 0.1 m per 1km. The area is prone to flooding by river Awash which carries considerable amount of silt and has a tendency to change the course very often (WWDSE 2005).

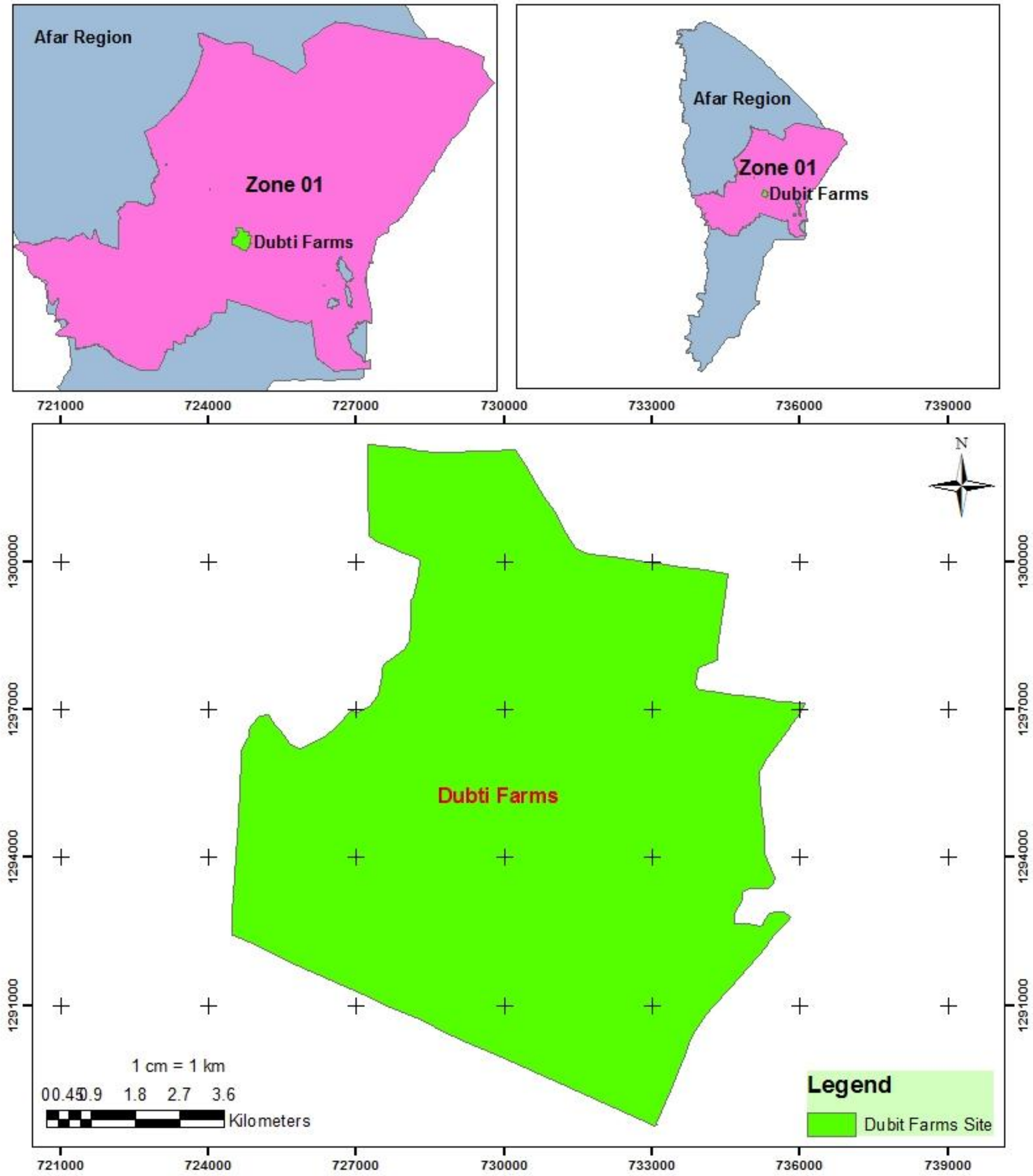

Figure 2 The map of studied area

3.1.2 Climate

The mean maximum monthly temperature of the command area varies between 32.9 to 43.2^{0}C and the mean minimum varies between 18.3^{0}C to 27.1^{0}C. The average annual rainfall is about 184.1 mm. The mean monthly relative humidity varies between 33.7 to 57.4%. The wind speed varies from 146.7 km/day in February to 91.9 km/day in October. The sunshine hours varies between 6.8 to 9.9 hr/day, (Appendix 7).

3.1.3 Soil

According to FAO classification, the soil of the study area can be categorized shown in Appendix 4. There are three major soil mapping units in Tendaho Sugar Project farm area. From these, the soil type of area under this study lies on lacustrine sediments, Calcaric vertisols and Orthic solonchaks of FAO soil units (Silty clay/calcaric fluvisols and Silty clay loam/orthic solonchaks textural classes). These two soil type's covers 9,367ha land of the sugar estate farm lands.

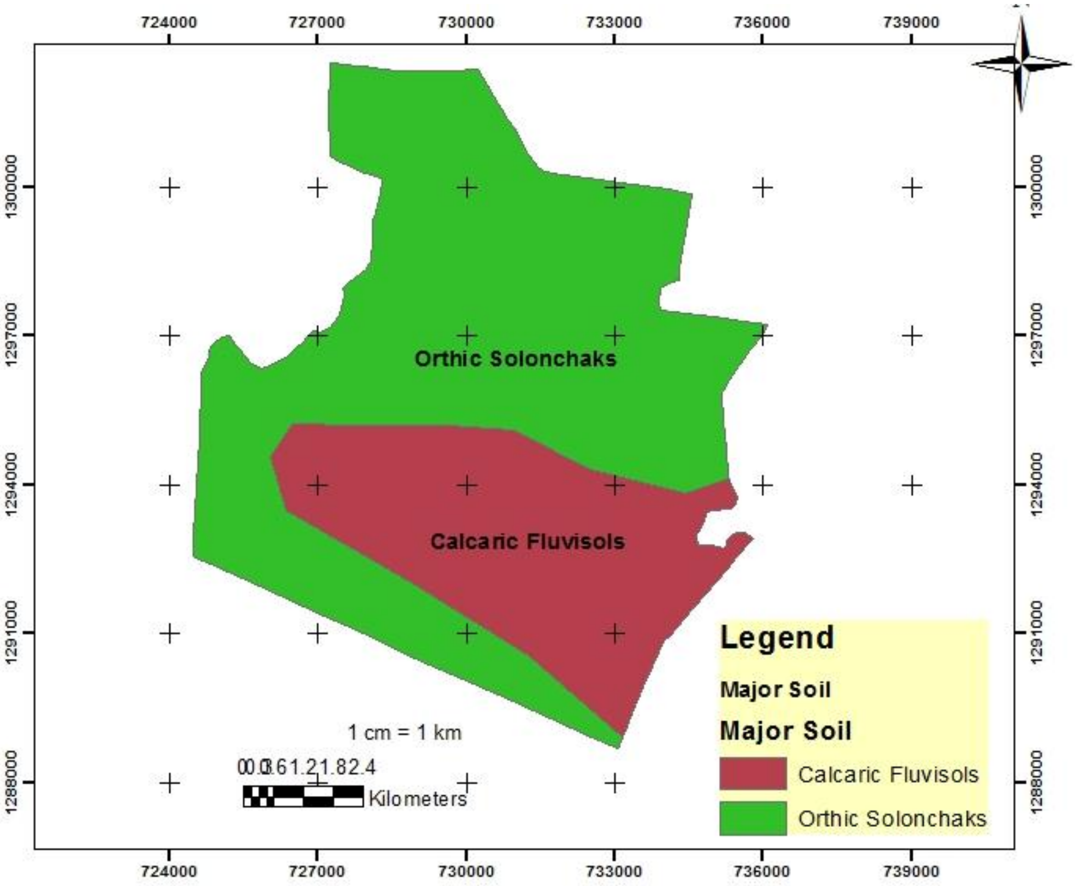

Figure 3 Soil map of the study area

3.1.4 Crops

Tendaho sugar project is one of the biggest sugar estates in the country growing sugarcane crop dominantly. Its net sugar production land is over 50,000 hectares for sugarcane plantation. Sugarcane is a grass family, gramineae, characterized by segmented stems, blade-like leaves, and reproduced by vegetation and seed, and needs more water for its growth.

3.2 Irrigation Method and Field Water Application Practice at Tendaho

3.2.1 Feeder Ditch Delivery Systems

Many methods have evolved for the delivering water from the head to the field edge of the furrows. The most common method is a feeder ditch having several blockages, which is impeded in sections of 15 to 20 furrows. The sides of the feeder ditch are breached at furrow spacing using a hoe to release water flow into each furrow. Compared to others, this method is cheap to construct but is a labor intensive, since the breaches have to be repaired before progressing to the next irrigation set. In this method, furrow flow rates were low, and water distribution is irregular and very dependent on the individual irrigator's skill.

Plate 4 Typical feeder ditches (a), siphon pipe (b) and gated pipe (c) in TSP

3.2.2 Siphon Pipes

Siphon pipes have provided much better control of water to individual furrows, and can cover the full range of flow rates required. Siphons were made from polythene pipe curved (PVC) into sections, and have diameters ranging from 25 to 75mm. The ideal operating head (i.e. tertiary canal water level to furrow water level) is 50-300mm. The plate above illustrates the siphon irrigation method in operation at Tendaho sugar estate.

3.2.3 Flexible Gated Pipes

Gated pipes of different types; one way and/or two ways, with varying length depending on size of field are used with design discharge capacity of 200 l/sec with each outlet expected to have capacities of 5 lit/sec discharges at spacing of 1.45m. Water application practice involves the theoretical irrigation intervals of the estate. An interval of one week was used for cane aged less than three months (before molding) and mostly 10 to 16 days interval for cane aged greater than four months (after molding) where molding is done at age of three months and application of water to each furrow were cut-off after water fully covered furrow tops. Nevertheless, it is hard to say that the irrigation system of this sugar project is completely modernized one. This is for it's really difficult to control "how much" water to be applied. Because in some fields, water application looks like flooding, flow in separate furrows made to be mixed other by cutting the ridges mostly due to defects of land leveling and furrow making problems and field water application faults.

Plate 5 Furrow interconnection during water application

In Tendaho irrigation schemes the water runs twenty-four hours except few delays on shifting of irrigation operators and tertiary canals to be operated with a total capacity of 5760 to 8640 m^3 discharge per 8 operation hours to deliver irrigation water to fields. Mostly on daytime, canes of age of less than 6 months are irrigated; whereas canes of age greater than this month are irrigated at night shifts. The area to be irrigated per operation depends on losses in hydroflumes; leakage and seepage loses in irrigation structure, and depth of irrigation application. Hence, 2.32 to 2.5ha area on average are irrigated per day. The theoretical irrigation intervals now in use are given in appendix 2.

3.3 Evaluation of Tertiary Canals Conveyance Efficiency

Since main canals and primary canals were lined HDPE one and the conveyance problems mainly observed on tertiary conveyance canals. Therefore, in this conveyance efficiency evaluation has done only for tertiary canals which are earthen types canals having trapezoidal shape. Evaluation has done in three replications for canal lengths of 400m. Canals of the same discharge and lengths were selected for evaluation. The replication has done on average at a distance of 2.5 to 5km from one tertiary to another, and to obtain better result rather than presenting single event for generalization of canal conveyance efficiency.

Evaluation of tertiary canals has done at full operation depth and for full length of operation hours. The canals layout of Dubti area sugarcane farm is shown on figure 4 below. The point from where representative canals are represented by dot points with upper cases letters.

Where, A is used to mean tertiary canal TC112, B=TC212, C=TC233, D=TC243, E=TC291 and F = TC2112.

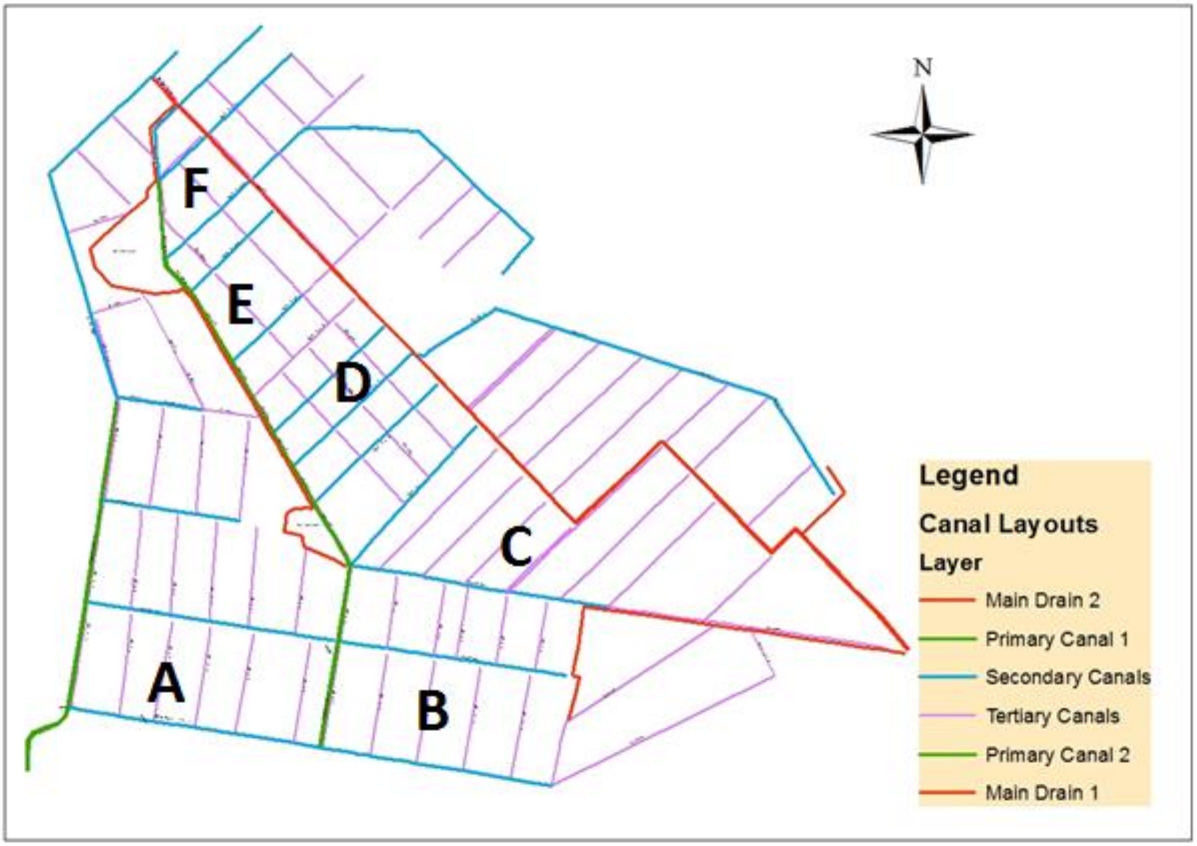

Figure 4 Canal layouts of Dubti area sugarcane farms

3.3.1 A Method to Evaluate Tertiary Canal Conveyance Efficiency

A method of measuring inflow and outflow in specific reaches using portable measuring devices was used to estimate conveyance efficiency and seepage losses from these open ditches. The physical functioning of the tertiary canals of the sugar estate was observed before installation of measuring devices. Selection of the representative canals have done based on soil types, canal type and their locations in the field, similarity in discharge capacity and canal length, and canal condition's. For the purpose of evaluation, Parshall flume devices were used, and set at upstream (inlet) and downstream (outlet point) to measure discharge amounts in canal section of 400m length. This length of canals were selected because, it is the only minimum length tertiary's over which water has not conveyed for at least 5days. Over the first 200m length of the canal, always water conveyed after 1 to 3 days since the last field has irrigated; even in some cases there is a flow of water over the tertiary canal with a 10 fields or more than this. This was because irrigation for those fields with irrigation interval is less than 10 days, the water has to supplied even before the end field are not irrigated. Since deep percolation loss has to also consider in category of these canals conveyance loss evaluation, dry canals were selected to increase the opportunity of obtaining feasible results from on field evaluations. Canals were selected within a 2 km distance from one another in a way that both soils area can be included as shown in figure 4 above. Canals dimensions data were collected at 50m intervals along the length of the canal.

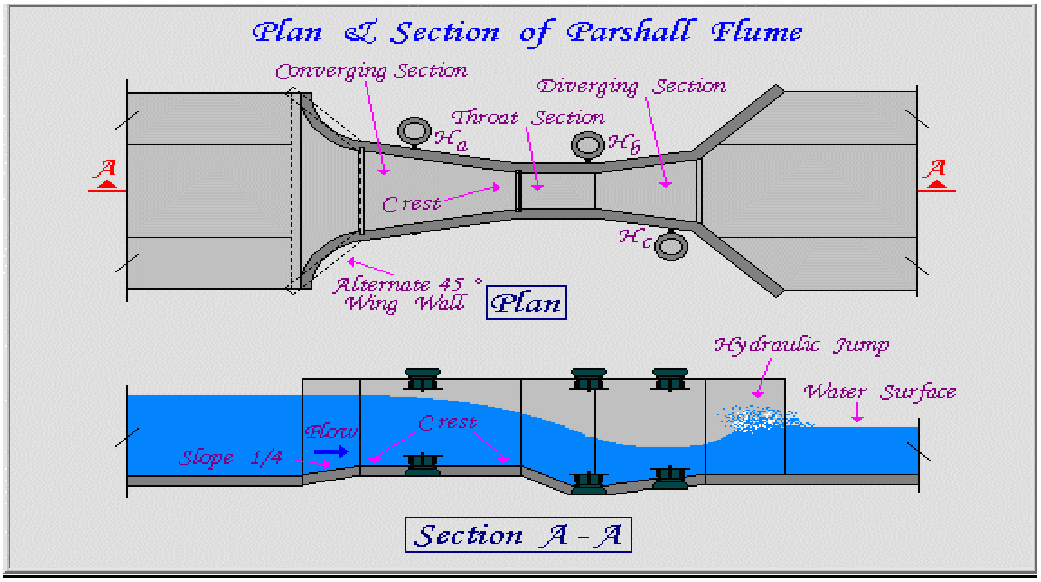

Figure 5 Plan and sections of Parshall flumes

During evaluations, Parshall flumes were normally calibrated against a piezometric head, Ha, which measured at a prescribed location at different time intervals in the converging section. The ‘downstream’ piezometric head h is measured in the throat.

- Six tertiary canals (fig. 1 below) were chosen and data were taken at upstream and downstream length of the canal for three replications over three irrigation events.
- The canal discharges was measured at increasing time intervals. The discharges of each time interval were calculated against piezometric heads. The discharge corresponding piezometric head and throat of each Parshall flumes at two points were obtained from table of discharge characteristics which are readily available for standard widths; the device is set at a distance of 10 from upstream inlet where flow becomes steady flow and at 10m distance before the advance flow reaches the downstream outlet; to a field.

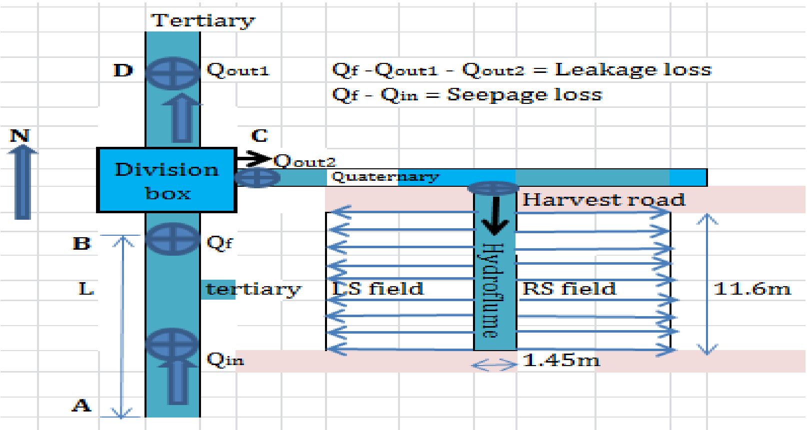

Figure 6 Setup of tertiary conveyance evaluation in Tendaho

- The volume of water that has diverted from the secondary canal into tertiary (m^3), and the volume of water reached the Outlet or division box of the tertiary (m^3), which was measured by help of Parshal flumes installed at upstream and downstream of the canal.
- After three replications, the collected data would analyze for each replications, and the discharge of the mean values of each replications would recorded, and finally after third repetition, the overall mean of three events would present as a mean result of conveyance efficiency of tertiary canals of the Tendaho sugarcane project.

3.3.2 Evaluation of Discharges

The upstream head–discharge (ha–Q) relationship of Parshall flume of different sizes, as calibrated empirically, is represented by general equations, having a general form (eqn 3.1);

$$Q = K * h_a^u \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 3.1$$

$$Q = 0.3812h_1^{1.58} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 3.1\text{ (a)}$$

$$Q = 0.6909h_1^{1.52} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 3.1\text{ (b)}$$

Where, K=dimensional factor which is a function of the throat width. The exponent u varies between 1.522 and 1.60, Q is the modular discharge (m^3/s), and h_a is the upstream gauge reading in meters. The flumes cover a range of discharges from 0.09 lit/sec to 93.04 m^3/s. Equation 3.1a was used for 6inch Parshall flume set at downstream of tertiary canal, and equation 3.1(b) was used for 1ft Parshall flume set at upstream to estimate canal discharges (m^3/sec).

3.4 Evaluation of Field Water Application of Furrow Irrigation

The methodology used for evaluation of furrow irrigation follows Walker (1989) as adapted by Calejo et al. (1998); the measurements were includes furrow discharge, furrow cross-sections, advance and recession times, hydraulics roughness and infiltration. The evaluation procedure begins by defining the cross sectional area of flow at the field inlet by checking all dimensions.

The individual performance of over nine fields of the estate was monitored during this study. Fields were selected based on soils types, crop age, irrigation intervals and management practices. The furrow lengths were 100m; points on each furrow length are marked with dyes or stakes at a regular interval in order to determine soils intake opportunity time, infiltration depths and to record the advance and recession data at each point over the furrow length.

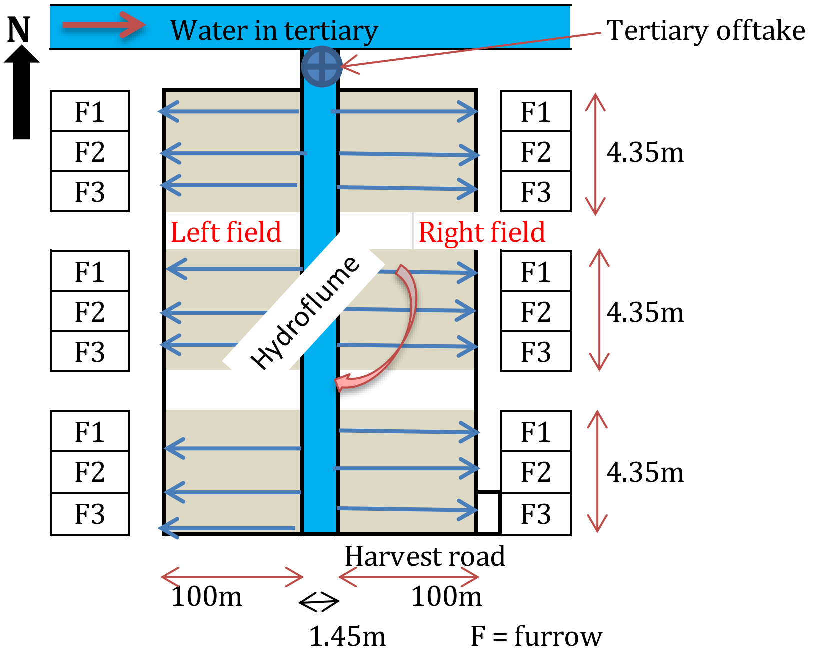

Figure 7 layout of a sample field to evaluate water applications of furrow irrigation

3.4.1 Inflow Measurements

Three inch Parshall flumes were placed at the upstream, middle and downstream of the field width for a three replicated irrigation events at inlet of the furrows, because furrows are close ended at downstream and there is no runoff at the outlet. The figure 7 shows furrow numbers, replication of flumes setup per irrigation event and the setup points. This replication was done honestly to know distribution uniformity of applied water over the whole field widths. This inflow maintained to be constant throughout the test. During the test, flow rates were initially measured every 2min until the flow became stable; after stabilization when flow become uniform, intervals have increased up to 6 minutes. Generally, evaluation was done with no interference to the normal water application practice of the sugar estate.

Plate 6 The advance and recession of the water over the field surface, measured as the elapse time needed for the inflow to advance to a point on the field

3.4.2 Cut-off Time

To supply the required amount of water to the full furrows with a given flow rate, a cutoff time was determined using equation 3.2 below (Solomon A. 2011). The most important effect of cut-off time is reflected on the amount of losses; deep percolation and surface run-off, and hence the efficiency as well as adequacy of irrigation. In general, for any given factor level combinations, the selection of an appropriate value of cutoff time are made on the basis of the target application depth and acceptable level of deficit. But, proper combination of shape, spacing, length, slope, inflow rate and cut-off time can be achieved by improving performance of irrigation systems.

$$\mathrm{Tco} = \left(\frac{\mathrm{L \ x \ S \ x \ Zreq}}{\mathrm{60 \ x \ Qo \ x \ Ea}} \right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3.2$$

Where; Tco = time of cutoff (min), L = furrow length (m), S = water surface width (m),Zreq = required depth of application (mm), Qo = flow rate (l/s), Ea = application efficiency (fraction).

There was furrow interconnection throughout the farm fields. This was a big problem during field data collections of advance and recession times, and exact time to cutoff water. This was because a water flowing in a given furrow is not flowing in the same furrow rather it mixed in middles or mixed by back flow (after reaching furrow end) to other furrow and speed up the advance time or can make not to get exact time in case of back flow of water coming back from other furrow overflow.

3.4.3 Determination of Furrow Characteristics

Furrow of a 100m length was used with spacing and depth of 1.45m and 0.3m respectively, which are the standard row and depth of sugarcane cultivation in Ethiopia sugarcane farms and they were constant in all farms. To check these fixed values, furrow geometry (top, middle and bottom width, and furrow depth) were measure directly during field to compare with the one which has made earlier by profile maker.

3.4.4 Determination of Infiltration Parameters

The infiltration characteristic of soil has been determined by ponding water in the metal double ring cylinders installed on each field at three 20m radial distances to observe rate at which the water level is lowered in the cylinder. To determine the infiltration parameters (a, k and f_o) the Kostiakov-Lewis equation illustrated in chapter two (equation 2.12) was used. from the advance and recession times which were collected precisely at an interval of 20m to obtain best opportunity time were used to calculate soil infiltration depths.

Plate 7 Determination of infiltration rate using double ring infiltrometer, TSP

3.4.5 The Required Depth of Water Application

A flow rate which is needed for adequate water distribution in a furrow depends on the length and cross-section of the furrow and on the infiltration rates of the soil. The required depth of application (Zreq) was estimated from field measurements of the soil water content before irrigation, which were used to compute the soil moisture deficit, SMD (mm) in the root zone (Walker, 1989).

Average depth of water application can be computed by the equation (Horst et al., 2005).

$$D_n = \frac{(Q * 3600)}{(F_s * L_f)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.3$$

Where, D_n-is average depth of water application (cm) in an hour, Q is stream size (l/sec), F_s-is furrow spacing (m), and L_f-is length of furrow (m) irrigated in an hour.

Measurements were carried out at the distances of 20m interval running from the upstream end of the furrows. The average SMD were assumed as the best estimates of Zreq. Average infiltrated depth (Z_{avg}) was estimated using the derived cumulative infiltration using equation 2.12. From this the depths of water infiltrated into the soil at different stations along the furrows (0, 20, 40, 60, 80, 100 m) were determined. The average of these values was taken as average infiltrated depth. The average of this was taken as depth of water stored in the effective root zone.

3.4.6 Soil Moisture Monitoring Before and After Irrigation

Soil moisture deficit is a measure of the soil moisture between field capacity and existing moisture content multiplied by the root depth, and it represents the depth of water the irrigation system should supply; which mean the required infiltration depth. Monitoring has done when the irrigation intervals were reached, to decide the next date of irrigation. In Ethiopian sugar estates, a feel method is widely using to know the date to irrigate the farm. This method is the oldest and simple methods of determining the soil moisture content. It is done by visual observation and touch of the soil by hand. The accuracy of judgment depends on experience of tester. This method is more subjective. Thus, different individuals who examine the same soil condition may obtain different answers.

For this study the soil moisture was checked through the soil drilling by auger. Soil drilling was executed one or two days before the theoretical irrigation interval date. Soil samples were collected at furrow top, middle and end for evaluating the soil moisture deficit prior to the irrigation. It was done by drilling the soil to the depth of 0 to 30cm and 30 to 60cm and decisions were made based on gravimetric results. Practically, for cane of three leaf stages to three month age starting from plating, drilling shall be limited to 30cm depth; and in top 60cm drilling for afterward months. Then the gravimetric moisture content (w/w) were calculated and converted to volumetric values (v/v) by multiplying by the dry bulk density. Then the soil moisture change was converted to the infiltrated depth at different sites of the furrow.

3.4.7 Rainfall Management

Allowance for rainfall may be considered necessary, but as a general rule, interruption during irrigation in the rainy season in the area is not recommended until 50mm amount of rain is recorded. However, irrigation interval or soil moisture monitoring dates may be extended by one day for each 5mm if accumulated rain is greater than 20mm and less than 50mm is recorded between irrigation intervals. Since there was no rainfall event during evaluation season of this study, no consideration of rainfall has done in analysis part of this paper.

3.4.8 Technical Parameters to Evaluate Water Application Efficiencies

The application performance indicators which were used for evaluation of field application are: on-field application efficiency, on-field storage efficiency, distribution uniformity, tail-water runoff, deep percolation fraction and non-erosive flow rate.

Data of furrow magnitudes (top width, bottom width and depth), inflow rate, cut-off time and field slope were recorded on each irrigation events. Stakes were placed at 20m intervals along the furrow length to measure water advance time, recession time and depth of flow. Evaluation has done for the three consecutive irrigation intervals. Replication is so important to obtain fair evaluation results for selected fields at a distance of 2 to 5km far from one another.

3.4.8.1 Determination of On-field Application Efficiency

Application efficiency is a comparison between the amount of water applied and the amount retained in the root zone. Losses from the field occur as deep percolation and as field tail water or runoff and reduce the application efficiency. Since furrow of the study area are block ended, runoff is expected. Therefore, to compute Ea it is only necessary to identify deep percolation losses as well as the amount of water stored in the root zone.

According to Rogers et al., (1997), it is possible to have high application efficiency and 50-90% can be used for general system type comparison. FAO (1989) reported that the attainable application efficiency according to the USSCS ranges from 55%-70%.

In this study, the field water application performances was determined for two types of soils of the cane farm, considered against target net application depth and soil moisture depletions. Three neighboring furrows at upstream, middle and downstream of the nine fields were selected. After determining the depth of water actually applied into the fields using a three inches Parshal flume and the depth of the water retained in the root zone of the soil based on the soil moisture contents of the soils before and after irrigation, the application efficiencies (Ea) of irrigation at the selected fields were calculated using equation 2.3 discussed in chapter two.

The depth of water retained in soil profile of root zone was determined by using the equation:

$$d = \sum_{i=1}^{n}\left(\frac{\theta_f - \theta_i}{100 * As_i * D_i}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.4$$

Where, θ_f =moisture content of the ith layer of soil after irrigation on oven dry weight basis, % θ_i= moisture content of the ith layer of soil before irrigation on oven dry weight basis, % Asi = apparent specific gravity of the ith layer of soil Di = depth of ith layer and, n = number of layers in the root zone

3.4.8.2 Determination of Storage Efficiency

Storage efficiency is indicator of how well the irrigation meets its objective of refilling the root zone. It relates to the actual volume of water stored in the root zone, to meet the crop water needs and to the total storage capacity of the root zone, Z_{req} (infiltration depth). The actual store volume of water in the root zone is less than or equal mean of Z_{req}. It is determined using similar method to determine application efficiency and needs to know potential soil moisture storage volume (Soil moisture deficit, m^3) and the volume water stored in root zone (m^3) and equation 2.4 was used to estimate storage efficiency.

Small irrigations may lead to high application efficiencies, yet the irrigation practice may be poor. The concept of water storage efficiency is useful in evaluating this problem. Water stored in the root zone is not 100% effective. Evaporation losses may remain fairly high due to the movement of soil water by capillary action towards the soil surface. Water lost from the root zone by deep percolation where groundwater is deep. Deep percolation can still persist after attaining field capacity.

Taking the above concepts in to consideration, based on the Fc, PWP, Bd of the soils of the selected irrigation fields and the root depth of the crop irrigated, the depth of irrigation water required by the crop was calculated at the 65% moisture depletion level. After determining the storage and the required depths, the storage efficiency was calculated using equation(Er) 2.4.

3.4.8.3 Determination of Distribution Uniformity

Uniformity of water distribution is another main point in field performance indicator which describes how evenly irrigation water is made available to plants throughout a field. This performance indicator could briefly describe in terms of Uniformity Coefficient (Cu), Christiansen (1942). Distribution uniformity is the ratio of the average of the lowest one-fourth of measurements of irrigation water infiltrated to the average depth of irrigation water infiltrated. It was determined from infiltration parameters and time of opportunities for each nine fields and the low quarter, mean and minimum results were identified.

Similarly, to determine the distribution uniformity of irrigation water in these furrow layouts auguring were done at selected points, starting from the upper end to lower end of the furrows at regular interval. And at each selected points of the furrow soil samples were collected at different depths with an interval of 30 cm up to 60 cm. And the soil moisture contents of the soils at the selected points were analyzed to determine the depth of water penetration.

Jurriens et al., (2001) proposed that distribution uniformity be defined as the average infiltrated depth in the low quarter of the field divided by the average infiltrated depth over the whole field. This term can be represented by the symbol, Du.

For calculating the distribution uniformity in the root depth of the crop was taken as the zone of distribution and the absolute distribution uniformity equation shown below was used

Du= minimum infiltration depth **/** Average infiltration depth was used.

3.4.8.4 Deep Percolation

It relates to the water lost through drainage beyond the root zone and it is a ratio of volume of deep percolation to the volume of water applied to the field. In this study, it has calculated using equation 2.6.

3.4.8.5 Determination of Critical Flow Rate That Does Not Cause Erosion

The inflow rate (stream size) should be non-scouring (non-erosive amount) and shall give uniform and efficient irrigation. However, in block ended furrows inflow rate should be large enough to advance to the end is not greater than 1.5 times the flow capacity of the furrow, nor result in excessive erosion (Jensen, 1983). The maximum non-erosive flow rate, Q_{max} can be estimated by empirical relationship (Hart et al., 1983):

$$Q_{max} = 0.63 / S_o \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 3.6$$

Where, Q_{max} - is a maximum non-erosive stream (l/sec) and S_o - is slope of furrow in direction of flow (m/m)

3.4.8.6 Evaluation of Inflow Rate and Cut-Off Time

Four fields (two from SIC and two from SICL) has selected for evaluation of inflow rate and cut-off time evaluations. The evaluation has done with aim of to check that inflow rate and cut-off time now practicing in normal irrigation condition needs modifications. The field variables have been taken as it is whereas decision variables, inflow rate of different rate are used to examine the cut-off time. Furrow lengths of 100 m were used; advance and recession times would recorded at different time intervals, and inflow rate are checked using 3 inch Parshall flumes set at upstream since there is no run-off at downstream ends.

Infiltration depths from Kostiakov-Lewis infiltration equation were adjusted for furrow irrigation and depth of applications. Adjustment to furrow irrigation was made by the wetted perimeter to spacing and adjustment to depth of application made by factor R.

i) Adjusted wetted perimeter, p (Jensen, 1983)

$$P = 0.265\left(\frac{Q * n}{S^{0.5}}\right)^{0.425} + 0.227 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 3.7$$

Where, Q=inflow rate (l/sec), n=Manning roughness coefficient, 0.04 and S=furrow slope (%)

ii) Adjustment factor, R – is a ratio of depth of water applied to average depth of water infiltrated

$$R = \frac{\text{Depth of water applied}}{\text{Average depth of water infiltrated}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 3.8$$

Finally, after 3replications, the estimated inflow rate and cut-off time of estate soils is presented in next section, chapter 4.

3.5 Evaluation of Irrigation Scheduling

To evaluate irrigation scheduling, the following criteria were considered:

- Design gross application equals to actual gross application
- Design net depth of applications equals to soil moisture deficit (SMD), or
- Design net depth of application equals to MAD at maximum rooting depth
- It is a time for irrigation when SMD equals or approximate MAD

The purpose of irrigation scheduling is to predict when the crop needs its next irrigation, and the amount required. The normal irrigation scheduling of the sugar state ranges from 7 to 30 day for cane age of 0 to greater than 12 months. Before scheduling can begin, the following preliminary information about field conditions were determined: the active crop root zone, the amount of soil water storage capacity in the root zone, the amount of allowable soil water depletion before irrigation, irrigation application amount, and finally compare the net irrigation application (Z_{req}) amount to the allowable soil water depletion.

Of several methods to determine when to irrigate, Water budget method is more commonly applied these days. The water budget technique is based on the equation:

$$I = ET - Pe + Roi + Dpi + L + Drz(\theta f - \theta i) \quad \ldots\ldots\ldots\ldots 3.8$$

Where: I= Irrigation requirement; ET= evapotranspiration; Pe= effective precipitation (cm); Roi,= runoff due to irrigation (cm); Dpi= deep percolation due to irrigation (cm); Drz= depth of root zone (cm); θf and θi = final and initial soil moisture contents.

3.5.1 Estimating the Water Balance Components in Irrigation Scheduling

Since irrigation scheduling by the water balance approach is based on keeping a balance of soil water content, the irrigation measure is the percent of water depleted from the soil water available to the plants. Two parameters determine the total soil water available to plants: Soil water holding capacity, which is the amount of water measured in (mm/m) held in the soil by capillary forces, and the effective root zone of the crop, which is the soil depth of the roots.

Fields with sugarcane of less than six month ages were selected, for ease of management. Soil samples were collected to determine soil physical properties, soil moisture contents before and after irrigation and other parameters at representative locations at depth of 0-30 cm and, 30-60 cm using auger and soil core samplers. Auger, plastic bags and core sampler are the materials used for soil sampling purpose.

Collected data for a scheduling includes: long year's climate data and soil data for field capacity, permanent wilting point, bulk density, and soil moisture contents before and after irrigation. The depth of water required to refill soil to its field capacity will maintained by taking soil bulk density, to root depth of sugarcane. Finally, scheduling parameters were computed using Microsoft excel and Cropwat 8.0 computer model, using climatic, crop and soil data.

3.5.2 Estimation of Crop Water Requirement

Many methods were developed to estimate the rate of crop water requirements, ETc based on climatic factors. Studies have shown that the Penman-Monteith method is more reliable for any length period than methods that use less climatic data (Jensen, et al. 1990). This method works well for daily calculations and for estimating monthly or seasonal water needs than other methods if an adequate data are available. Therefore, for this thesis work this method was selected, and both climatic and crop data such as crop coefficient (Kc), depletion level (ρ) for sugarcane growth in the study area were collected from secondary data sources. Crop water requirement was determined for sugarcane of the study area on the monthly time step over the growing season using the average climatic data obtained from Dubti metrology station, by computer program of Penman-Montieth Approach.

It was calculated by multiplying the reference evapotranspiration (ETo) by corresponding crop coefficient (Kc) of different growth stages;

$$ETc = ETo * Kc \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.9$$

Where, ETc is crop evapotranspiration (mm), ETo is reference evapotranspiration and Kc is the crop factor/crop coefficient.

3.5.3 Crop Coefficient

Evapotranspiration from a cropped field is composed of transpiration from the crops and evaporation from the soil surfaces. The rate of evapotranspiration from the crops (ETc) depends on the type of crops, stage of growths, moisture content of the surface soil, and the amount of energy available to evaporate water. Thus, the factor that relates the actual crop water use to reference crop evapotranspiration is called the crop coefficient (Kc). Usually, the determination of Kc involves the knowledge of crop type and date of plantation, length of the total growing season, the duration of initial stage, the duration of crop development stage, the duration of mid-season stage and the duration of late season stage and climatic data such as wind speed and humidity. However, Kc values of sugarcane are available in the literature for respective growth stages. According to Kakde (1985), growth stage of sugarcane can be classified to four stages;

Table 2 Growth stages of sugarcane at Tendaho sugar estate.

Level	Days	Growth	Canopy coverage, %	Kc
0 to 3 months	90	Stage 1	0 – 25	0.5
3 to 6 months	182	Stage 2	25 – 100	0.8
6 to 15 months	365	Stage 3	100	1.3
>15 months	425	Stage 4	100	0.8

3.5.4 Reference Evapotranspiration

The most accurate, and complex, method is the Penman-Monteith method as presented by Allen et al., (1986) using FAO CROPWAT 8.0 software. Monthly reference crop evapotranspiration (ETo) of long years (2000-2014) climatic data was used. The Penman-Monteith method requires location (altitude, latitude and longitude) of the metrological station, climatic data for air temperature and humidity, wind speed, sunshine hours and solar radiation. If accurate climatic data are available the method can be used for daily computation of ETo values.

3.5.5 Determination of Irrigation Interval

Irrigation frequency is defined as the frequency of applying to a particular crop at a certain stage of growth and is expressed in days.

$$I = \frac{(TAW * P * Dr)}{ETc} = \frac{ASMD}{ETc} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.10$$

Where, TAW-total available soil moisture = (fc-pwp), mm, P – Allowable depletion (decimal), Dr – effective root zone depth, (mm) and ASMD – is allowable soil moisture depletion ,mm

3.5.6 Data Analysis for Irrigation Scheduling

Water available to the crop can be measured from soil moisture contents in a laboratory. Soil moisture contents or soil wetness refers to the relative water content in the soil; and was determined for soil samples collected during field measurement, using gravimetric method. It is the ratio of mass of water to the mass of soil.

$$W = \frac{(Wws - Wds)}{Wds} * 100 \text{ ………………………………………….. } 3.11$$

Where, Wws= weight of wet soil sample (lit); Wds= weight of oven dry soil sample, and W= water content expressed on weight basis in (%)

Gravimetric method has used to determine an average soil water deficit for each site, which was used in the subsequent determination of irrigation efficiency. Finally, application efficiency would obtain from the percent ratio of volume of water added to crop root zone to the volume of water applied to a field. In this study, the total infiltrated volume was assumed to be equal to that of the water applied because there was no loss by tailwater.

Composite of undisturbed soil samples at two soil depths, 0-30 and 30-60 cm were taken from five spots. The collected undisturbed soil samples were analyzed for soil texture, field capacity (Fc), bulk density and permanent wilting point (PWP) at Water Works Design and Supervisions Laboratory Center. The percentage of sand, silt and clay of the composite soil sample were determined by sieve analysis (sand and silt) and hydrometer method (clay). After the percentage of sand, silt, and clay was measured, finally the soil textural class was assigned using the USDA textural triangle. Soil bulk density (g/cm^3) was determined using the methodology described in Walker (1989). Using core samplers of known volume and the samples were weighed and placed in oven dry at 105 ^{0}C for 24 hrs, and then from oven dried soil the bulk density was calculated.

Soil Moisture Deficit, SMD was estimate by gravimetric method for each irrigation events and compared with the calculated MAD values.

$$SMD = 10\sum_{i}^{n}\left(WFci - Wi\right) * Asi * Dr\mathit{i} \text{ …………………………………….. } 3.12$$

Where, SMD-soil moisture deficit, Wfci-moisture content at field capacity (%), Wi-moisture content before irrigation (Ww+Ws) (%), Dri-depth of the soil layer within root zone and Asi-apparent specific gravity of that soil layer (ratio of bulk density to water density)

Management allowable depletion, MAD is the management allowable deficit at maximum level of depletion, ρ; then the MAD was estimated as:

$$MAD = \rho * TAM * Dr \qquad 3.13$$

Where, the total available water (TAM) for plant use in the root zone was a difference in moisture content between field capacity and permanent wilting point given by James (1993), and depth of application related with available water as follows;

$$dn = MAD = \rho * TAM * Dr \text{ (mm)} \qquad 3.14$$

Readily available water (RAW) for plant use in the root zone was computed as the difference in moisture content between field capacity and critical water content (θcri) given by James (1993)

$$RAW = 10\sum_{i}^{n}(\theta fci - \theta cri) * Dri \qquad 3.15$$

Where, θ_{fci}- moisture content at field capacity at ith layer of soil (%),θ_{cri}-is the moisture content at critical point (lower moisture level for full irrigation) in ith layer of soil.

Effective rainfall would analyze using USDA soil conservation service method FAO recommended the following formula to estimate effective dependable rainfall.

Pe = 0.8P – 24 for P > 70 mm/month Pe = dependable effective rainfall

Pe = 0.6P – 10 for P < 70 mm/month Pe = monthly mean rainfall

3.6 Materials Used

The materials which were used in this thesis work were: Augers, core samplers, graduated buckets, shovels, stop watch, measuring tapes, pegs or dyes, Oven dry, cans, plastic bags, weight balance, meters Parshall flumes, hydroflumes, rulers, markers, tag paper, Sheet metals, siphons, double ring infiltrometer apparatus, hammer, sacks etc. Cropwat version 8.0, Arc GIS 9.3, Global mapper 8.0, and Microsoft spread sheets and Microsoft excels optimizer.

Plate 8 Partial list of material used during field works

4 RESULTS AND DISCUSSIONS

4.1 Design Condition of Irrigation Systems and Water Application Practices

According to WWDSE (2005), all the components of the distribution system except field channel are proposed to be lined with HDPE film and gabion with adequate thickness of rock covers to attain the overall application efficiency of irrigation system 65%. But, now a time, the lined canals were losing HDPE lining which is making the canal management issue more difficult.

Furthermore, the sugar estate is also facing huge salinity expansion problems which is a natural, but has close relationship with misuse of irrigation water aggravating salinity effects. Similarly, drainage structures were not properly prepared, and they are not functioning now, there is no drainage water flow out of the field. This interns causing the accumulation of salt water on the soil surface resulting in wide salinity challenge for the sugar factory.

Table 3 The designed peak duty for different components of Canal System, Tendaho

Component	Design efficiency, %	Duty, liter /sec/ha
At head of Primary canal	0.950	1.14 ≈ 1.15
At head of Secondary canal	0.950	1.08 ≈ 1.10
At head of Tertiary canal	0.925	1.00 ≈ 1.00
At head of Quaternary canal	0.925	0.936 ≈ 0.90
At field (field application efficiency)	0.850	0.79 ≈ 0.80

(Source: Design document of Tendaho sugar project, 2005)

4.2 Parameters Used for Field Evaluations

4.2.1 Soil Parameters

Two soil textural types were selected for evaluation; namely silty clay and Silty clay loam types which were categorized under vertisols according to the Guidelines of World Reference Base for Soil Resources (FAO, 2006). Vertisols are very deep, fine textured with vertic properties, sub angular blocky structure, occurring on nearly leveled land, developed on old alluvium, moderately fertile, moderately to highly sodic and none to slightly saline, infiltration and permeability slow to moderately slow with high water holding capacity, calcareous and moderate to well drained. It is also dark cracking and swelling heavy clay soil, and found along the right bank of Awash river in low lying zones and left behind swamps including Dubti farm, and cover 37 % of the project area (WWDSE, 2005)

The average available water holding capacity of the studied soils ranges from 13 to 19 % by volume in Silty clay soil and 15 to 19 % by volume in silty clay loam soils. Average bulk density ranges from 1.34 g/cm^3 in silty clay to 1.50 g/cm^3 in silty clay loam soils as tabulated in table 5.

The water held in the soil above PWP throughout the entire range of moisture content until FC can be used by plants and is considered as available water (AW).

Table 4 Soil available water capacity and Bulk density of each field under study

Physical property		FC (%V)		PWP (%V)		AWC (%V)		Bulk density, g/cm^3					
Fields	Soil Type	0 -30	30 -60	0 -30	30 -60	0 - 30	30 - 60	0 - 30 cm depth		Ave	30-60 cm depth		Ave
FC1143	SiC	37	39	18	22	19	17	1.12	1.53	1.33	1.13	1.55	1.34
FC1153	SiC	37	40	19	25	18	15	1.20	1.61	1.41	1.22	1.71	1.47
FC2326	SiC	36	39	21	21	15	18	1.15	1.55	1.35	1.21	1.61	1.41
FC2332	SiC	35	38	22	23	13	15	1.21	1.48	1.35	1.26	1.52	1.39
FC2414	SiCL	39	43	20	24	19	19	1.23	1.53	1.38	1.31	1.63	1.47
FC2423	SiCL	36	42	21	23	15	19	1.33	1.39	1.36	1.28	1.48	1.38
FC2441	SiCL	38	40	20	22	18	18	1.24	1.54	1.39	1.36	1.44	1.40
FC2913	SiCL	37	40	21	23	16	17	1.19	1.33	1.26	1.24	1.48	1.36
FC21224	SiCL	37	38	20	22	17	16	1.21	1.56	1.40	1.29	1.7	1.50

Where, SIC = Silty clay, and SICL = Silty clay loam

Table 5 Average soil available water

Physical property		FC (%V)		PWP (%V)		AWC (%V)		Bulk density,	
Depth cm		0-30	30-60	0-30	30-60	0-30	30-60	0-30	30-60
Soil types	Silty clay	36.3	39.0	20.0	22.3	16	17	1.356	1.401
	Silty clay loam	37.4	40.6	20.4	22.8	17	18	1.355	1.421

The knowledge of soil infiltration rate helps in determining proper frequency and depth of irrigation. The infiltration rates of the two soil has been done using double ring infiltrometer. Kostiakov-Lewis soil infiltration parameters ‘a, k and f_o’ indicated in equation 2.12 was used.

Table 6 Infiltration parameters

Soil type	a	k(m/min^a)	f_o (m/min)
Silty clay	0.433	0.0027	0.00023
Silty clay loam	0.398	0.0036	0.00055

From table 6, the basic infiltration rate, f_o of silty clay soil is higher than silty clay loam.

The infiltration capacity of the soil was very slow; this was because the soil pores of surface soil were sealed due to sedimentation of silts, water logging and initial soil moisture contents. The mean of three double rings of results of the basic infiltration rate and cumulative infiltration of the fields has been plotted as figure 8 and 9.

From the evaluation results, the general Kostiakov-Lewis equation would have the following form, for time t and infiltration depth, Z.

$$Z = 0.0027t^{0.433} + 0.00023t \qquad \text{for silty clay soils, and}$$

$$Z = 0.0036t^{0.396} + 0.00055t \qquad \text{for silty clay loam soils.}$$

Where, t is opportunity times, (minutes)

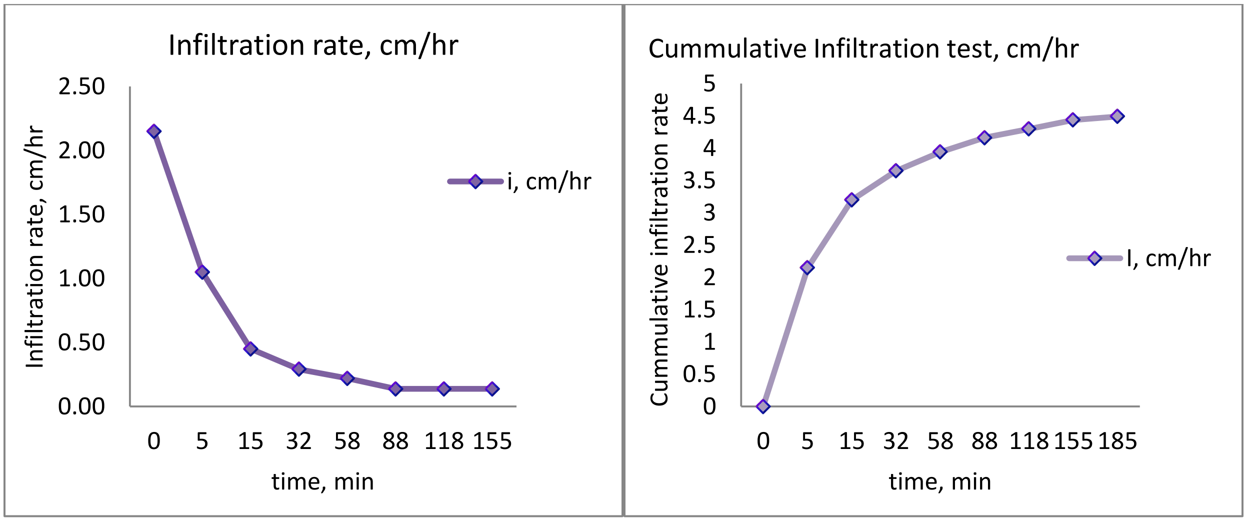

Figure 8 the average basic infiltration and cumulative infiltration rate of SiC

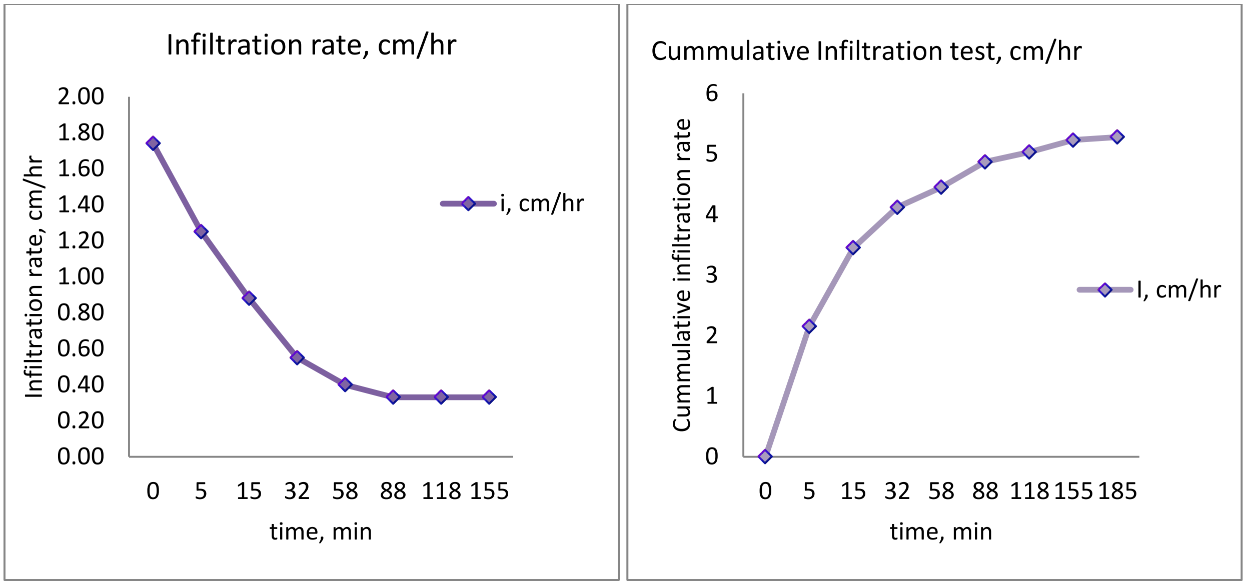

Figure 9 The average basic infiltration and cumulative infiltration rate of SiCL.

SiC = Silty Clay, SiCL = Silty Clay Loam

4.2.2 Furrow Dimensions

Measurements of the top, middle and bottom widths and the depths of furrows were collected during field works. From table 7, the average of top widths is 61.2 cm, maximum depth 21.9 cm, middle width 39.9 cm, and bottom width 22.0 cm. However, the furrow dimensions set during land preparation was: top width 60 cm, maximum depth 30 cm, middle width 40 cm, and bottom width 20 cm, with spacing of 1.45m and slopes of 0.05%

From table 7, the depth of furrow varies in between 0.14 m to 0.29 m. From observations, the depths of furrows were decreasing whereas furrow widths shows winding trends. These were due to collapse or erosion of furrow walls and formation of deposit inside the furrows. The next pronouncing effect of furrow dimension change is molding problems. After the planted canes have reached an age of three months, the ridges would change to furrow. From table 7, the current condition of furrow was not similar as designed dimensions. This was not only due to the above mentioned problems, it was also due to land leveling and furrow making defects. The furrow slopes and spacing were not uniform. They varies from furrow to furrow even in between neighboring's. These irregularities were main points for having low irrigation efficiencies at the sugar estate.

Table 7 Furrow dimensions of selected fields

Field code	Top width, m	Middle width, m	Bottom width, m	Depth, m
FC1-1-4-3	0.66	0.40	0.19	0.22
FC1-1-5-3	0.60	0.38	0.29	0.23
FC2-3-2-6	0.61	0.37	0.21	0.18
FC2-3-3-2	0.61	0.41	0.21	0.18
FC2-4-1-4	0.52	0.36	0.22	0.24
FC2-4-2-3	0.68	0.39	0.17	0.29
FC2-4-4-1	0.68	0.45	0.17	0.29
FC2-9-1-3	0.55	0.43	0.26	0.14
FC2-12-24	0.61	0.38	0.21	0.19
Mean	0.61	0.40	0.22	0.22

4.2.3 Inflow rate – Cutoff time

Though there was no fixed inflow rate and cut-off time implementation practices in this sugar estate, the existing inflow rate and cut-off data of cultural practice of the state cane farm was collected as presented in table 8. Figure 10 follows the mean inflow rate curve of water supply through furrow during field irrigation. The mean values of inflow rate vary in between 2.74 and 3.5 l/sec. These values were very low compared to expected designed discharge of 5 l/sec. this was due to lowered hydroflumes bed and low pressure inside hydroflumes. The water leaks over all parts of the gated pipes body and outlets, reducing discharge.

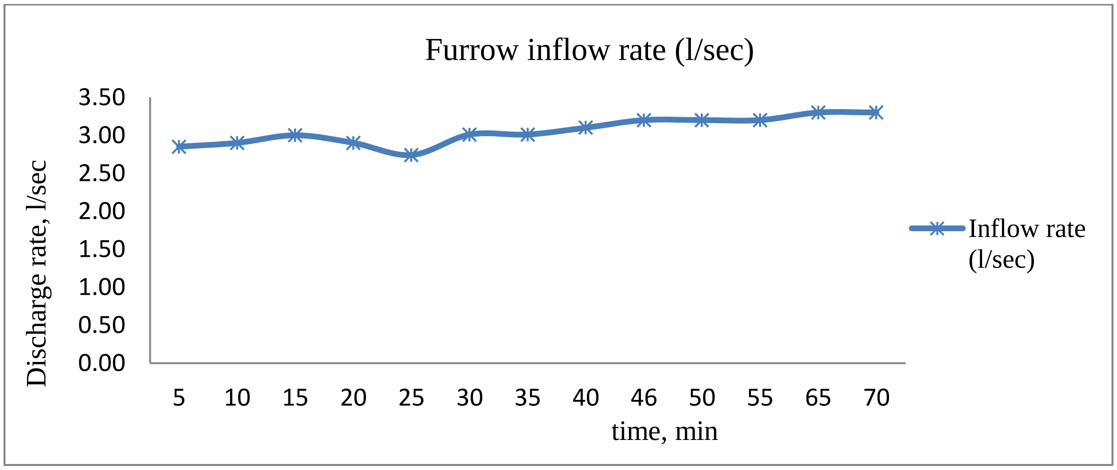

Figure 10 Inflow rate at the supply furrow inlet during irrigation

Table 8 Average Inflow rate and Cutoff times

S.No	Fields	Replications	Inflow rate Q, (l/sec)	Mean Q, (l/sec)	Cut-off time, t_{co} min	Mean t_{co}, min
1	FC1143 (Silty clay soil)	Rp1	3.20	2.85	70	60.46
		Rp2	2.65		50	
		Rp3	2.70		61	
2	FC1153 (Silty clay soil)	Rp1	3.30	3.38	78	68.70
		Rp2	3.10		69	
		Rp3	3.74		59	
3	FC2326 (Silty clay soil)	Rp1	3.60	3.40	68	65.88
		Rp2	2.70		59	
		Rp3	3.90		70	
4	FC2332 (Silty clay soil)	Rp1	3.10	2.78	79	74.25
		Rp2	2.99		67	
		Rp3	2.25		76	
5	FC2414 (Silty clay loam)	Rp1	2.85	2.74	70	67.90
		Rp2	3.10		57	
		Rp3	2.27		77	
6	FC2423 (Silty clay loam)	Rp1	2.76	3.01	61	70.00
		Rp2	2.88		75	
		Rp3	3.39		73	
7	FC2441 (Silty clay loam)	Rp1	3.12	3.41	67	78.00
		Rp2	3.02		85	
		Rp3	4.09		82	
8	FC2913 (Silty clay loam)	Rp1	3.33	3.53	70	58.32
		Rp2	3.72		61	
		Rp3	3.54		44	
9	FC2-12-24 (Silty clay loam)	Rp1	3.51	3.23	57.22	65.67
		Rp2	2.89		69	
		Rp3	3.29		70	
	Mean		3.1477	3.15	67.69	67.69
	Std.dev, %		0.46	0.31	9.68	6.16
	Coef. Var, %		14.49	9.72	14.30	9.09

Similarly, the inflow rate at each replication differs from each other. This was happened due to field application condition of the irrigators and water supply conditions. Since the irrigators (daily laborers) main aim was observing whether the water has advanced at downstream reach, they don't have any know how on deciding the amount of inflow rates and cutoff times. They can also open more numbers of outlets at once so that they irrigate more hectare of land per day. Opening many outlets can reduce discharge rate, but increases opportunity time and higher deep percolation rates. The poorest inflow rate was recorded in field FC2332 with 2.25 l/sec. This was occurred due to operating many outlets at a time. Sometimes, different tertiary canals were let to operate at the same time. Then amount of water supplied into a given tertiary canal would become low. This also result in reduced inflow rates in the fields. On other hand, there was better performance in field FC2913 with mean inflow rate of 3.53 l/sec in silty clay loam soils, which is the higher inflow rate of the estate gated pipes supply. From the field observations, the main causes of the discharge variations are land leveling problems, low bed of hydroflumes are not higher enough than level of furrow elevations so that they can discharge out a water with enough head, and poor skills of field irrigators. The observed flow rates showed standard deviation of 0.31% and coefficient of variation of 9.72%.

Again from table 8, the mean of cut-off times under existing water application practices were varies even among same soils and different fields ranging from 58.32min to 74.25min. In this sugar estate the interconnection of furrow by cutting ridges at several intervals is very common. They were making this, because there is land leveling problems, the furrows slope are not facilitating downstream flow and the water can't reach the downstream end of all furrows at uniform time. So, to make thing simple they made this choice. But, this is causing a flow in a given furrow is not to going in the same furrow rather it mixed in middles or mixed by back flow (after reaching furrow end) to other furrow and speed up the advance time or can make not to get exact time in case of back flow of water coming back from other furrow overflow.

4.2.4 Soil Moisture Deficit

Soil moisture deficit (SMD) was estimated using gravimetric method for each irrigation events and cross-checked with calculated MAD values as shown in table 9, which shows there is a variation in SMD during irrigation even within the same soil type indicating that variation in irrigation timings and amount of water application within the same soils.

Table 9 Soil moisture deficit and Management allowable depletion at top 30 cm soil depth

Field No.	Soil type	Fc	PWP	TAW	Wi	Asi, %	SMD, mm	MAD, mm
FC1-1-4-3	SiC	0.38	0.20	0.18	0.22	1.33	62.39	24.38
FC1-1-5-3	SiC	0.39	0.21	0.18	0.28	1.44	44.92	24.38
FC2-3-2-6	SiC	0.38	0.21	0.17	0.34	1.38	15.01	24.38
FC2-3-3-2	SiC	0.37	0.23	0.14	0.32	1.37	18.13	24.38
FC2-4-1-4	SiCL	0.41	0.22	0.19	0.29	1.43	51.52	25.50
FC2-4-2-3	SiCL	0.39	0.22	0.17	0.33	1.37	24.70	25.50
FC2-4-4-1	SiCL	0.39	0.21	0.18	0.26	1.40	55.27	25.50
FC2-9-1-3	SiCL	0.39	0.22	0.17	0.24	1.31	58.34	25.50
FC2-12-24	SiCL	0.38	0.21	0.17	0.28	1.44	40.07	25.50

Table 9 shows there is variation in soil moisture deficit during irrigation indicating that variations in timing and amount of water application in the soils.

4.2.5 Advance and Recession Times

Advance and recession showed wide variation even in the same soil in each replication due to fluctuation in inflow rates and furrow conditions. Actually in all fields it was difficult to record the advance times except in some furrows. This was because the neighboring furrows are purposely interconnecting to each other in shorter intervals to overcome the problems of land leveling and furrow dimensions distortion. In some furrows it was not possible to find the recession data due to larger water application and longer infiltrations rate. The water was pond on field even for one to two days after irrigation.

The advance front's movement down the supply furrow is presented graphically in figure 11. It took a mean of 46.01 minutes for the front to reach the end point at the last bed where the irrigation to commence. From figure 11, the infiltration opportunity time is not fairly uniform which may relate to a problem of uneven slope, low stream size and normal flow interruption of irrigators.

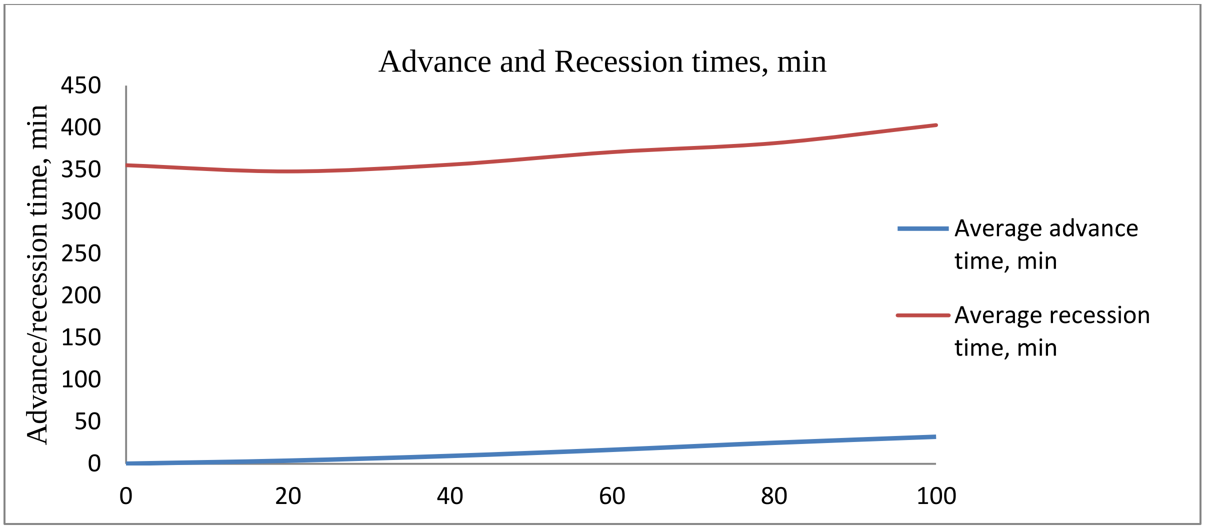

Figure 11 Average advance and recession times in 100 m furrow length

4.2.6 Target Application Depth

The design target application depth was determined as 75mm according to WWDSE (2005). However, at this time there is no known application depth used by estate irrigation staffs. But, culturally they know that irrigation should be apply when the irrigation interval reached and apply the water until the water appears at downstream furrow ends and sometimes until the fields become flooded (appendix 14a). No worrying of deficit irrigation (over or under irrigation).

Table 10 Calculated target application depths (perceived application depth)

Soil type	FC (%)	PWP (%)	ρ, depletion factor	Root depth (m)	Z_{req} (mm)
Silty clay	33.44	18.78	0.60	1.00	86.53
Silty clay loam	39.00	21.60	0.60	1.00	104.40

4.2.7 Gross Application Depth

Average gross depth of water applied during irrigation events was obtained as 79.97 mm (table 13). The variation in inflow rate and cut-off time across irrigation events were expressed in the variation of application depth. From the results (table 13), there are variations of application depths across the soil types and field length. But, this variation is a problem when there is variation in the same soils and field length to a constant depth irrigation scheduling which shows lack of control to flow rate and cut-off times. These variations of application depth can only managed by proper inflow rate and cut-off time managed on field.

4.3 Evaluation of Tertiary Canals Conveyance Efficiency

The estate tertiary canals were planned to delivery irrigation water by receiving from secondary canal through off-takes to water passes to field via feeder ditches or gated pipes. The following problems were noticed before and during the actual evaluation activities have started.

1. The physical conditions: structures of some tertiary canals were not in the shape of their designed conditions. Side walls have eroded (widen widths), plants/grasses has grown inside the canals which can reduce the flow velocity, conveyance efficiency, irrigation speeds. The canal bed slope was also causing backflow in the case when no sufficient water was supplied to the canals. And in some tertiary there were also conditions of siltation problem decreasing flow depth, widening of canal widths.
2. Seepage from canal side walls along the canal length and Leakage from off-take points, which were more difficult to measure it are predominantly feasible in the area.
3. The operational losses has observed
4. Dead storages were formed at different points inside the canals along the length of the canal which facilitates irrigation water loss via evaporation and deep percolation.
5. Overtopping due to excess water releasing, damage to fields and harvest roads

4.3.1 Tertiary Canal Dimensions and Canal Flow Hydrograph

On field collected data of the tertiary canal dimensions were presented in table 13. From this table, the design dimensions and the actual practicing dimension were not similar. This shows there is a difference between actual and designed capacity of the canals. This might be due to not taking preventive care not to damage canal shapes and no routine maintenances, overtopping of water, effect of wild animals (mainly boars). Similarly, from table 13, one can expect that the carrying capacity of the canal was higher than the designed capacity since the canal dimensions were becoming larger. But, since there is higher seepage, the canal loss was higher nearly to 40%. Plates shown in appendix 14b shows on field observed tertiary canal problems: over topping problems which are potentially affecting canal structure, harvest road and affects fields by letting unwanted water to the farms.

Table 11 Tertiary Canal Dimensions of representative tertiaries

Tertiary Canal	Measured Dimension		Design dimensions, (m)
	Dimension, m	Values, m	
TC-2-11-2 1:1 canal side slope	Top width	1.48	1.20
	Bottom	1.15	0.30
	Depth	0.40	0.40
TC-1-1-2 1:1 canal side slope	Top width	1.22	1.20
	Bottom	1.07	0.30
	Depth	0.43	0.40
TC-1-1-5 1:1 canal side slope	Top width	1.72	1.20
	Bottom	0.81	0.30
	Depth	0.35	0.40
TC 2-3-2 1:1 canal side slope	Top width	1.77	1.20
	Bottom	0.85	0.30
	Depth	0.47	0.40
TC-2-9-1 1:1 canal side slope	Top width	1.35	1.20
	Bottom	0.86	0.30
	Depth	0.35	0.40
TC 2-4-1 1:1 canal side slope	Top width	1.55	1.20
	Bottom	0.75	0.30
	Depth	0.30	0.40
Mean dimension, m	Top width	1.525	
	Bottom width	0.898	
	Depth	0.383	

The deviation between top widths or bottom widths were might occurred as result of unsafe canal cleaning, canal erosions due to repeated excess water flow above free board level, overtopping at some canal banks. A canal depth varies in between 30 to 47m. Siltation problems which were resulted from canals side erosion and from sediment particles brought to canals with irrigation water.

The mean canal flow hydrograph in selected tertiary canal has plotted against time elapsed as shown on figure 12. From this figure, it can be observe that the amount of irrigation water losing in the canal throughout operation was higher. Seepage losses and leakages at canal reaches are the dominant losses in these canals. The normal carrying capacity of tertiary canal was 100 l/sec. But, there were a time at which the flow is above the mentioned carrying capacity, resulting in overtopping (figure 12).

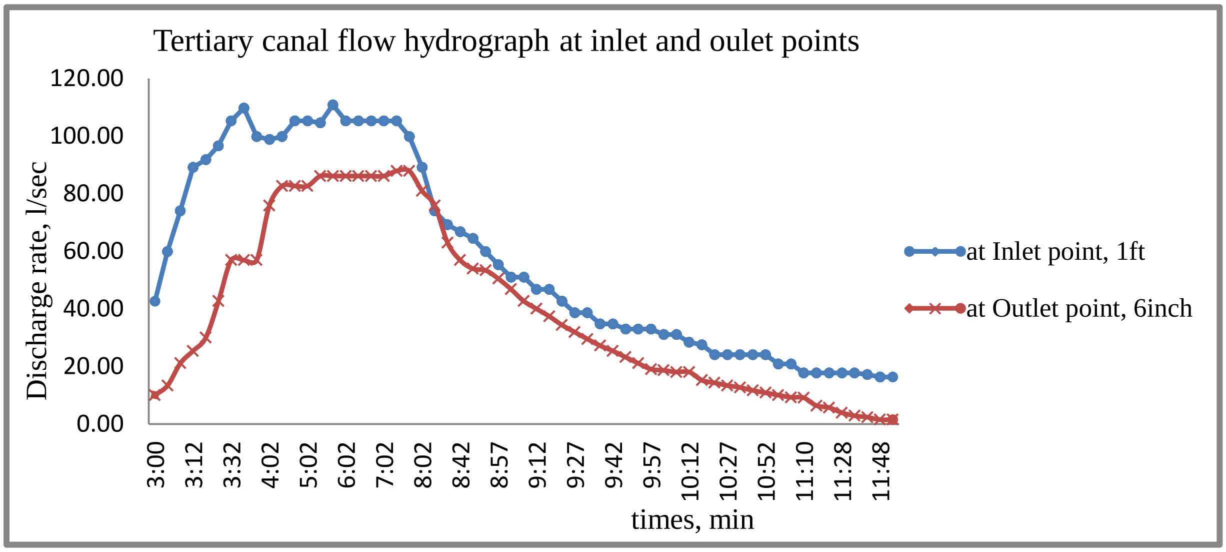

Figure 12 Flow rate at tertiary canal inflow and outflow hydrographs

4.3.2 Conveyance Efficiency of Selected Canals

The overall mean tertiary canal conveyance efficiency was found as 59.5897%. During evaluation each canals were showing different conveyance efficiencies. This was due to some management activities and might be due to measuring devices setup errors, leakage in intakes/turnouts, overtopping due to low embankments, leakage through cracks of lined canal reach, seepage through porous canal reach, and increased efficiency as a result of canals maintenances and cleaned vegetated grasses and regulated water supply from operators.

It was observed that water was leaking from where the canals were broken, the flow in canal network was not uniform, canals were heavily vegetated, water flows over the banks of the canals. From the results evaluation results (table12), the conveyance efficiency of tertiary canal FC291 on the first evaluation day shows a worst value. But, on second evaluation its efficiency was better than previous due to canal cleaning and maintenances. The mean conveyance efficiency of this canal was almost equal to the losses. Tertiary canal TC112 can be taken as a good canal compared to others; because it was conveying irrigation water with nearly similar conveyance efficiency throughout all replications with a mean conveyance efficiency of 63.26% as compared to other tertiary canals of similar length and similar discharge capacity.

Again from the table 12, the highest mean conveyance efficiency of all tertiary canals was 65.21% and the lower efficiency was 50.64%. Efficient water saving can be achieved by keeping the conveyance losses to a minimum level. In this study, large amount of water is lost during its route up to the farms. The main reasons for these conveyance losses in watercourses are leakages from turnouts, high density of vegetation in the unlined watercourses, turns in the watercourse, uncompact and weak banks, and siltation, holes made by rodents or boars and lack of maintenance.

Finally, there observed a water diverted from secondary canal to tertiary canals with mean loss of 40.41% per 400m length of tertiaries before it reaching the farm gate. This high amount loss would further result in yield reduction.

Table 12 Performance evaluation of tertiary conveyance efficiency

S.No	Tertiary canal code	Replications	Volume of water diverted from the source, m^3	Total volume delivered to farm, m^3	Total volume of water lost, m^3	Evaporation losses, (3% of total losses), m^3	Conveyance efficiency, %
1	TC 233	Rp1	4459.06	2980.47	1478.59	44.36	66.84
		Rp2	5342.75	3124.16	2218.60	66.56	58.47
		Rp3	4638.56	2432.67	2205.89	66.18	52.44
Mean			4813.46	2845.77	1967.69	59.03	59.25
2	TC 291	Rp1	6585.04	3334.96	3250.09	97.50	50.64
		Rp2	6464.25	3545.25	2918.99	87.57	54.84
		Rp3	6945.65	3245.54	3700.11	111.00	46.73
Mean			6664.98	3375.25	3289.73	98.69	50.74
3	TC 112	Rp1	4251.44	2626.78	1624.65	48.74	61.79
		Rp2	4012.33	2599.90	1412.44	42.37	64.80
		Rp3	4345.35	2745.64	1599.71	47.99	63.19
Mean			4203.04	2657.44	1545.60	46.37	63.26
4	TC 243	Rp1	6440.36	4241.99	2198.37	65.95	65.87
		Rp2	5601.25	3441.35	2159.91	64.80	61.44
		Rp3	5789.58	3956.24	1833.33	55.00	68.33
Mean			5943.73	3879.86	2063.87	61.92	65.21
5	TC 212	Rp1	6443.84	3857.98	2585.86	77.58	59.87
		Rp2	6312.41	3479.84	2832.57	84.98	55.13
		Rp3	6617.28	3899.15	2718.14	81.54	58.92
Mean			6457.85	3745.66	2712.19	81.37	57.97
6	TC 2 11 2	Rp1	7159.40	4476.93	2682.47	80.47	62.53
		Rp2	6443.55	3641.34	2802.21	84.07	56.51
		Rp3	5978.99	3477.81	2501.18	75.04	58.17
Mean			6527.31	3865.36	2661.95	79.86	59.07
Average							**59.5896581**

4.4 Performance Evaluation of Field Water Application of Furrow Irrigation

i) Evaluations Based On Target Application Depths

Target application depth has calculated as presented in table 11 including other field water application performance indicators. These monitored events were evaluated assuming that the soil moisture deficit is equal to calculated target application depths. The evaluation has done for three consecutive replications irrigation events to measure: application efficiency, storage efficiency, deep percolation ratio, distribution uniformity and coefficient of uniformity. The mean results of each three replications and the overall field evaluation mean values of replications are tabulated in table 16. Since the furrow outlets were closed, it was assumed that all the water entering the field did infiltrate, no run-off or tail water reuse was considered here.

4.4.1.1 Application Efficiency

From the results obtained in table 13, the overall mean application efficiency was 56.57% for which it varies in between 40.28% to 76.91%. The variation between consecutive irrigation events were happened because of variations in inflow rate and cut-off times (generally called decision variables) and a field parameters mainly soil infiltration characteristics, flow resistance, required depth of irrigation, and soil moisture depletion prior to irrigation. The lowest application efficiency was recorded on the first evaluation in field FC21224 with only 40.28% application efficiency. In this field much water infiltrated beyond maximum root depth. Highest application efficiency is recorded in field FC1143. Almost in first two replicated irrigation event the application efficiency of this field was nearly equal. But, on the third irrigation event the application event was reduced by 16% from it's the last two application performance. This reduction was happed due low water supply at a day and because the irrigator has irrigated the field at lower application depth. When the application efficiency of the two soils were compared to each other, the application efficiency of the first four fields (silty clay) was better than the rest silty clay loam soil fields with an overall mean of 57.04 and 46.83% respectively.

Coefficient of variation in application efficiency across the irrigation events was 14.83%. The variation in application depth and variation in gross application depth is correlated with significant cut-off time (table 8). This shows that cut-off time is a significant factor for variation in application efficiency as inflow rate is not significantly correlated with variation in application efficiency. Therefore, for better performance of irrigation events, optimum inflow rate and cut-off time combinations should be identified with precision land preparation for higher field water application efficiency. Finally, when the application efficiencies of two soils were compared, on-field water application efficiency of both soils was almost similar, having a mean value of 57.04 and 56.19% respectively.

4.4.1.2 Deep Percolation Fraction

Since the furrow was a block ended type, there were no considered run-off problems. Therefore, deep percolation fraction was obtained using 2.6 discussed in chapter 2. From the results presented in table 13, higher deep percolation loss has recorded in field FC21224 for first evaluation event, with highest deep percolation loss of 59.72%. It was a result of long water ponding opportunity time. When deep percolation loss from field to field was compared to each other, it was shows reducing trend except few replications. This was definitely due to awareness of the field irrigators and irrigations experts from what was implemented on the fields during study.

4.4.1.3 On-Field Storage Efficiency

From table 13, the overall mean storage efficiency of evaluation result was 70.30% with a coefficient of variation of 3.95%. From results, under current water application practice, almost in whole part of the field water storage looks similar ranging in between 65 to 71% except highest storage efficiency observed in field FC1143 and the lowest storage efficiency which was recorded in the first irrigation event in field FC21224. Finally, variation in storage efficiency across irrigation events is significantly correlated to the distribution uniformity and uniformity coefficients along the length of the furrow. Mainly depends on infiltration characteristics and also correlated to the higher deep percolation loss in the fields beyond the crop root zone.

4.4.1.4 Distribution Uniformity

From evaluation, the replications mean distribution uniformity of the field was 91.93%; coefficient of variation is 3.95% were obtained. Higher distribution uniformity was a result of having higher opportunity time due to ponded water rather than due to having good land leveling and good advance water flows. The distribution uniformity depends on the applied depth through the couple of inflow rate and time for cut-off. Beside these variables, the application efficiency also depends on the timeliness of irrigation. Similarly, the results obtained using Kostiakov-

Lewis equation to calculate infiltration depth at 20m intervals along the furrow length using opportunity times were also confirmed there was higher distribution uniformity of 91.93%. The variation in distribution uniformity among each replications and different fields was a result of variation in cut-off time across irrigation events. When the water is let into the top of the furrow, it takes time to reach the down end of the furrow. But, when you turnoff water in a furrow, it is essentially gone immediately. Blocking furrows would increase the opportunity time at the bottom of a furrow. But, blocking may or may not increase distribution uniformity depending on the increase in opportunity time. For example, if you are running an 8hrs set, and it takes 6hrs for water to run from the top of the furrow to the bottom; thus, the opportunity time at the top of the furrow is 24hrs and at the bottom only 2hrs. More water will soak in at the head of the furrow than at the bottom. But, a large difference in opportunity time from top to bottom of a furrow doesn't necessarily mean that there will be a large difference in total water soaked at the top than bottom.

4.4.1.5 Coefficient of Uniformity (Cu)

The mean uniformity coefficient was 95.20%, with coefficient of variation 2.20 %. Variation of coefficient of uniformity across the monitored fields was significantly related with distribution uniformity and storage efficiency.

Table 13 Mean Performance evaluations of field water applications at target application depth.

Fields	Replication	On-field Performance indicators, %						
		Q (l/sec)	Ea, %	DPR, %	Du, %	Cu, %	Es, %	Ad(mm)
FC1143	Rep1	2.36	76.91	23.09	89.23	92.94	81.24	60.07
	Rep2	3.24	75.32	24.68	89.23	93.61	80.21	58.91
	Rep3	2.95	63.23	36.77	83.89	96.67	73.12	65.44
	Mean	2.85	71.82	28.18	87.45	94.41	78.19	61.47
FC1153	Rep1	3.38	48.84	51.16	94.46	97.97	66.16	102.05
	Rep2	3.05	48.97	51.03	91.24	95.25	66.21	81.46
	Rep3	3.46	52.37	47.63	96.00	98.65	67.74	79.02
	Mean	3.30	50.06	49.94	93.90	97.29	66.70	87.51
FC2326	Rep1	3.40	48.71	51.29	83.49	94.77	66.10	86.70
	Rep2	2.88	55.00	45.00	91.40	95.24	68.97	63.72
	Rep3	3.24	57.00	43.00	96.73	86.35	69.93	85.05
	Mean	3.17	53.57	46.43	90.54	92.12	68.29	78.49
FC2332	Rep1	2.54	45.07	54.93	91.28	93.31	64.55	83.03
	Rep2	3.00	55.00	45.00	89.24	91.35	68.97	72.65
	Rep3	2.80	58.00	42.00	85.58	96.74	70.42	80.81
	Mean	2.78	52.69	47.31	88.70	93.80	67.88	78.83
FC2414	Rep1	2.83	59.76	40.24	88.30	94.92	71.31	80.81
	Rep2	2.50	72.00	28.00	89.10	90.76	78.13	60.54
	Rep3	2.89	69.00	31.00	84.14	93.20	76.34	79.39
	Mean	2.74	66.92	33.08	87.18	92.96	75.14	73.58
FC2423	Rep1	2.93	50.72	49.28	98.07	98.28	66.99	67.87
	Rep2	3.15	60.00	40.00	97.80	98.62	71.43	89.72
	Rep3	2.95	58.00	42.00	94.50	96.78	70.42	81.78
	Mean	3.01	56.24	43.76	96.79	97.89	69.56	79.79
FC2441	Rep1	2.96	44.35	55.65	90.55	93.84	64.25	72.56
	Rep2	2.95	57.47	42.53	93.78	95.24	70.16	91.74
	Rep3	3.12	55.35	44.65	95.84	94.60	69.13	93.60
	Mean	3.01	52.39	47.61	93.39	94.56	67.75	85.96
FC2913	Rep1	3.34	57.43	42.57	94.19	94.84	70.14	85.02
	Rep2	3.80	63.50	36.50	98.14	97.22	73.26	84.29
	Rep3	3.45	59.40	40.60	96.78	99.36	71.12	55.20
	Mean	3.53	60.11	39.89	96.37	97.14	71.48	74.84
FC21224	Rep1	3.35	40.28	59.72	94.63	96.58	62.61	82.15
	Rep2	3.78	44.35	55.65	90.50	96.70	64.25	111.78
	Rep3	3.46	51.24	48.76	94.11	96.67	67.22	103.80
	Mean	3.53	45.29	54.71	93.08	96.65	64.64	99.24
Mean of means		3.10	56.57	43.43	91.93	95.20	70.30	79.97
St. deviations		0.30	8.39	8.39	3.63	2.09	5.08	10.47
CV, %		9.70	14.84	19.32	3.95	2.20	7.23	13.09

Where, Q=inflow rate, Ea=application efficiency, DPR=deep percolation ratio, Du=distribution uniformity, Cu=coefficient of uniformity, Es=storage efficiency and Ad=gross application depth.

4.4.1.6 Determination of Critical Flow Rate That Does Not Cause Erosion

The critical flow rate of each flow rate during all replication has showed lower results of critical flow which can't cause erosion. This was checked using the formula presented in equation 3.6, and the mean values critical flow has calculated as tabulated below using slope of 0.5%.

Table 14 Evaluation of critical flow rate

Fields code	Mean Q (l/sec)	Obtained	Required Maximum	Slope, %
FC1143	2.85	1.43	0.63	0.05
FC1153	3.38	1.69		
FC2326	3.40	1.70		
FC2332	2.78	1.39		
FC2414	2.74	1.37		
FC2423	3.01	1.51		
FC2441	3.01	1.51		
FC2913	3.53	1.77		
FC21224	3.53	1.77		
Mean	3.14	1.57		
St.dev	0.32	0.16		
CV, %	10.31	10.31		

ii) Evaluations Based On Soil Moisture Depletions Of Irrigation Scheduling

The effect of irrigation scheduling on Zreq and infiltration behavior of soils was considered under this section. Thus, the effect of irrigation scheduling on field application performance has computed considering SMD as Zreq. This was done because the SMD before the irrigation events are different from calculated target application depth (table 11),

Table 15 Performance evaluations of field water applications at SMD.

Fields	Replication	On-field Performance indicators, %						
		Q(l/sec)	Ea	DPR	Du	Cu	Ad(mm)	Es
FC1143	Rep1	2.36	78.91	21.09	94.89	92.94	81.24	60.07
	Rep2	3.24	75.32	24.68	89.23	93.41	80.21	58.91
	Rep3	2.95	73.23	26.77	94.34	96.37	73.12	65.44
	Mean	2.85	75.82	24.18	92.82	94.24	78.19	61.47
FC1153	Rep1	3.38	58.84	41.16	94.46	97.97	66.16	102.05
	Rep2	3.05	56.97	43.03	88.00	93.25	66.21	81.46
	Rep3	3.46	60.37	39.63	96.00	91.50	67.74	79.02
	Mean	3.30	58.73	41.27	92.82	94.24	66.70	87.51
FC2326	Rep1	3.40	52.71	47.29	83.49	79.44	66.10	86.70
	Rep2	2.88	59.55	40.45	91.40	95.24	68.97	63.72
	Rep3	3.24	60.43	39.57	80.77	86.35	69.93	85.05
	Mean	3.17	57.56	42.44	85.22	87.01	68.29	78.49
FC2332	Rep1	2.54	50.07	49.93	96.28	95.31	64.55	83.03
	Rep2	3.00	61.65	38.35	96.24	98.67	68.97	72.65
	Rep3	2.80	57.35	42.65	95.00	97.74	70.42	80.81
	Mean	2.78	56.36	43.64	95.84	97.24	67.88	78.83
FC2414	Rep1	2.83	67.22	32.78	98.30	99.72	71.31	80.81
	Rep2	2.50	70.34	29.66	99.10	96.76	78.13	60.54
	Rep3	2.89	72.45	27.55	94.35	99.20	76.34	79.39
	Mean	2.74	70.00	30.00	97.25	98.56	75.14	73.58
FC2423	Rep1	2.93	56.36	43.64	98.07	98.28	66.99	67.87
	Rep2	3.15	63.42	36.58	97.80	98.00	71.43	89.72
	Rep3	2.95	58.44	41.56	99.78	96.78	70.42	81.78
	Mean	3.01	59.41	40.59	98.55	97.69	69.56	79.79
FC2441	Rep1	2.96	54.35	45.65	98.55	99.84	64.25	72.56
	Rep2	2.95	65.47	34.53	98.78	99.24	70.16	91.74
	Rep3	3.12	68.35	31.65	99.70	99.54	69.13	93.60
	Mean	3.01	62.72	37.28	99.01	99.54	67.75	85.96
FC2913	Rep1	3.34	65.43	34.57	98.03	99.00	70.14	85.02
	Rep2	3.80	68.50	31.50	98.14	98.22	73.26	84.29
	Rep3	3.45	64.40	35.60	96.78	99.36	71.12	55.20
	Mean	3.53	66.11	33.89	97.65	98.86	71.48	74.84
FC21224	Rep1	3.35	53.28	46.72	94.63	96.58	62.61	82.15
	Rep2	3.78	62.35	37.65	95.24	96.70	64.25	111.78
	Rep3	3.46	57.24	42.76	94.11	93.76	67.22	103.80
	Mean	3.53	57.62	42.38	94.66	95.68	64.64	99.24
Mean of means		3.1	62.70	37.30	94.87	96.04	70.30	79.97
St.dev		0.30	6.67	4.28	4.28	3.85	5.08	10.47
CV, %		9.71	10.64	4.51	4.51	4.02	7.23	13.09

Computing the performance parameters values which were obtained in the table 13 and table 15, the results are tabulated in table 16 as below. That irrigation scheduling affects all parameters of field water application.

Table 16 Mean performance at target application depth and SMD

Considerations	Ea	DPR	Du	Cu	Es
Target depth, mm	56.57	43.43	94.87	96.04	70.30
SMD, mm	62.70	37.30	94.87	95.90	73.04

The mean overall field application efficiency and the mean storage efficiency calculated with respect to soil moisture deficit was showed a better result than as compared to the one computed with respect to target water application depths. This was happened because soils were dry enough to intake the applied amount of the late applied irrigation water in SMD cases.

4.4.1.7 Evaluation of Inflow Rate and Cut-Off Time of The Estate Irrigation System

Consideration of both management and field variables are the most important issues in planning and designing irrigation system. In this study the following adjusting data were used for the existing 100m length of the furrow: a) inflow rate was adjusted to be 5 l/sec , b) the target depth of application stated in table 11 were used, c) infiltration parameters (table 7), d) furrow lay out is similar to the existing practice (100m length and with 0.05% slope), e) furrow dimensions of 0.6 top width, 0.40 at middle width, 0.30m maximum depth, and 0.20m bottom width is used. These dimensions are the normal dimensions used by estate, and evaluation of decision variables has done because there was no know inflow rate and cut-off time for now practicing irrigation condition.

Evaluations on nine commercial fields show a wide range of operating and design parameters (length, furrow inflow, slope, and cut-off time) (Table 7 and 8). It was necessary, therefore to determine combinations of these variables that maximize application efficiency for a given field.

Field data were collected using similarly methods outlined in chapter three for evaluation of field water application performance evaluations under section 3.3 except new molded furrows, and the mean inflow rate of 5 l/sec was used. After three replicated evaluations, the results of optimum inflow rate and cut-off times of these events were presented in table 17 as shown below. Though these parameters requires other simulation software, the results of field management leaded to decide analytic corrections which were showed a better performance parameters for the existing furrow length, with uniform inflow rate. In both soil types, better performance has obtained at target application depth and existing infiltration rates. This was happened because inflow rate was uniform across the furrow length, better distribution uniformity and best management activities.

Table 17 Estimation of most favorable field management variables from field data

Fields	Replication	Field measurements				On-field Performance indicators, %			
		Q, l/sec	L, m	W, m	Tco,min	Ea	DPR	Du	Es
FC2326	Rep1	5.00	100.00	1.45	45.00	77.46	22.54	92.54	81.60
	Rep2	4.80	100.00	1.45	45.00	83.91	16.09	91.40	86.14
	Rep3	5.20	100.00	1.45	45.00	82.20	17.80	94.25	84.89
	Mean	5.00	100.00	1.45	45.00	81.19	18.81	92.73	84.21
FC2332	Rep1	4.80	100.00	1.45	45.00	82.20	17.80	9.4.34	84.89
	Rep2	5.00	100.00	1.45	45.00	82.20	17.80	93.24	84.89
	Rep3	5.00	100.00	1.45	45.00	82.20	17.80	95.00	84.89
	Mean	4.93	100.00	1.45	45.00	82.20	17.80	94.12	84.89
FC2414	Rep1	5.10	100.00	1.45	45.00	82.20	17.80	93.39	84.89
	Rep2	4.80	100.00	1.45	45.00	80.56	19.44	92.10	83.72
	Rep3	5.00	100.00	1.45	45.00	83.91	16.09	94.35	86.14
	Mean	4.97	100.00	1.45	45.00	82.22	17.78	93.28	84.92
FC2423	Rep1	5.20	100.00	1.45	45.00	82.20	17.80	91.15	84.89
	Rep2	4.90	100.00	1.45	45.00	78.21	21.79	92.30	82.11
	Rep3	5.00	100.00	1.45	45.00	83.05	16.95	94.22	85.50
	Mean	5.03	100.00	1.45	45.00	81.15	18.85	92.56	84.17

Table 18 Summary of recommended inflow rate cut-off time result

Soil types	Decision variables		Performance parameters, %			
	Q(l/sec)	Tco, min	Ea	DPR	Du	Es
Mean values for SiC	5	45	81.16	18.84	93.43	84.18
Mean values for SiCL	5	45	81.69	18.31	92.92	84.54

Where, T_{co} is cut-off times, minutes.

The mean inflow rate of 5 l/sec was attained for opening of 20 outlets per set of gated pipe irrigation. But, the expected outlet operated per one set was 40 for gated pipe discharge capacity of 200 l/sec and 5 l/sec from each outlet. But, in Tendaho field conditions it not seems feasible. It is better to operate only 20 outlets per set even to attain higher discharge rate. Similarly shorter cut-off time was assigned with shorter irrigation intervals as presented in section 4.5.9 shown in next discussion. The inflow rate should generally be constrained within a certain range. It should not be too high as to cause scouring and should not be too small as otherwise the water will not advance to the downstream end.

By improving the irrigation practices, a better water saving is achieved in both soil types under different irrigation event. From table 13, 15 and 17; water saving was increased trend by application efficiency. Similarly, all other performance parameters were increased for similar effects and deep percolation rate was showed decreasing trends which shows good achievement of application efficiencies.

Generally, if the field management conditions were well managed without any modifications, the field water application can maintain its efficiency range even though there could be other operational losses. The application requires availability of the design inflow rate at acceptable uniformity across the furrows in addition to uniform slopes along the furrow. Though may not, the performance parameters values in the above table may not exact throughout the field, inflow rate and cut-off combination of that range can help to attain better field water management and improved cane yield and productivities for the two soil types.

4.5 Optimizing Irrigation Scheduling and Management

4.5.1 Estimation of Application Depths

The net depth of water application for current two soils under consideration were determined based on consideration of soil water holding capacity, maximum rooting depth and optimum factor of depletion. Soil water holding capacities of the soils considered during study are shown in table 11Table 10. According to CROPWAT 8.0 software default data, the sugarcane root depth may go up to 1.5 m, but in Ethiopian sugar estates the maximum is considered to be 90cm and effective root depth of 60cm.

Actually, the net depths of application for current two soils in Tendaho sugar estate were found as 86.53mm and 104.40 mm respectively (table 11Table 10). However, the design net depth at Tendaho sugar estate was identified 75 mm over all soils, with an application efficiency of 85% (WWDSE, 2005). Target application depth for respective soils in table 11 was considered as net design depth of application for field irrigation system of the current two soils which are under considerations.

4.5.2 Reference Evapotranspiration

The reference evapotranspiration (ETo) for the months of the year was calculated using CROPWAT 8.0 is tabulated as table 19 below.

Table 19 Reference evapotranspiration for each months of a year (CROPWAT 8.0)

Station: Tendaho Altitude: 350 m Latitude: 11.30 ^{o}N Longitude: 41.00 ^{o}E
Reference evapotranspiration: CROPWAT 8.0 model

Months	Min temp, (^{o}C)	Max temp, (^{o}C)	Humidity (%)	Wind, km/day	Sunshine hours	RAD MJ/m^{2}/day	ETo mm/day
January	18.7	32.9	57	534	8.8	19.9	7.13
February	19.2	34.7	38	568	9.1	21.8	8.37
March	21.8	37.1	50	556	7.6	20.8	9.18
April	27.0	39.1	48	501	9.6	24.3	9.91
May	25.6	41.6	42	396	9.9	24.4	10.06
June	27.1	43.2	34	454	7.5	20.4	11.28
July	26.8	41.6	42	529	6.8	19.5	10.89
August	25.7	39.5	50	455	7.2	20.4	9.10
September	25.1	39.8	47	355	7.0	19.9	8.38
October	21.8	38.0	48	353	9.6	22.8	8.25
November	19.0	35.5	51	405	9.6	21.3	7.58
December	18.3	33.4	55	432	9.3	20.1	6.84
Average	21.0	38.0	47.0	462	8.5	21.3	8.91

4.5.3 Crop Coefficient/Crop Factor

According to Rajegowda et al., (2004), the crop coefficient (Kc) value of sugarcane during initial growth stage was found around 0.5 and then gradually increased during vegetative phase and decreased to 0.8 at maturity.

Table 20 Crop coefficient values of sugarcane (Rajegowda et al., 2004)

Initial growth phase	Development stage	Mid-season	Late season	Harvest	Total period
0.4 - 0.5	0.7 - 0.8	1.0 - 1.3	0.75 - 0.80	0.5 - 0.6	0.85-1.05

The growth stages of sugarcane of the state (field information, 2015) can be classified by four age groups for irrigation purpose as shown in table 3 discussed in chapter 3. In addition to these above mentioned Kc values, for irrigation scheduling, rooting depth data corresponding to cropping stages were obtained from previous survey data made at Metahara sugar estate by

Solomon (2010) and Habib (2001); relatively because the same cane varieties grown, and cane management practices done in Ethiopian sugar estates, in this thesis the same root depth values were used as maximum rooting depths at given cane ages as shown in table 21.

Table 21 Root depth at different growth stages (Habib, 2001), and (Solomon, 2010)

Age group (month)	Root depth (cm)
0 – 3	30
3 – 6	45
6 – 15	60
12 and above	90

Booker Tate (2009) was recommended, considering top 60cm as an effective rooting depth was appropriate to estimate soil moisture deficit for irrigation timing of sugarcane. This was to protect the crop from moistures stress in its effective root area.

4.5.4 Effective Rainfall

Defined as that part of the rainfall which is effectively used by the crop after rainfall losses due to surface run off and deep percolation have been accounted for. The effective rainfall is the rainfall ultimately used to determine the crop irrigation requirements. Feeding the rainfall data in CROPWAT 8.0 software, the effective rainfall was estimated as shown in table 21 below.

Table 22 Monthly effective rainfalls of the area

Station: Tendaho sugar factory Eff. Rain method: USDA S.C Method

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Rain, mm	3.0	3.0	9.0	24.0	4.0	1.0	39.0	67.0	14.0	8.0	5.0	7.0	184.0
Eff. RF, mm	3.0	3.0	8.9	23.1	4.0	1.0	36.6	59.8	13.7	7.9	5.0	6.9	172.7

4.5.5 Crop Water Requirement

Crop water requirement, ETc is calculated by multiplying the reference evapotranspiration, ETo, by corresponding crop coefficient (Kc) using Cropwat computer model. From table 21, the crop evapotranspiration of cane varies with crop development stages and cropping seasons. It is lower in January at initial growth stages and higher in May, in the third growth stage.

Initially, the crop water requirement was lower and gradually increases and higher in third growth stage which would decrease after fourth growth stages (table 21).

Table 23 Crop evapotranspiration, ETc for the months and crop stages

Months	ETo (mm/day)	ETC (mm/day)			
		0 to 3 months	3 to 6 months	6 to 2 months	> 12 months
Jan	7.13	3.57	5.70	8.20	5.70
Feb	8.37	4.19	6.70	9.63	6.70
Mar	9.18	4.59	7.34	10.56	7.34
Apr	9.91	4.96	7.93	11.40	7.93
May	10.06	5.03	8.05	11.57	8.05
Jun	11.28	5.64	9.02	12.97	9.02
July	10.89	5.45	8.71	12.52	8.71
Aug	9.10	4.55	7.28	10.47	7.28
Sept	8.38	4.19	6.70	9.64	6.70
Oct	8.25	4.13	6.60	9.49	6.60
Nov	7.58	3.79	6.06	8.72	6.06
Dec	6.84	3.42	5.47	7.87	5.47

4.5.6 Readily Available Water

Readily available water in root zone for the four growth stages in the two soils were calculated and summarized in table 22 by corresponding root depth, allowable factor of depletion and water holding capacity of soils, also by considering the maximum effective root zone of 60 cm the readily available water was determined.

Table 24 Readily available water in root zones for different growth stages and soil types

Growth stage (months)	0 to 3	3 to 6	6 to 12	12 and above
Silty clay	24.5 mm	41.3 mm	60.1 mm	90.2 mm
Silty clay loam	20.8 mm	44.1 mm	90.2 mm	96.1 mm

4.5.7 Net Irrigation Requirement

Net irrigation requirement (NIR, mm/day) of sugarcane is the amount of water needed to be applied as irrigation to supplement the water received through rainfall and soil water contribution in meeting the water needs of the crop for optimum growth and yield. The net irrigation requirement of the two soils of the study area was estimated on daily bases for the respective months and crop stages by considering the monthly effective rainfall was estimated as presented in table 22. But, for crops age less than 3 months, the net irrigation requirement was made equals to crop water requirement (ETc) to provide more frequent irrigation water requirement. The gross irrigation requirements (GIR) of sugarcane at different growth stages was calculated for currently practicing irrigation efficiency of 56.57%.

Table 25 Estimation of net irrigation requirement, (NIR) and

Months	0 to3 months		3 to 6 months		6 to 12 months		> 12 months	
	NIR	GIR	NIR	GIR	NIR	GIR	NIR	GIR
Jan	3.57	6.30	5.61	9.91	8.10	14.33	5.61	9.91
Feb	4.19	7.40	6.59	11.65	9.52	16.83	6.59	11.65
Mar	4.59	8.12	7.06	12.48	10.27	18.16	7.06	12.48
Apr	4.96	8.76	7.16	12.66	10.63	18.79	7.16	12.66
May	5.03	8.89	7.92	14.00	11.44	20.23	7.92	14.00
Jun	5.64	9.97	8.99	15.90	12.94	22.88	8.99	15.90
July	5.45	9.63	7.53	13.32	11.34	20.05	7.53	13.32
Aug	4.55	8.04	5.35	9.46	8.54	15.09	5.35	9.46
Sept	4.19	7.41	6.25	11.05	9.18	16.23	6.25	11.05
Oct	4.13	7.29	6.35	11.22	9.23	16.32	6.35	11.22
Nov	3.79	6.70	5.90	10.43	8.55	15.12	5.90	10.43
Dec	3.42	6.05	5.25	9.28	7.64	13.51	5.25	9.28

(-) means irrigation is not required, since rainfall will be sufficient

4.5.8 Net Irrigation Depth and Actual Irrigation Requirements

Net irrigation depth and actual irrigation required per irrigation events is shown in table 26.

Table 26 Net irrigation depth and Actual irrigation requirement

Fields	Inflow rate, l/sec	Time , min	L, m	S, m	Dn, (mm)	d, mm
FC1143	2.85	60.46	100.00	1.65	77.73	58.51
FC1153	3.38	68.70	100.00	1.55	91.59	64.62
FC2326	3.40	65.88	100.00	1.60	86.70	60.69
FC2332	2.78	74.25	100.00	1.45	85.13	59.80
FC2414	2.74	67.90	100.00	1.66	74.28	55.38
FC2423	3.01	70.00	100.00	1.58	80.01	57.01
FC2441	3.01	78.00	100.00	1.64	85.90	58.61
FC2913	3.53	58.32	100.00	1.65	83.44	71.11
FC2-12-24	3.53	65.67	100.00	1.40	93.80	72.12
Mean	3.14	67.69	100.00	1.58	84.28	61.98

Where, L=furrow length, S=furrow spacing, Dn=net irrigation depth, d= depth of actual irrigation application

4.5.9 Irrigation Intervals

It was computed for respective soils and tabulated in table 26 and table 27, except in last growth stage each fields would irrigate at least twice a month. For the first growth stage the irrigation frequency should reasonably take as a week intervals because cane crop needs frequent water at its initial growth stage. For the rest growth stage irrigation intervals have done based on the soil moisture depletion and crop water requirement of the soil.

Irrigation intervals of the above tables can be used as reference; but during implementation of it, the following points have to be considered. Exact interval cannot give for young plants of less than 60 days the intervals depends on the normal weather condition and the depth of root penetrations. In this early age, soil aeration is the most important; therefore, drier condition is preferred at germination and tillering stages. In determining irrigation intervals, auguring test has to take by irrigation expertise to decide the next date of irrigation.

Table 27 Irrigation interval for silty clay soils

Months	Days			
	0 - 3 months	3 - 6 months	6 - 12 months	> 12 months
Jan	7	7	7	16
Feb	6	6	6	13
Mar	5	6	6	12
Apr	5	5	5	11
May	5	5	5	11
Jun	4	5	5	10
July	4	5	5	10
Aug	5	6	6	*
Sept	6	6	6	13
Oct	6	6	6	14
Nov	6	7	7	15
Dec	7	8	8	16

Table 28 Irrigation interval for silty clay loam soils

Months	Days			
	0 - 3 months	3 - 6 months	6 - 12 months	> 12 months
Jan	6	8	11	17
Feb	5	7	9	14
Mar	5	6	9	13
Apr	4	6	8	12
May	4	5	8	12
Jun	4	5	7	11
July	4	5	7	11
Aug	5	6	9	*
Sept	5	7	9	14
Oct	5	7	10	15
Nov	5	7	10	16
Dec	6	8	11	18

The irrigation intervals shown in table 26 and 27 shown above can be used instead of older irrigation intervals (appendix 7). The star sign (*), show no need to irrigate a field for there is sufficient rainfall in this month (appendix 3). Generally, in the existing irrigation scheduling the target application depth was not well defined and rough application estimation is using, which is wider irrigation intervals (appendix 2). Thus this wide irrigation interval is affecting the growth and millable sugarcane of the estate.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The evaluation of Tendaho irrigation systems was of extreme importance. By knowing how and whether the irrigation system complies with the requirements set for it, better decisions can be made on how to maintain and manage the system to improve their irrigation efficiency and uniformity. This paper was discussed on the ways to evaluate furrow irrigation system of Tendaho sugar estate and has made opportunities for improvements of field water application problems the estate farms. The evaluation results indicate the effectiveness and efficiency of field water application of the study area needs a dual consideration: design and management activities. Evaluation of canals conveyance efficiency was started from tertiary canals. This was done because the field water applications problems and canal conveyance efficiency were starts from these canals. The result of canals evaluation showed a huge percentage of water conveyance loss in these canals having mean conveyance efficiency of 59.589 % over 400m tertiary canals length. The conveyance efficiency of these canals was poorer due to seepage, percolation, structural cracking, and damaging of the earthen channel. Seepage loss in irrigation water conveyance system is very significant, as it accounts the major portion of the water loss in this sugar estate. The loss in conveyance is unavoidable unless the canal is lined or can be minimized with better canal management activities. Irrigation canals function well as long as they kept clean and if they are not leaking. In this sugar estate, the extra leakages of water through the tertiary canals were probably due to eroded mortar, cracks and structural failure of the lined banks. In addition, the capacity of tertiary canal is also reduced due to silting, resulting in overtopping of flows at many sites. If no attention is paid to the canal system, plants/grasses may grow and the problem of siltation may arise. Even worse, the canals may suffer from leakages. Finally, the reason of the less conveyance efficiency in tertiary canal watercourses in this sugar estate was absolutely due to lack of proper maintenance of the watercourses hence more seepage and leakage losses, presence of vegetation, improper alignment of the watercourses and rodent effect.

From the field water application evaluations of furrow system, the performance parameters were also showed the required level of improvement at field water application at field levels. On-field mean application efficiency of the estate farm was indicated as 56.57%, on-field mean storage efficiency of 70.30%, and distribution uniformity of 94.87%. These results clearly show level of field irrigation of furrow system which needs further improvements. The field application performance was evaluated considering two scenarios. Field water application evaluations at target application depth and field irrigation evaluation at SMD. From the results, irrigating the fields considering SMD, higher application efficiency has been obtained than considering target application depth.

Irrigation intervals and soil moisture management activities of this sugar estate were not as such effective, which were mainly leading to the low irrigation efficiency of the system. The current irrigation scheduling of the estate is not well suited to the current conditions of soil and crop growth stages. It was weekly described. This indicates that the field water application of the study area was also significantly affected by irrigation scheduling in addition to field management variables. Based on the results obtained in this study, for cases in which water is stored beyond the conventionally defined root zone, irrigation scheduling and management can be altered in favor of improving water use efficiency. Management allowable depletion can be increased, by including the deep percolated water, normally considered as “loss”. Effective depth of root zone can also be redefined. The target application depth needs to be increased, with shorter irrigation intervals due to higher crop water requirement of the area. Longer or shorter irrigation intervals mostly put plants under stress, but it depends on the climate of the area. In the areas like Tendaho climatic condition, since there are high evapotranspiration, wind speed, longer sunshine hours irrigation intervals might be shorter based on crop growth stages and root depths. Finally, the author advices to use the now revised irrigation scheduling to soil types of studied area for better water management and crop growths.

A good performance of irrigation system significantly related to a field management variables: inflow rate and cut-off times. Therefore, effective and efficiency irrigation has to relate these two basic parameters side by side for better performance of the irrigation scheme. Flow rate is a key variable that affects the outcome of irrigation event because it influences the advance time of the inflow and consequently, the irrigation uniformity, efficiency and adequacy. An increase in irrigation performance is achieved by modifying the cut-off times and inflow per unit width. Improved practices have a positive impact on the water use in terms of water savings. From field evaluation, for Tendaho field conditions inflow rate of 5 l/sec and cut-off time of 45 minute was suggested for two studied soils.

The results of the evaluation reported in this paper confirm that the evaluation of field water application of irrigation systems was essential to increase water use efficiency and a crop yields in the sugar industry. And the author believes that this small but not a little study can bring a change on the field water application performance of the sugar estate for its sustainability.

5.2 Recommendations

Typical recommendations and expected results of the study are presented as follows:

- In order to maintain irrigation system as efficient as possible and to make immediate correction measures, feeder ditches and hydroflumes should be checked at intervals and minor repairs should be carried out before major works required.
- Increase the furrow flow rate – to improve down-row uniformity. Water is advancing too slowly and much more water is infiltrating at the top of the furrow than at the bottom.
- To have higher application efficiency, do not completely fill or over fill the root zone. Overfilling may leaches agricultural chemicals and fertilizers, waste water and increases the operation costs.
- Use a soil probe to judge when to start or stop irrigating - Soil refills to field capacity from the top down. During irrigation, the top of the root zone will nearly saturate. As the irrigation stops, the excess water will redistribute downwards. Using a probe is a good indication of when to change sets.
- Reduce the furrow flow after water has reached the furrow end - cutbacks may be advantageous where very large furrow flows are used to achieve sufficiently quick advance rates. If the cutback was not performed, excessive tail water would result.
- Improve irrigator’s mobility – It may be, especially if the irrigators adjust furrow flows continually. They should go back and forth between the top and bottom of the field many times to ensure uniform applications.
- Improve overall farm coordination: the irrigation program needs to be meshed efficiently with the pest control/fertility/cultural operations programs.
- There are specific soil problems in the field - saline portions, false line (intake more water than expected infiltration rate speed of ever: field FC2226, FC3113) and the weed outbreak; something is reducing distribution uniformity.

- Avoid field supply variations – water is distributed on the farm are varying. Irrigators are changing the total flow conditions in the field. Thus, the discharge per furrow will go only some distance in a given furrow and then flow is diverted to other furrow.
- Proper observation: though this study was concerned on the field water application performance evaluation, during the field observations and implementations works, there observed design problems of irrigation systems and drainage system, which needs much more rehabilitation expenses to put back a system as its designed operations. Therefore, further collaborated action has to be made with stakeholder, particularly with universities.
- Management training is a basic necessity: there are some excellent computer models, such as CROPWAT Model that determine irrigation scheduling and allow management staff to learn from their mistakes before they even get out on the job. Learning from your mistakes is best way there is.
- Provide repair and maintenance works for canals, field and gated pipes. It is best if sediments, vegetation/grasses are cleared from both irrigation and drainage canals in a way that it cannot lose its original shape of cross-section, and remove bushes or trees on canal embankment, because they can create channels through canal bank and will create high leakage losses
- Conveyance structures has to be rehabilitated to attain the designed conveyance efficiency; especially, for those leaking off-takes, bowed sidewalls of conveyance canals
- Extensive land leveling and furrow making process have to done with care.
- Improve irrigation scheduling for each soil types of the estate farms in accordance to the recent field condition.
- Improve water application; give attention to cutoff time over-irrigate or under irrigate the fields - flooding has to be improved.
- Though there were lines of surface drainage system in the estate farms, they are not functioning; rehabilitate the existing drainage networks and put them back in to action. Some additional cross drainage structures will also essential to construct other than previously constructed structures, depending on the recent conditions of the cane fields.
- Rehabilitate tertiary off-take/turnout gates to reduce leakage, and release of unwanted water that is not intentionally required and to prevent accidental water not to enter farm and cause damage if gate is open.

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Appendix

Appendix 1 Means maximum temperature, ^{0}C (+1.5 m)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	32.8	34.6	36.5	39.6	41.8	43.4	41.4	38.0	39.9	37.0	34.0	32.6	37.6
2001	31.3	36.0	35.5	39.0	41.9	43.2	42.4	39.5	39.2	37.9	33.0	32.9	37.7
2002	32.4	34.0	36.8	38.5	42.5	43.5	42.9	40.7	39.9	38.4	35.0	32.4	38.1
2003	32.7	35.0	38.4	38.4	41.7	43.3	41.5	37.6	39.8	36.1	35.0	32.3	37.7
2004	32.9	34.1	36.9	38.0	41.7	42.8	41.7	41.0	37.8	37.7	35.0	33.1	37.7
2005	33.1	36.0	39.5	39.2	40.9	43.2	40.7	39.7	40.6	37.9	36.0	33.1	38.3
2006	33.5	35.0	37.4	37.9	41.9	43.7	41.7	39.1	40.3	38.0	35.0	33.5	38.1
2007	32.8	35.4	38.0	39.6	42.3	43.5	39.5	39.2	40.3	37.7	35.0	33.3	38.1
2008	33.0	33.2	37.1	39.7	42.0	43.4	42.1	41.1	41.3	38.8	35.0	32.9	38.3
2009	32.2	34.9	37.4	39.6	42.2	43.9	41.9	41.2	41.8	38.6	37.0	34.9	38.8
2010	33.4	34.5	36.6	39.4	40.9	42.5	39.9	37.7	38.9	38.2	34.0	30.5	37.2
2011	31.5	33.5	35.1	38.9	39.8	42.3	42.0	39.6	41.2	38.6	37.9	34.6	37.9
2012	34.3	35.1	37.2	39.1	41.7	42.9	41.5	39.6	34.3	38.1	37.4	35.4	38.0
2013	33.9	34.5	37.0	39.4	41.4	43.0	41.3	38.1	40.6	39.1	36.6	34.6	38.3
2014	33.7	34.3	37.0	40.5	41.5	43.8	42.9	39.7	40.3	38.1	36.7	34.5	463.0
Mean	32.6	34.7	37.1	39.0	41.6	43.2	41.5	39.5	39.6	37.9	35.2	33.0	38.0
St.D	0.7	0.9	1.1	0.6	0.7	0.5	0.9	1.2	1.1	0.7	1.3	1.1	0.4
C.V(%)	2.0	2.5	3.1	1.6	1.7	1.0	2.3	3.1	2.7	1.9	3.6	3.2	1.1

Appendix 2 mean minimum temperature, ^{0}C (+1.5 m)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	16.7	17.3	20.5	23.4	26.2	28.2	27.3	24.2	25.5	23.0	19.0	16.5	22.3
2001	16.7	18.0	29.9	23.0	26.4	25.7	26.2	25.2	24.6	23.1	18.0	17.2	22.8
2002	20.5	19.8	23.7	23.8	24.9	27.3	27.0	26.4	25.4	20.8	19.0	20.0	23.2
2003	19.2	21.2	23.0	23.8	24.8	28.6	27.6	25.3	25.8	20.2	19.0	18.2	23.1
2004	20.2	19.0	19.1	25.0	25.0	27.3	27.7	26.7	25.5	21.5	19.0	19.8	23.0
2005	19.9	20.2	24.3	24.1	26.7	28.1	26.6	26.0	27.3	21.8	18.0	20.2	23.6
2006	19.3	22.0	22.2	23.9	26.5	28.1	27.8	25.7	26.5	22.5	19.0	20.9	23.7
2007	20.2	21.9	22.7	24.6	27.2	27.2	25.6	25.5	25.6	21.9	19.0	17.0	23.2
2008	19.0	17.9	16.4	22.1	25.8	26.4	24.6	24.9	25.4	22.1	21.0	15.6	21.8
2009	18.4	18.0	21.8	23.4	25.0	27.5	26.7	26.3	25.8	22.3	18.0	20.7	22.8
2010	18.1	19.8	21.2	24.3	27.3	27.9	27.0	25.3	24.8	23.2	18.0	16.3	22.8
2011	18.4	17.9	19.4	23.4	24.2	26.0	27.5	25.4	25.4	20.8	21.5	25.6	23.0
2012	18.3	17.1	19.0	23.9	24.2	26.5	26.9	25.8	18.3	19.8	18.2	16.9	21.2
2013	17.8	18.3	21.0	24.2	25.0	26.1	27.0	28.5	26.1	22.4	19.2	14.1	22.5
2014	17.1	20.2	22.1	23.2	25.2	26.3	26.8	24.3	25.2	22.2	18.9	15.8	267.4
Mean	18.9	19.4	22.0	23.7	25.8	27.4	26.8	25.6	25.6	21.9	19.0	19.0	22.9
St.D	1.2	1.6	3.2	0.7	1.0	0.9	0.9	0.7	0.7	0.9	1.1	2.7	0.5
C.V(%)	6.5	8.2	14.5	3.1	3.8	3.2	3.4	2.6	2.6	4.2	5.7	14.1	2.2

Appendix 3 Mean rainfall data, mm

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	0.0	0.0	0.0	30.4	2.4	0.0	27.4	112	2.5	44.4	25.0	0.0	243.9
2001	0.0	0.0	29.2	0.0	22.9	0.0	56.0	34.8	17.0	0.0	0.0	0.0	159.9
2002	0.0	0.0	4.6	15.4	0.0	0.0	6.9	38.0	11.5	0.0	0.0	63.2	139.6
2003	0.0	31.6	2.0	28.2	0.0	0.5	22.0	135	6.8	0.0	0.0	43.2	269.1
2004	3.0	0.0	14.0	62.9	0.0	0.0	17.0	45.8	16.5	0.0	0.0	0.0	159.2
2005	0.0	0.0	3.2	37.9	10.7	10.4	64.2	66.2	15.9	0.0	0.0	3.2	211.7
2006	2.2	3.2	3.0	40.3	0.0	0.0	19.2	82.6	7.5	0.0	0.0	0.0	158.0
2007	0.0	3.5	0.0	80.6	0.0	0.0	163	40.0	16.2	0.0	0.0	0.0	303.4
2008	0.0	0.0	0.0	13.0	7.5	0.0	36.1	36.5	36.6	0.0	50.0	0.0	179.7
2009	31.8	0.0	0.0	9.2	0.0	6.9	27.3	83.4	1.2	27.8	0.0	0.0	187.6
2010	0.0	1.8	18.9	25.7	0.5	0.0	56.1	87.6	48.8	0.0	0.0	0.0	239.4
2011	0.0	0.0	27.5	15.3	0.0	0.0	7.2	27.6	11.3	4.5	0.0	0.0	93.4
2012	0.0	0.0	0.0	6.7	7.1	0.8	46.3	102	0.0	0.0	0.0	0.0	0.0
2013	0.0	0.0	0.0	0.0	15.3	0.0	22.4	48.8	17.8	0.0	0.0	0.0	0.0
2014	0.0	0.0	0.0	0.0	0.0	0.0	19.2	61.7	0.0	40.9	0.0	0.0	0.0
Mean	3.1	3.3	8.5	29.9	3.7	1.5	41.9	65.8	16.0	6.4	6.3	10.0	195.4
St.D	8.7	8.6	10.5	22.1	6.7	3.3	40.8	33.0	13.2	13.8	14.9	20.8	57.3
CV(%)	282.6	257.8	123.5	74.0	183	221.6	97.5	50.2	82.8	215	238.0	209.2	29.3

Appendix 4 Mean wind speed data, m/sec

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	6.30	5.00	6.50	5.00	4.90	5.80	6.50	5.10	3.90	2.70	4.10	4.30	5.01
2001	4.70	5.00	9.70	5.00	3.90	4.40	5.80	5.90	2.70	3.90	3.50	4.90	4.95
2002	4.90	7.70	8.00	7.40	3.60	4.70	7.80	5.40	3.40	2.90	4.20	3.90	5.33
2003	3.90	5.40	5.70	6.10	4.10	5.40	5.30	1.80	3.40	3.20	5.40	4.10	4.48
2004	5.20	5.20	5.30	4.90	3.40	5.10	5.90	5.60	3.40	3.80	4.70	5.40	4.83
2005	5.00	8.80	6.00	6.70	5.00	5.40	6.90	6.00	5.50	5.20	6.00	6.00	6.04
2006	8.50	9.10	7.80	6.70	6.50	6.70	7.20	7.00	5.70	7.20	6.70	7.40	7.21
2007	9.30	7.20	8.50	9.30	5.50	7.20	6.20	5.80	6.00	5.00	5.50	5.70	6.77
2008	6.70	7.00	5.30	5.00	5.60	5.80	6.00	5.20	5.10	4.20	4.20	5.20	5.44
2009	6.01	5.48	5.54	4.86	4.38	4.38	6.12	5.56	4.09	5.91	5.00	6.73	5.34
2010	7.55	7.38	5.76	5.89	4.55	5.20	5.68	5.42	3.48	2.60	4.10	3.73	5.11
2011	6.07	5.56	3.21	2.75	3.58	2.95	4.07	4.40	2.62	2.36	2.90	2.67	3.59
2012	3.95	4.86	0.00	3.10	2.96	3.47	4.90	5.05	3.95	3.37	3.98	3.58	3.60
2013	4.69	4.36	0.00	3.80	3.46	3.23	5.40	4.59	3.39	2.68	3.89	3.65	3.59
2014	4.75	3.66	0.00	2.25	2.81	3.62	4.06	4.53	3.10	2.41	2.83	2.87	3.07
Mean	6.18	6.57	6.44	5.80	4.58	5.25	6.12	5.27	4.11	4.08	4.69	5.00	5.34
St.D	1.55	1.42	1.69	1.57	0.91	1.07	0.91	1.20	1.12	1.43	1.03	1.29	0.93
CV(%)	25.04	21.65	26.21	27.01	19.85	20.31	14.90	22.78	27.38	35.04	22.02	25.81	17.42

Appendix 5 Mean sunshine data, hours

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000	10.5	10.3	10.2	9.8	10.3	8.8	6.7	8.3	7.3	9.6	11.0	9.7	9.4
2001	8.2	10.0	6.1	10.0	10.8	0.0	0.0	0.0	0.0	10.2	10.0	10.3	6.3
2002	8.4	10.9	9.3	10.3	10.9	8.7	7.8	8.4	8.4	10.6	10.0	7.0	9.2
2003	8.3	9.6	10.0	9.2	10.5	8.6	7.0	6.2	7.1	9.6	10.0	10.1	8.9
2004	8.3	9.3	9.4	8.7	10.4	8.9	7.7	8.0	7.2	9.7	10.0	8.7	8.9
2005	7.5	9.6	9.1	9.6	9.9	8.6	7.7	7.9	7.7	10.2	10.0	10.2	9.0
2006	9.1	9.1	7.4	8.6	10.4	8.4	7.3	8.0	7.8	9.8	10.0	8.6	8.7
2007	9.3	9.0	9.3	10.3	10.3	7.3	8.5	8.3	7.7	9.9	9.9	10.2	9.2
2008	8.6	8.5	10.4	9.0	9.6	9.1	7.9	8.5	7.9	9.2	9.2	10.2	9.0
2009	8.9	10.1	9.8	10.0	10.2	8.2	6.1	6.7	7.6	8.7	8.7	8.4	8.6
2010	8.5	6.8	8.0	9.4	8.0	5.6	7.0	6.7	7.7	9.1	9.1	8.6	7.9
2011	9.3	9.2	0.0	10.3	8.8	7.3	6.4	7.0	7.3	9.8	7.7	9.2	7.7
2012	8.4	8.6	5.9	8.7	9.7	6.4	7.0	7.7	8.4	9.1	9.9	9.6	8.3
2013	8.9	8.3	9.3	10.0	9.9	7.1	6.5	7.8	6.3	8.6	9.4	9.5	8.5
2014	9.1	7.9	0.0	10.5	9.2	8.8	7.6	8.0	7.2	9.3	9.5	9.5	8.1
Mean	8.8	9.1	7.6	9.6	9.9	7.5	6.8	7.2	7.0	9.6	9.6	9.3	8.5
St.D	0.7	1.0	3.3	0.6	0.8	2.2	1.9	2.0	1.9	0.5	0.7	0.9	0.8
C.V (%)	7.5	11.1	42.9	6.5	7.6	29.9	28.3	28.4	27.7	5.6	7.5	9.5	9.0

Appendix 6 Mean relative humidity data, %

Year	Jan	Feb	Mar	April	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Mean
2000	49.5	42.1	41.5	38.7	33.4	27.5	40.5	51.5	49.9	51.0	56.6	57.5	45.0
2001	56.0	51.0	58.1	43.0	42.9	33.4	39.0	49.4	53.5	63.3	42.5	52.9	48.8
2002	61.8	49.0	50.4	44.3	31.5	29.1	34.1	42.8	43.2	43.3	45.4	54.0	44.1
2003	55.6	53.3	48.0	48.0	37.7	30.6	38.3	53.3	44.5	45.7	50.0	58.0	46.9
2004	60.0	50.0	40.0	53.0	32.0	31.0	38.1	45.8	43.0	44.0	49.0	53.0	44.9
2005	54.0	47.0	47.0	44.0	39.0	31.0	40.0	45.0	41.0	38.0	43.0	47.0	43.0
2006	53.0	51.0	44.0	50.0	39.0	30.0	39.0	50.0	44.0	47.0	48.0	56.0	45.9
2007	58.0	53.0	48.0	46.0	38.0	34.0	48.0	52.0	45.0	43.0	49.0	54.0	47.3
2008	58.0	55.0	44.0	45.0	42.0	37.0	41.0	46.0	43.0	44.0	54.0	53.0	46.8
2009	61.0	57.0	54.0	49.0	46.0	37.0	44.0	46.0	40.0	48.0	51.0	56.0	49.1
2010	55.0	54.7	49.4	53.0	50.0	33.5	43.6	52.3	49.1	47.6	50.9	54.3	49.4
2011	59.7	58.4	57.9	48.2	49.5	35.7	43.5	50.1	42.8	46.5	54.7	56.0	50.2
2012	58.2	58.0	54.8	56.3	49.4	38.8	47.0	54.8	58.2	53.9	57.0	58.5	53.7
2013	63.9	62.4	59.3	54.3	47.5	37.2	46.0	53.0	58.2	45.1	55.9	53.4	53.0
2014	56.6	59.2	60.1	49.6	48.5	39.7	47.8	53.7	56.4	56.2	62.3	62.3	54.4
Mean	57.4	53.4	50.4	48.2	41.8	33.7	42.0	49.7	47.5	47.8	51.3	55.1	48.2
St.D	3.5	4.9	6.2	4.5	6.1	3.5	3.8	3.5	5.9	5.8	5.2	3.2	3.3
C.V(%)	6.1	9.2	12.3	9.3	14.6	10.4	9.1	7.0	12.5	12.2	10.1	5.8	6.8

Appendix 7 Mean Monthly Climatic Parameters of years (2000– 2014)

Station: Tendaho, Dubti Metrology Station

Altitude: 350 m a.s.l Latitude: 11.30 degree (North) Longitude 41.00 degree (East)

Months	Max. Temp (^{O}C)	Min. Temp (^{O}C)	Rain fall (mm)	Sunshine (hr/day)	RH (%)	Wind speed (km/day)	Pan Evaporation (mm)
Jan	32.6	18.9	3.1	8.8	57.4	534	243
Feb.	34.7	19.4	3.3	9.1	53.4	568	229
March	37.1	22.0	8.5	7.6	50.4	556	276
April	39.0	23.7	29.9	9.6	48.2	501	287
May	41.6	25.8	3.7	9.9	41.8	396	344
June	43.2	27.4	1.5	7.5	33.7	454	342
July	41.5	26.8	41.9	6.8	42.0	529	375
Aug	39.5	25.6	65.8	7.2	49.7	455	283
Sept	39.9	25.6	16.0	7.0	47.5	355	259
Oct	37.9	21.9	6.4	9.6	47.8	353	249
Nov	35.2	19.0	6.3	9.6	51.3	405	222
Dec	33.0	19.0	10.0	9.3	55.1	432	229

Appendix 8 Theoretical irrigation intervals for respective soils and growth stage

Texture class of soil mapping units	Silty clay soil				Silty clay loam soil			
Cane age, months	0 to 3	3 to 6	6 to 12	> 12	0 to 3	3 to 6	6 to 12	> 12
Jan	11	10	12	19	10	9	11	18
Feb	9	9	10	17	9	8	9	16
Mar	8	9	10	18	8	9	10	17
April	8	10	11	21	7	9	10	19
May	8	10	11	20	7	9	10	19
Jun	8	14	14	-	7	13	13	-
July	8	30	24	-	7	28	22	-
Aug	8	-	-	-	8	-	-	-
Sept	9	-	-	-	8	-	-	-
Oct	9	-	-	-	9	-	30	-
Nov	10	19	19		9	17	17	-
Dec	11	11	12	21	10	10	12	20

The (-) sign indicates there no need irrigation or maximum of a single irrigation is required per month for that given stage because the interval is greater than 30 days.

Appendix 9 Furrow dimensions of the fields under study, (representative of all soil types)

Measurement	Fields								
	FC 1143	FC 1153	FC 2326	FC 2332	FC 2414	FC 2423	FC 2441	FC 2913	FC 21224
Top width, m	0.66	0.64	0.61	0.68	0.51	0.59	0.68	0.56	0.59
Max. depth, m	0.19	0.24	0.20	0.29	0.24	0.18	0.19	0.13	0.18
Middle width, m	0.41	0.38	0.39	0.43	0.34	0.38	0.46	0.41	0.39
Bottom width, m	0.22	0.29	0.20	0.17	0.23	0.22	0.29	0.26	0.22

Appendix 10 FAO classification soil-mapping units and their extent in project area

Soil Mapping Unit	Land form/ major soil group	FAO soil units
RA – 1 to RA-6	Recent alluvium	Calcaric fluvisols
		Eutric fluvisols
		Glegic fluvisols
		Pellic vertisols
		Salic vertisols
LS -1 to LS-13	Lacustrine sediments (Vertisols, Dubti farm where the study is under taken; Silty clay and Silty clay soil textures)	Sodic solonchaks- Solonetz
		Pellic vertisols
		Calcaric vertisols
		Natric vertisols
		Eutric fluvisols
		Pellic vertisols, Indandic phase
		Eutric vertisols ,gilgai phase
		Arenic Regosols
		Salic solonetz
YA-1	Young riverine alluvium	Calcaric fluvisols, Inandic phase

Appendix 11 Calculated target application depths, mm

Field no	Soil type	FC(%v)	θi(%wt)	BD(g/cc)	RD(m)	Zreq(mm)
FC1-1-4-3	SiC	39.5	25.9	1.33	1.00	100.96
FC1-1-5-3	SiC	41.0	24.8	1.44	1.00	100.96
FC2-3-2-6	SiC	39.5	23.6	1.38	1.00	100.96
FC2-3-3-2	SiC	38.5	28.2	1.37	1.00	100.96
FC2-4-1-4	SiCL	41.0	18.6	1.43	1.00	114.00
FC2-4-2-3	SiCL	40.5	25.3	1.37	1.00	114.00
FC2-4-4-1	SiCL	40.5	31.5	1.39	1.00	114.00
FC2-9-1-3	SiCL	42.5	26.9	1.31	1.00	114.00
FC2-12-24	SiCL	42.5	37.9	1.44	1.00	114.00

Appendix 12 Advance time, minutes

Field	Average advance time of fields for three replications, min										
		20 m		40 m		60 m		80 m		100 m	
	0 m	Repl	mean	Repl	mean	Repl	mean	Repl	mean	Repl	mean
FC 1143	0	4.00	3.50	11.00	9.08	18.10	16.54	30.00	26.15	45.34	39.35
	0	3.20		8.00		14.30		29.23		31.55	
	0	3.30		8.24		17.22		19.22		41.16	
FC 1153	0	3.33	3.33	11.22	9.24	12.30	16.38	30.00	25.54	39.05	36.15
	0	4.20		7.42		16.45		27.30		28.14	
	0	2.46		9.08		20.39		19.32		41.26	
FC 2326	0	3.56	4.00	7.11	7.55	17.00	14.45	21.55	21.3	29.44	28.24
	0	5.42		9.44		14.00		20.00		27.00	
	0	3.02		6.10		12.35		22.35		28.28	
FC 2332	0	4.5	3.50	8.00	8.36	12.00	11.52	19.00	17.46	22.50	20.17
	0	4.00		9.00		13.00		18.00		20.00	
	0	2.00		8.08		9.55		15.38		18.00	
FC 2414	0	2.00	3.50	5.00	4.18	8.20	7.26	13.52	11.97	18.12	15.58
	0	2.40		3.55		7.44		12.22		15.46	
	0	6.10		4.00		6.14		10.17		13.14	
FC 2423	0	5.00	5.00	14.00	12.03	22.45	23.52	30.00	28.00	37.41	36.07
	0	3.40		13.50		21.55		31.00		36.25	
	0	6.60		8.59		26.57		23.00		34.55	
FC 2441	0	3.40	4.20	9.30	8.14	17.40	15.35	24.35	26.55	30.21	31.29
	0	4.53		8.00		13.44		28.27		34.20	
	0	4.67		7.12		15.21		27.03		29.47	
FC 2913	0	4.00	4.50	10.00	12.47	18.35	21.43	45.34	37.06	54.20	46.01
	0	3.00		14.00		22.50		33.41		44.50	
	0	6.50		13.41		23.45		32.42		39.33	
FC 2 12 2 4	0	3.50	3.50	12.00	10.11	18.00	20.00	25.10	28.58	32.31	35.53
	0	2.45		8.00		21.45		33.05		40.20	
	0	4.55		10.33		20.55		27.58		34.08	
Mean of means			3.89		9.02		16.27		24.73		33.63

Where, Repl – is to mean replications of evaluation events

Appendix 13 Recession times, minutes

Field	Average recession time, min											
	0.0 m		20 m		40 m		60 m		80 m		100 m	
	Repl	mean	Repl	mean	Repl	mean	Repl	mean	Repl	mean	Repl	mean
FC 1 1 4 3	320	289	300	263	340	300	350	317	390	344	450	359
	270		245		290		315		320		300	
	278		243		269		287		322		328	
FC 1 1 5 3	270	250	220	242	200	236	240	266	255	264	300	279
	235		250		280		300		280		265	
	245		257		227		258		257		273	
FC 2 3 2 6	300	239	250	212	230	226	270	256	255	254	280	270
	215		185		225		290		300		300	
	203		202		222		208		207		229	
FC 2 3 3 2	450	389	420	335	400	355	450	377	420	383	440	418
	390		370		370		385		400		395	
	327		216		296		295		330			
FC 2 4 1 4	345	402	380	433	420	459	460	469	550	489	600	522
	420		450		435		470		515		480	
	441		469		522		478		403		487	
FC 2 4 2 3	500	439	455	432	425	436	470	436	455	444	470	459
	399		425		450		395		415		480	
	419		416		434		444		463		428	
FC 2 4 4 1	460	339	440	332	385	336	400	356	380	364	400	389
	325		350		365		370		390		375	
	233		207		257		298		322		393	
FC 2 9 1 3	400	402	425	393	400	381	385	369	450	389	465	422
	378		400		380		365		380		375	
	428		354		363		358		338		427	
FC 2 12 2 4	477	447	484	488	470	475	500	491	515	502	540	526
	399		450		445		465		485		500	
	464		531		510		507		505		539	
Mean of means		355		348		356		371		381		405

Appendix 14 Photos taken during field works

a) Some observable field water application defects

b) Overtopping and leakage problems on tertiary canals

c) Torched and tired hydroflumes letting unwanted irrigation water to a field.

d) Tertiary off-takes closed by mud and mud filled in sack

e) Vegetated Tertiary canals

Distortion of irrigation canals observed in the Dubti area sugarcane farm, Tendaho

f) Parshall flumes set up to measure furrow inflow rates

g) Setting up Parshall flumes for estimation of tertiary conveyance efficiency, Tendaho