JIMMA UNIVERSITY
JIMMA INSTITUTE OF TECHNOLOGY
SCHOOL OF GRADUATE STUDIES
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING
CHAIR OF HYDRAULIC ENGINEERING

HYDRAULIC AND ECONOMIC PERFORMANCE OF HYDRO-FLUME IRRIGATION AT METAHARA SUGAR PLANTATION, OROMIYA REGION, ETHIOPIA

A RESEARCH SUBMITTED TO SCHOOL OF GRADUATE STUDIES OF JIMMA UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR DEGREE OF MASTERS OF SCIENCE IN HYDRAULIC ENGINEERING

BY

SOLOMON ASHEMO

March, 2016
Jimma, Ethiopia

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March, 2016
Jimma, Ethiopia

DECLARATION

JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

HYDRAULIC ENGINEERING CHAIR

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BY

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ABSTRACT

Any modest improvement in the performance of irrigation water management for thirsty sugarcane schemes management has substantial impact. One way this can be achieved is through a systematic evaluation of the performance of existing schemes in order to take action towards improving the technical, environmental and economic health of the system. This is specifically true with the introduction of new water conveyance system such as hydro-flume. This study was initiated to investigate performance of Metahara Sugar Estate irrigation system in terms of hydraulic and economic performance indicators. The performance indicators used to evaluate the irrigation schemes are oriented towards the variables that directly or indirectly affect water deliveries and water spreading effects. The evaluation was made using seven technical performance indices such as conveyance efficiency, application efficiency, water storage efficiency, water distribution uniformity, deep percolation fraction, runoff ratio, sustainability, sugarcane performance as a function of water application and cost-benefit comparison of open earthen ditch (feeder ditch) with hydro-flume. Crop water requirement based on soil classification and irrigation scheduling of the scheme were also assessed. The technical evaluation was done using three irrigation events on three representative plantations' fields (from the head, middle and tail end of the command area); whereas the performance of sugarcane as a function of flow rate and cost benefit analyses of hydro- flume was evaluated using sample cane from different variety from different field evaluation was done by laboratory, secondary data was collected from stakeholder. The results indicated that the mean values of discharge were 2.88, 3.45 and 3.45 l/s respectively which is less than the designed discharge of 5 l/s. The field assessment shows that performance of the irrigation scheme is unsatisfactory in terms of conveyance efficiency, application efficiency, deep percolation fraction, run-off ratio and sustainability with mean values of 92.17%, 58.55%, 22.92%, 18.58% and 93%, respectively. However, the distribution uniformity, and water storage efficiency were satisfactory with mean values of 85.42%, and 99.43. The range of cane and sugar yield found in the study was from 9.08 to 13.12 t/ha/month, respectively. Total net cost saving and revenue obtained by implementation of hydro-flume were 1,947,883.64 birr, respectively. As a result, weak operation of irrigation water, poor irrigation water management and poor maintenance of the scheme is seen and its sustainability is uncertain.

Key words: Hydro-flume, furrow irrigation, Metehara, sugarcane

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ACKNOWLEDGEMENT

It is a great pleasure to acknowledge the assistances rendered and the contributions made by different organizations and individuals during the course of field work through provision of data and information as well as materials required to realize this thesis.

Above all, the author is highly grateful to God, the One and Only Creator and Governor of this universe, for answering all the author prayers. The author also forwards his heartfelt thanks to his friends, Kassahun Wale, Gezachew Beyene, Adane Mulegeta, Abedela, Keder, Abebe Yeuna, Tewodrose Negusse, Yewlsew Ejigu, Abera, Mamo, Tofik Jemal, Abebe Girma, Hailu Mamo, Jemal Zeynu, Asmamaw Abate for their continuous and unreserved support and encouragement given during the study period. The author feels that he could not have completed this thesis without them being by his side.

The author is highly indebted to his advisors, Dr. Tena Alamirew (major advisor) and Keneni Elise (PhD candidate, co-advisor), who directed him in preparing the proposal, edited the draft thesis, and gave the required guidance during the data collection. The relentless assistance and professional guidance they provided in preparing the thesis is priceless, without which the completion of the thesis would not have been realized.

I extend special thanks to Metahara Sugar Factory management especially Ato Eshetu H/wold (D/General Manager) for providing vehicle during field work, wisdom in the crop production and facilitating the field work at Metahara Sugar Estate. I would like to sincerely acknowledge the staff of the Research Directorate of Metahara Sugar factory as a whole and Ato Endris Yosef (Team Leader) for providing Technical, and laboratory support to undertake this research work.

Finally, my heartfelt thanks extend to my family who received all kinds of suffering during my study. I want them to know that I respect and always keep in my memory their boundless and invaluable support.

LIST OF ACRONYMS AND ABBREVIATIONS

AFI	Alternative furrow irrigation
AR	Advance Ratio
Ea	Application Efficiency
AMC	Available Moisture Content
BD	Bulk Density
CFI	Conventional furrow irrigation
Kc	Crop Coefficient
CWR	Crop Water Requirement
DPR	Deep Percolation
DU	Distribution Uniformity
EC	Electrical Conductivity
FC	Field Capacity
FAO	Food and Agricultural Organization
Gp	Gated pipe
IWMI	International Water Management Institute
IWUE	Irrigation Water Use Efficiency
MD	Man per day
MSF	Metehara sugar Factory
PWP	Permanent Wilting Point
RAM	Readily Available Moisture
ETo	Reference Evapo-transpiration
Z_{req}	Required depth to refill the field capacity
RO	Runoff Loss
SMD	Soil Moisture Deficit
Es	Storage Efficiency
SURDEV	Surface Irrigation Design, Operation and Evaluation
TWR	Tail Water Runoff
TAM	Total Available Moisture

1. INTRODUCTION

1.1. Background

Ethiopia is endowed with a substantial amount of water resources. But this is spatially and temporally variable. Annual rainfall varies from less than 100 mm along the border with Somalia and Djibouti to 2400 mm in the southwest highlands, with a national average of 870 mm (FAO, 1995).The surface water resource potential in particular is known to be impressive, but little developed. Integrated development master plan studies and related river basin surveys undertaken at the end of the 1990s indicate that the aggregate annual runoff from nine Ethiopian river basins is about 122 km^3 (FAO, 2005).

Most of the rivers in Ethiopia are seasonal and about 70% of the total runoff is obtained during the period June-August. Dry season flow originates from springs which provide base flows for small-scale irrigation. The groundwater potential of the country is not known with any certainty, but so far only a small fraction of the groundwater has been developed, mainly, for local water supply purposes (FAO, 2005).

Irrigation in Ethiopia dates back several centuries while "modern" irrigation is known to have been started in early 1950s by the Imperial Government of Ethiopia and the Dutch company known as HVA-Ethiopia (Awulachew *et al.*, 2007; FAO, 2005). In Ethiopia, under the prevalent rain fed agricultural production system, the progressive degradation of the natural resource base, especially in highly vulnerable areas of the highlands coupled with climate variability have aggravated the incidence of poverty and food insecurity. Water resources management for agriculture includes both support for sustainable production in rain-fed agriculture and irrigation (Awulachew *et al.*, 2005).

River basin master plan studies and related surveys indicate that irrigation potential that can be developed using both surface and groundwater is estimated to be about 5.7 million ha. The medium and large scale irrigation potential that can be irrigated using surface water alone is estimated as 3.7 million ha (FAO, 2005; Awulachew *et al.*, 2007). Further Minister of water resource has identified 560 irrigation potential sites on major river basins.

Surface irrigation is the most widely used irrigation method. This is due to its low capital and maintenance costs, and low energy requirements (Walker and Skogerboe, 1987). A surface irrigation event is composed of four phases: advance, wetting or storage, depletion and recession. When water is applied to the field, it 'advances' across the surface until the water extends over the entire area. It may or may not directly wet the entire surface, but all of the flow paths have been completed. Then the irrigation water either runs off the field or begins to pond on its surface. The interval between the end of the advance and when the inflow is cut off is called the wetting or ponding phase (Abdaldafi, 2006).

Among the factors used to judge the performance of an irrigation system or its management, the most common are efficiency, adequacy and uniformity. These parameters have been subdivided and defined in a multitude of ways. There is no single parameter that adequately defines irrigation performance. 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 runoff or tail water, the uniformity of the applied water, and the remaining deficit or under-irrigation within the soil profile following irrigation. Ultimately, the measure of performance is whether or not the system optimizes production and profitability on the farm (Walker, 2003).

The efficient application and distribution of water by furrow irrigation is dependent on furrow irrigation parameters such as inflow, soil texture, field slope, soil infiltration, plant coverage, roughness coefficient, field shape, irrigation management, etc. It is essential to understand the role and inter-dependence of these factors, which determine the prescribed amount of water to apply and ensure uniform application down the full furrow length. Improved efficiency in irrigation system design can help reduce the amount of irrigation water applied there by reducing waterlogging and salinity problems while at the same time maintaining crop water needs (Assefa, 2011).

An alternative to flooding the entire field surface is to construct small channels along the primary direction of water movement. Water introduced in these furrows, creases, or corrugations infiltrates through the wetted perimeter and moves vertically and laterally thereafter to refill the soil. Furrows can be used in conjunction with basins and borders, as noted earlier, to overcome topographical variation and crusting. When individual furrows are supplied water as opposed to field spreading prior to the furrows, the method will be called furrow irrigation (Walker, 2003).

Runoff losses from open-ended furrows and borders can be reduced either by blocking the lower ends of the furrows and borders or by reducing the inflow (cutback) at a pre-determined moment. With the cutback method, irrigation starts at a selected flow rate and continues at this-rate for part of the application period. At a certain moment, the flow rate is cut back to a level that is sufficient to complete the irrigation application adequately. In furrow and border irrigation systems, it is usually assumed that this moment will come at the end of the advance phase. This is a fairly easy way to use the cut back method (Jurriëns *et al*., 2001).

Furrow irrigation is the most common method of irrigating Sugarcane in Ethiopia. Block-ended furrow system is practiced in the Estate; there is no tail water loss. All the applied water would have to stay in the furrows until it finally infiltrates. As such, there is expected large amount of water percolating to the sub-soil which ultimately can lead to unproductive conditions due to water-logging and salinity particularly in heavy soils (Bishaw, 2015).

Since the establishment but there is little quantitative information about the field performance of irrigation systems. The features of field layout are a” herringbone” irrigation system which has 100 m furrow length on each side of feeder canal and 0.05 % slope. These short rows hampered the efficiency of tillage and harvesting activities (Assefa, 2011).

1.2. Statement of problem

Metahara Sugarcane Plantation is facing problems with respect to irrigation water management: reduced systems (canals and night storages) capacity due to siltation, irrigation water shortage due to high water demand in Upper Awash Basin upstream of the diversion weir of Metahara Sugarcane Factory (development of expansion and new projects) and due to decreasing capacity of Koka Dam (Tate, 2009). The Estate has faced challenges such as siltation of canals and reservoirs, waterlogging, shortage of water supply.

Water shortage has also frequently been reported that associated with siltation, the canals and reservoirs capacity are reduced. This resulted in difficulty to irrigate at required irrigation intervals. On the other hand, the irrigation schedule under use is old to fit with the existing soils, and climates, and is rigid with crop growth stages. It appears that the water management problems are getting complicated with time (Mulugeta, 2014).

The significant expansion of Lake Basaka during the past 35 years aggravated with the establishment of Metahara Sugar Estate is affecting both the groundwater dynamics and soil salinization of the nearby sugarcane plantation. If it continuous, the sustainability of the plantation itself is threaten. The future expansion of the highly saline lake may be aggravated towards the east and northeast direction due to the topography of the area. This has the potential to displace Matahara Town and impact the Sugar Plantation during the next 25-30 years. Assuming the past trends, the lake is expected to join Awash River, impacting all downstream irrigation developments in the Awash Basin, and affecting the livelihood of the people depending on the water resources of this basin (Olumana *et al*., 2009).

The Abadir Farm is located in this catchment, which has been inundated and lost income from 161.55 ha of land and some farms has been suffers from salt-water encroachment and more land is currently in danger because of the Lake Beseka expansion. Metahara Sugar Factory data indicates that the overall financial loss of the factory is estimated at Birr 190,108,627.29 for the indicated period. The flooded area of the factory sugarcane plantations was increasing, the commutative flooded area and financial loss trends from June 2000 to June 2010 (Fisehatsion *et al*., 2011).

The Sugar Estate has planned to improve the irrigation performance, uniformity, improve sustainability of the farmland and minimize water loss, through improved irrigation water management. The Estate started 2005/2006, and it utilizes flexible gated pipe (hydro- flume), without cost- benefit analyses as means of irrigation application and uses laser technology for land grading. However, the cost-benefit analyses, and improvement obtained from these technologies is not yet studied. Moreover, there is little quantitative information about the field performance of irrigation systems.

To maximize benefit from gated pipe (hydro-flume), application, water use productivity, amount of area saved, the performance of the system under gated pipe, design flow rate 5 l/s and 100 m furrow length, need study in order to confirm whether the required application performance can be attained or not its maximum application and flow rate are not yet studied.

In Metahara Sugar Estate, attempts have been made to improve the irrigation system to minimize waterlogging and water deficit in the farm as one of the measures to, maximize efficiency, uniformity, and minimize loss, improve irrigation water use management, improve sustainability of the farm, cost-benefit analyses and increase cane productivity. However, a strategy should be prepared to provide the revised irrigation scheduling and improved field water management practices based on the new soil classification. The irrigation scheme is also currently commanding less area than that was initially developed to irrigate. Hence, the probable causes for this underperformance of the scheme needed to be systematically and objectively investigated.

1.3. Objectives

The overarching goal of this research is to contribute towards enhanced water productivity in the sugarcane industry by reducing water loss along the distribution systems.

The specific objectives of this study include:

- To evaluate flow parameters (head and , discharge relationships), of hydro-flumes;
- To evaluate the technical performance of irrigation system in terms of efficiency,; uniformity and adequacy as the function of furrow length and application rate;
- To evaluate sugarcane performance as function of irrigation water application; and
- To determine the cost-benefit of hydro-flume irrigation system.

1.4. Research Questions

To address the above objectives, the following research questions are designed

1. How are flow parameter (discharge and head) varying along the length of the hydro-flume?
2. How are discharge and length of furrow affecting the performance of hydro-flume irrigation system?

3. How can we determine the effect of furrow length, slopes and flow rate on cane and sugar yield?
4. What will be the cost-benefit of hydro-flume irrigation system?

1.5. Significance of the study

The ultimate aim of this study is to generate information on furrow irrigation variables specifically, furrow length and inflow rate, and their relation with irrigation performance parameters. Improved efficiency in irrigation system design can help reduce the amount of irrigation water applied there by reducing waterlogging and salinity problems while at the same time maintaining crop water need. The findings will be used by the Estate to modernize its surface irrigation management. Metahara Sugar Plantation is affecting by waterlogging, canal conveyance efficiency, and application efficiency, and distribution uniformity, scarcity of irrigation water, system sustainability and flow rate along the furrow, pressure and water losses. It is for this reason that this research was proposed and made.

2. LITERATURE REVIEW

In this section, literature related to surface irrigation systems, evaluation of flow parameter, head and discharge relationships of hydro-flume, technical performance of irrigation system in terms of efficiency, uniformity and adequacy as the function of furrow length and application rate, evaluation of sugar cane performance as a function of irrigation water application and the cost-benefit of hydro-flume irrigation system are reviewed.

2.1. Surface Irrigation System and Processes

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. To move forward, the flowing water must have a downward slope in the direction of flow. The soil surface serves the dual role of water conveyance and distribution (Reddy, 2007). It is technique of water application over the soil surface in order to wet it, either partially or completely.

The process of surface irrigation is characterized by four phases: advance, storage, depletion, and recession phases. 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 top 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 time is termed as the wetting or storage phase. As the inflow ceases, the water will continue to runoff and infiltrate 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 (Jurriëns, 2001).

2.1.1. Furrow irrigation

Among surface irrigation methods, furrow irrigation is known to have better potential in situations where water shortage is critical. In furrow irrigation, water is conveyed in small, evenly spaced, shallow channels down or across the slope of the field to be irrigated. The amount of water loss in furrow irrigation can be extensive under farmer’s management. Water is lost in furrow as deep percolation and runoff. With furrow irrigation, moderate to high application efficiency can be obtained if good water management practice is followed and the land is properly prepared (Kebede, 2009).

Furrows are small channels, which carry water down the land slope between the crop rows. Water infiltrates into the soil as it moves along the slope. The crop is usually grown on the ridges between the furrows. This method is suitable for all row crops and for crops that cannot stand water for long periods (Abdaldafi, 2006).

An alternative to flooding the entire field surface is to construct small channels along the primary direction of water movement. Water introduced in these "furrows," "creases," or "corrugations" infiltrates through the wetted perimeter and moves vertically and laterally thereafter to refill the soil. Furrows can be used in conjunction with basins and borders, as noted earlier, to overcome topographical variation and crusting. When individual furrows are supplied water as opposed to field spreading prior to the furrows, the method will be called furrow irrigation (Walker, 2003).

Water is supplied to each furrow from the field canal, using canal breaching or by means of siphons or spiels. Sometimes, instead of supplying the field canal with siphons or spiels, a gated pipe is used. Using gated pipe systems to convey and distribute water increases on-farm irrigation efficiency, provide better irrigation control, and reduce labor costs (Tate, 2009).

Furrows provide better on-farm water management capabilities under most surface irrigation conditions. Flow rates per unit width can be substantially reduced and topographical conditions can be more severe and variable. A smaller wetted area can reduce evaporative losses on widely spaced crops. Furrows provide operational flexibility important for achieving high efficiencies for each irrigation throughout a season. It is a simple (although labor intensive) matter to adjust the furrow stream size to changing intake characteristics by simply changing the number of simultaneously supplied furrows (Walker, 2003).

According to Michael (2008), as compared to other methods of surface irrigation the furrow method has several distinct advantages: (i) Water in the furrows contacts only one-half to one-fifth of the land surface, thereby reducing pudding, and (ii) earlier cultivation is possible which distinct advantage is in heavy soil.

2.1.2. Hydro-flume

Hydro-flume irrigation is a type of surface irrigation in which the conventional main ditch and field lateral ditch or siphons are replaced by an above ground pipeline and gated pipe. Irrigation water flows from gates which are regularly spaced alone the pipeline (Micheal, 1978). Hydro-flume is available in 5 sizes; it is made of VU (ultra-violate), and thermal protected low density Polyethylene of 700 micron wall thickness for maximum service life time in hot and tropical conditions. It is flexible so that no alluvial clings to its wall. Gated pipes are portable lines with uniformly spaced outlets used for releasing irrigation water to furrows, border strips or check basins. Gated pipes are usually constructed of aluminum, light weight steel tubing or rubber materials (Micheal, 2008).The gated pipe furrow irrigation system consists of relatively large diameter pipes of about 0.46 m (18 inches), with gates usually equipped on one side and corresponding to the furrow spacing.

Hydro-flume is an option used in furrow irrigation. 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 (made of plastic or aluminum) or Flexible (made of polyethylene) with outlets to each furrow. The outlets, which can either be fixed or adjustable, are 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, 2009).

The Hydro-flume gave water saving of 25-28%, a 19-29% increase in water use efficiency and 25% of electricity energy saving compared to conventional basin irrigation. Economic analysis indicated that the PVC gated pipe system has lower investment and higher irrigation efficiency among the conventional ditches, underground pipe, aluminum gated pipe and hand move sprinkler irrigation system. Commercialization and widely extension of this gated pipe irrigation system could reduce agricultural water use (Michael, 2008). According to Alla et al, (2015), Hydro-flume compared with open field head ditch irrigation method, the Hydro-flume system for furrow irrigation can reduce the irrigation quota by 20 to 65 m^3/irrigation cycle depending on the pre-irrigation soil water content. The irrigation time saved when using open field head ditch system was ranging from 112 to 180 minutes per irrigation cycle depending on furrow length and the pre-irrigation soil water content. Hydro-flume is relatively low cost, easily transportable and requires little storage space. 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.

2.2. Variables and Parameters that Influences the Surface Irrigation Process

Surface irrigation processes are governed by general physical laws such as conservation of mass, energy, and momentum, which are expressed as a function of physical quantities, categorized the physical quantities affecting the outcomes of an irrigation event as field parameters and decision variables. Field parameters are situational data (i.e. data that describe the field situation) and are not variables as a design engineer or farmer cannot assign them another value. They are those physical quantities that measure the intrinsic physical characteristics of the system under study and hence little or no modification is practically possible. Decision variables are those physical quantities, whose magnitude can be varied, within a relatively wide band, by the irrigator during system design, management, and evaluation (Jurriëns *et al*., 2001).

2.2.1. Field parameters

The field parameters include the required amount of application (Z_r), the maximum allowable flow velocity (V_{max}), Manning's roughness coefficient (n), the field slope (S_o), the infiltration parameters (k, a and f_o, given the modified Kostiakov Lewis infiltration equation is used) (Jurriëns *et al*., 2001).

2.2.1.1. Infiltration characteristic

Infiltration is the most important process in surface irrigation. It essentially controls the amount of water entering the soil reservoir, as well as the advance and recession of the overland flow. Infiltration rate and cumulative infiltration are the two parameters commonly used in evaluating infiltration characteristics of soil, (Walker, and Skogeroboe,1987). Infiltration rate is the characteristic determining the rate at which water enters the soil vertically downwards under specific conditions (Michael, 2008).

According to Abdaldafi (2006), the infiltration rate is greater during the first irrigation event than in subsequent ones It is normally expressed in units of length per unit time or volume per unit area per unit time (e.g. cm/h, mm/h).Whereas, cumulative infiltration is the total amount of water infiltrated at any time (Michael, 1978).

Inflow-outflow methods for determining infiltration provide good measures of total infiltration (Walker, 1989). In the inflow- outflow method, the infiltration rate is determined by measuring the rates of flow into and out of a section of a furrow when the depth of flow in the furrow is changing slowly, the infiltration equals the difference between the inflow and outflow rates. Flumes or weir plates can be used for measuring inflow and outflow (Michael, 1978).

2.2.1.2. Manning’s roughness coefficient

According to Gilley and Finkner (1991), Manning’s roughness coefficient (n) is a measure of the resistance effects that flow may encounter as it moves down the furrow. It represents the effect of combined resistant force, which acts opposite to the direction of flow. The combined resistant force includes both shear and drag forces. During the irrigation, the sheer force is developed due to the uneven furrow bottom surface, whereas the drag force is developed due to the vegetation growth in the furrow (Assefa, 2011).

The value of manning’s roughness coefficient range from about 0.02 for previously irrigated and smooth soil, to about 0.04 for freshly tilled soil, to about 0.15 for conditions where dense growth obstructs the water movement. For the furrows, this roughness (n) is either calculated from a single water depth at the upstream end or set to a constant value (typically n=0.03 - 0.04). For furrows which have plant, surface roughness is a function of the plant density and plant height (Walker, 1989).

2.2.1.3. Field slopes

An initial decision as to the specific type of surface irrigation system to be utilized will limit field slope. Basins are designed without slopes in either the advance direction or across the field. Borders are similar in having zero cross-slope, but may have advance slopes of 0.05 to 0.1%, depending on crop and soil conditions. Furrow irrigation systems work well with advance slopes of 0.5 to 3 % and cross slopes of 0.5 to 1.5 %.If the average natural slopes are greater than these ranges, terraces or benches should be constructed (Walker, 2003).

The slope or grade of furrow is important because it controls the speed at which water flows down the furrow. A minimum furrow grade of 0.05 % is needed to ensure surface drainage (Michael, 1978)**.** Recommended safe limits of land slopes in furrows are 0.25 % to 0.6 % for sandy loam to sandy soils, 0.2 % for medium loam soils and 0.05 to 0.2 % clay loam soil (Abdaldafi, 2006).

For graded borders and furrows, the field slope (So) should not be too high (to prevent erosion) or too low (to prevent slow advance). The engineer may have problems ensuring the best field slopes if the cost of land grading is high or if the orientation of the fields is unfavorable. A relatively flat slope may pose drainage problems in areas of high rainfall intensity. For borders, the most suitable slopes are usually less than 0.5 %. But, if planted with sod crops, slopes up to 4 % can also work well. For furrows, suitable slopes vary between 0.05 and 1 %. Slopes up to 2 % can work for small furrows and corrugations (Jurriëns *et al*., 2001).

2.2.1.4. Design application of depths

The correct amount of water to apply-net depth of application at each irrigations varies with soil water holding capacity and soil intake rate, root depth, and soil moisture status. Gross application depends on the net application depth and application efficiency required. Flexibility to adapt irrigation depth with crop growth stages is, however, highly limited in furrow irrigation and even in sprinkler irrigation methods like drag line sprinklers (Mulugeta and Bishaw, 2014).

Each irrigation designed to apply a depth of water to the soil that replaces the water already extracted by the crop .The user can enter either required depth or intake opportunity time and the other variable will be automatically computed. Increasing the required depth of application will generally improve application efficiency but also increase the duration of the irrigation. Large depths imply longer periods between irrigations and thus increase the risk of crop stress (Walker, 2003).

The application depth is estimated after observing three irrigation events in each farm. Infield one, the farmer applied 86.1 mm, 73.54 mm and 79.54 mm of water at 1st, 2nd, and 3rd irrigation periods respectively. This indicates that daily workers lack of knowledge of water application depth and requires skill of irrigation scheduling. Application depth is one of important indicators in evaluation of water management in every irrigation systems. It is dependent on the physical characteristics of the soil under irrigation. The depth of application per irrigation is the amount of water added to the root zone in one irrigation event (Mamo and Wolde, 2015).

2.3. Decision variables

Whereas the decision variables have a given value for a given location, the design and decision maker is able to play with a restricted number of system variables, within a relatively wide range, in order to optimize the design or management of the system. The main design and management variables are the unit flow rate (Q_0) 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 *et al*., 2001).

2.3.1. Inflow rate

Like furrow length, L, flow rate is a variable whose value can be fixed by the engineer at the design phase or prior to or following the initiation of every irrigation such that system performance is maximized. The inlet flow 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. Moreover, in case of border irrigation unit flow rate must exceed a certain minimum value which is needed for adequate spread (Jurriëns *et al*., 2001).

Flow rate of 2.7 l/s is practically not suitable for 70 m blocked furrow in 0.2 % slope due to overflow at the end of the furrow. Flow rate of 0.3 l/s permits more application depth with good uniformity at 70 m furrow length with 0.2 % slope but its maximum attainable application efficiency is less than that of 0.4 l/s inflow rate in 3 % slope. Flow rate of 1.1 l/s gives maximum uniformity with the limitation of 22 mm average depth of application and less maximum attainable application efficiency compared to other flow rates. But recommendations of inflow rates are made based on both application efficiency and uniformity (Narayana and Abate, 2014).

2.3.2. Furrow length

The optimum length of a furrow is usually the longest furrow that can be safely and efficiently irrigated. Proper furrow length depends largely on the hydraulic conductivity of the soil. The length of furrow which can be efficiently irrigated may be as short as 45 m for irrigating soils which take up water rapidly, or as much as 300 m or longer on soils with low in filtration rates (Michael, 2008). Solomon (1998) stated that optimal furrow length is primarily controlled by the intake rate of the soil and the stream size.

The existing operational furrow length at Koga is extremely long which lead to very low application efficiency. With the test furrow length of 90 to 110 m, it can be concluded that the irrigation application time per furrow was extremely long and difficult to establish appropriate irrigation operation rules among users for the whole scheme. The illustration of advance time by length graphs revealed that optimum furrow length at different sites can only be possible at short application time. In order to maximize application efficiency and minimize the losses, examining and determining an optimum furrow length before the operation of the whole scheme is essential by doing performance evaluation at different furrow lengths and application time (Desta *et al*., 2013).

Furrow length and application time the most important factors affecting efficiency in furrow irrigation. Under given soil condition, when the furrow length is short, surface runoff increases; if furrows are long, then deep percolation loss increases. From the point of view of farming practices, longer furrows are recommended. Longer furrows allow good mechanization and limit the land area to be occupied by farm channels and drains. On the other hand, shorter furrow lengths will make mechanization difficult and requires close attention in changing flow from one to the next furrow (Assefa, 2011).

2.3.3. Cutoff time

Cutoff time (Tco) is the amount of time that elapses from the start of irrigation to the cutoff of the inflow. In simulations, cutoff time can be either input or output, as with the other decision variables. Cutoff for all three irrigation methods occurs usually sometime after the end of the advance time so as to obtain infiltration to the required depth at the downstream end of the field. If cutoff time is substantially later than advance time, this will have a clear effect on the deep percolation and surface runoff losses. If cutoff occurs too early, infiltration to the required depth will often not happen at the end of the field. So, clearly, there are limits to the value that you can choose for the cutoff time, to achieve good irrigation performance (Jurriëns *et al.*, 2001).

Cutoff time is the time at which the supply is turned off, measured from the onset of irrigation. It is one of the three variables, the other two being L and Q_0, over which the engineer and irrigator has a degree of control. Cutoff time has no impact on advance as long as the latter is taken equal or larger than the advance time. Cutoff time, however, has an influence on recession. The most important effect of cutoff time is reflected on the amount of losses, deep percolation and surface runoff, and hence efficiency as well as adequacy of irrigation. In general for any given factor level combination the selection of an appropriate value of t_{co} is made on the basis of the target application depth and acceptable level of deficit (Assefa, 2011).

In clay soils cutoff ratio of 0.85 in steeply sloping fields (1 %) to 0.95 in low sloping fields (0.1 %) can be used, which is roughly equivalent to cutting off the inflow when the water front strike the end of the furrow and bounced back for a length of 5 and 15 % of the furrow length, for respective 0.1 % and 1 % slope in clay soils. For 100 m furrow cut off when water front strike furrow end and bounced back for 5 m and 15 m for 0.1 % and 1 % slopes, respectively (Yonts and Eisenhauer, 2007).

2.3.4. Crop water requirement and irrigation scheduling

The term crop water requirement is defined as the amount of water required to compensate the evapotranspiration loss from the cropped field. Although the values for crop   and crop water requirement are identical; crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration (Allen *et al*., 1998).

The crop water demand described above may be satisfied by rainfall or soil moisture. Whenever the amount of available water drops below the crop water demand, irrigation is needed. The irrigation requirement is thus the difference between the crop water requirement and the effective rainfall (Laycock, 2007).

The purpose of irrigation scheduling is to maintain a good soil moisture status in the root zone reservoir and thereby provide near optimum environmental conditions for crop growth. Traditionally, irrigation scheduling is considered as a decision-making process used by irrigators to decide when to irrigate their crops and determine the appropriate quantity of water to apply. One purpose of irrigation scheduling is to determine when to irrigate. Irrigations should occur at intervals such that crop yield is not adversely affected by insufficient soil moisture. For furrow, flood, and sprinkler irrigation methods, the irrigation interval depends on potential evapotranspiration, soil type, and allowable depletions. A second purpose of irrigation scheduling is determining the amount of water to be applied. The amount of water applied is determined by using a criterion to determine irrigation need and a strategy to prescribe how much water to apply in any situation (Abdaldafi, 2006).

Intervals between irrigations vary with soil, season, and crop growth phase. It is shorter in light soils and medium in heavy soils during growth. Irrigation interval shortens also during dry season. Irrigation interval that can be achieved is highly dependent on irrigation method, system water delivery capacity, and flexibility and manageability of the field application system. However, having considered that any such limitations would be mitigated (Mulugeta, 2014).

2.4. Irrigation efficiency

According to Cuenca (1989), in discussing any type of irrigation system, it is useful to have concepts of efficiency to enable comparison of different systems or different management strategies for a particular system. There have been over 20 different ways of quantifying efficiency proposed for irrigation systems. Most of these methods are useful, although some appear more cumbersome or abstract than others (Mekonnen ,2009).

According to Zerihun *et al.* (1997), performance terms measure how close irrigation, is to an ideal one. An ideal or reference irrigation is one that can apply the right amount of water over the entire region of interest without loss. Excess application of irrigation water though unavoidable in a real life situation, must be minimized. Application efficiency, water storage efficiency and distribution uniformity are irrigation performance indices and the runoff loss which represent that part of the applied water that has left the subject region as surface runoff and deep percolation loss which represents that portion of the irrigation water loss that is attributed to percolation below the bottom boundary of the subject region are irrigation water loss indicators (Kebede, 2009).

According to Holzapfel *et al*. (1985), the performance of an irrigation method can be evaluated by determining how well the irrigation meets the water requirements and how well the applied water is distributed throughout the field. Water applied for irrigation should: (1) meet the plant water requirements at the time of irrigation; (2) not exceed the available water-storage capacity of the soil profile; (3) avoid leaching in excess of that required to prevent soil salinization and excessive runoff; and (4) minimize erosion and deterioration of the soil structure. On the other hand the performance of an irrigation method is affected by: (1) rate of infiltration of water into the soil; (2) inflow rate of the water; slope of the field; (3) time of irrigation; (4) time of recession of water from the soil surface; (5) soil moisture prior to irrigation; (6) spatial variability of the soil; (7) climatic conditions; and (8) furrow shape.

2.4.1. Conveyance efficiency

According to FAO (1989)**,** the conveyance efficiency (Ec) mainly depends on the length of the canals, the soil type or Permeability of the canal banks and the condition of the canals. In large irrigation schemes, more water is lost than in small schemes due to a longer canal system. From canals in sandy soils, more water is lost than from canals in heavy clay soils. When canals are lined with bricks, plastic or concrete, only very little water is lost.If canals are badly maintained, bund breaks are not repaired properly and rats dig holes, a lot of water is lost (Mekonnen, 2009).

Canal seepage varies with the nature of the canal lining; hydraulic conductivity; the hydraulic gradient between the canal and the surrounding land; resistance layer at the canal perimeter; water depth; flow velocity; and sediment load.

In Egypt, canal tail losses are estimated to account for 25-50 % of the total water losses in irrigation. It is expected that operational losses can be reduced significantly when measures such as automatic controls and night storage are introduced (FAO, 2002).

According to FAO (1989), Table 1 provides some indicative values of the conveyance efficiency (Ec), considering the length of the canals and the soil type in which the canals are dug. The level of maintenance is not taken into consideration: bad maintenance may lower the values of Table 1 by as much as 50 % (Mekonnen, 2009).

Table 1. Indicative values of the conveyance efficiency (Ec, %) for adequately maintained canals

Canal length	Unlined canal on			Lined canal
	Sandy soil	Loam soil	Clay soil	
Length (>2000m)	60	70	80	95
Medium(200 – 2000m)	70	75	85	95
Short(<200m)	80	85	90	95

Source: (FAO , 1989).

2.4.2. Application efficiency

After the water reaches the field supply channel, it is important to apply the water as efficiently as possible. A measure of how efficiently this was done is the application Efficiency (E_a). One very common measure of on farm irrigation efficiency is E_a. That shows how much of the water applied to the crop is actually used for crop growth or other beneficial uses. Losses from the field occur as deep percolation and as field tail water or runoff and reduce the E_a (Gebre-Egziabiher, 2013).

2.5. Uniformity

2.5.1. DistributionUniformity

Water distribution efficiency, under cutback system, increased as the initial inflow rate increased. Water distribution efficiency increased from 87.54 % to 89.74 % as the initial inflow rate increased from 1.7 l/s to 1.9 l/s and from 89.74 % to 91.46 % as the initial inflow rate increased from 1.9 l/s to 2.2 l/s for 220 m length of furrow.Water distribution efficiency, under cut-back system, also increased as the furrow length decreased. Water distribution efficiency increased from 91.46 % to 92.87 % as the length of initial application decreased from 220 m to 200 m and from 92.87 % to 95.34 % as the length of initial (Mohammed *et al*., 2006).

According to FAO (1989), distribution uniformity is the most commonly used uniformity index in surface irrigation application. Soil moisture stored at the effective root zone of the crops fields are 91.25 % and 86.16 %which is below 100 % and show entire field receives non uniform depth of water. The values of DU found within the acceptable limits, which is 80 % .The DUs are better than the value of 70 % that was found Pitts *et al*. (2001), in the irrigations systems of Western United States.

When water is applied to the field, how uniformly it is distributed over the field needs to be assessed as this factor determines the yield of the crop Pitts (2001), noted that a highly uniform water application does not ensure high efficiency since water can be uniformly under or over-applied. However, itis noted that a highly efficient system along with good crop yields requires uniform water applications. Solomon (1998), states that the phrase ‘irrigation uniformity’ refers to the variation or non-uniformity in the amounts of water applied to locations within the wetted area. Uniformity is related to crop yields through the agronomic effects of under and over watering.

2.5.2. Adequacy of irrigation (Water storage efficiency)

The storage efficiency is an index used to measure irrigation adequacy. It is the ratio of the quantity of water stored in the root zone during irrigation event to that actually applied to the field. Due to spatial variability of the term it was lately replaced by another term, the uniformity index. The spatial uniformity of irrigation water application provides an indication of adequacy of storage over the area.

Based on the FC (field capacity), PWP (permanent wilting point), and BD (bulk density) of soils of the selected irrigation fields and the root depth of the crop irrigated, the depth of irrigation water required to fill the root zone to field capacity level (Dreq) can be calculated. The water requirement (storage) efficiency (Es) 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 becomes important when water supplies are limit. This parameter is the most directly related to the crop yield since it will reflect the degree of soil moisture stress. Usually, under irrigation in high probability rainfall areas is a good practice to conserve water but the degree of under-irrigation is a difficult question at the farm level (Walker, 2003).

Adequacy of irrigation turn in terms of storage efficiency and the purpose of an irrigation turn are 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 runoff or tail water the uniformity of the applied water, and the remaining deficit or under irrigation within the soil profile following irrigation. The water storage efficiency refers how completely the water needed prior to irrigation has been stored in the root zone during irrigation (Jurriëns, 2001).

2.6. Irrigation water loss indicators

Surface irrigation losses include runoff, deep percolation, ground evaporation and surface water evaporation (Solomon, 1998). Runoff losses can be significant if tail water is not controlled and reused. Although use of tail water reuse pits could generally increase surface application efficiency, many surface irrigators use a blocked furrow to prevent runoff. Usually the lower portion of the field is leveled to redistribute the tail water over that portion. While runoff may be reduced to near zero, deep percolation losses may still be high with this practice.

To improve the performance of a surface irrigation system, the measures of uniformity and efficiency may need to be more qualitative. DU gives minimal information about the magnitudes of losses or under-irrigation. Ea does not allow the engineer to segregate deep percolation losses from tail water losses and it is difficult to assess the degree of under-irrigation. Since these items are important, deep percolation ratio (DPR) and tail water ratio (TWR) are proposed as an additional indicator (Walker, 2003).

Evaluation of the irrigation scheme considered the amount of water lost from the field during irrigation applications of the farm. The water applied to fields was lost in the form of evaporation, runoff and deep percolation. The evaporation loss was accounted as ET of the crop. But the relative amounts of runoff and deep percolation losses were estimated through runoff ratio and deep percolation fraction, respectively. Evaluation of these losses is essential for identifying the loss that is primarily contributing to the low efficiency (Mekonnen, 2009).

2.6.1. Runoff ratio

Runoff from over-irrigation in the field can be a serious source of wastage. Surface irrigation of dry foot crops is often imprecise and difficult, unless the land is very carefully prepared beforehand. It's quite common to find the drains running as hill as the canals, so it's a good idea to look at the drains first in any inspection. If they are full then look for problems of over-irrigation or careless canal operation (Laycock, 2007). Runoff Ratio (RR) or tail water ratio (TWR) has been formulated to describe the proportion of water lost as runoff from the field. It is defined as the ratio between the depths of water lost as runoff to the depth of water applied to the field.

2.6.2. Deep percolation ratio

Estimates for deep percolation have been made on the basis of the following assumptions: no surface runoff occurs under drip and sprinkler irrigation; during daytime sprinkler irrigation evaporation losses can be up to 10 % and during night irrigation 5 %; tail water in furrow and border irrigation can be up to 10 % and evaporation losses up to 5 %; and no runoff occurs in basin irrigation and evaporation losses can be up to 5 % (Kenneth *et al*., 2002).

Deep percolation losses occur in the field when irrigation water goes below the root zone and is lost to the plant. When applying water by surface irrigation methods, it can be difficult to get an even distribution of water across the field. In order to get enough water to the end of the field it may be necessary to put too much on at the start of the field, and excessive percolation loss is the result. Similarly, an irrigation application discharge that is too small can lead to excessive percolation loss due to the long travel time across the field. For this reason, the design duty of field channels needs a lower limit of about 20 1/s in order to get a practical size of field application. Furrow and border strip applications are often given a heavy initial application which is then cut back by reducing the inflow when the advance wave has reached about two-thirds of the length of the field (Laycock, 2007).

According to Ley and Clyma (1981), the acceptable value of deep percolation for furrow irrigation is less than 10 %. However, their study on several furrow irrigation systems in Northern Colorado found out that the deep percolation ratios ranged from 0 % to 57 % with a median having no deep percolation.

2.6.3. Sustainability of irrigation system

Within the irrigated area, several negative impacts (waterlogging, expansion of the effect of saline lakes, expansion of small scale community farm and water shortage due to competition) cause a reduction of the (actually) irrigated area. A further reduction of the irrigated area is related with population growth and the related urbanization, road construction, etc. Aspects of physical sustainability (of the irrigated area) that can be affected by irrigation managers relate primarily to over- or under-supply of irrigation water leading to waterlogging or salinity, According to Bo’s (1997), the trend of sustainability of an irrigation scheme could be measured dividing the current irrigated area by the initial irrigated area when the system was first fully developed. A trend toward reduced area generally indicates that the system is not sustainable.

If area has increased significantly from the designed area, it may indicate that the water supply is now distributed over too much land, or delivery capacities are being exceeded. The current irrigated area must be updated periodically to reflect the actual situation on the land. If irrigable land is not being irrigated, that can also indicate a problem, such as an undependable water supply (Nelson, 2002).

2.7. Sugarcane

Sugarcane, *Saccharum off icinarum,* is a grass family, *gramineae*, characterized by segmented stems, blade like-leaves, and reproduced by stem (Sundara, 2000). It being a long duration crop producing huge amounts of biomass is classed among those plants having a high water requirement and yet it is drought tolerant. Most of the rain fed and irrigated commercial sugarcane is grown between 35°N and 35°S of the equator. The crop flourishes under a long, warm growing season with a high incidence of radiation and adequate moisture, followed by a dry, sunny and fairly cool but frost-free ripening and harvesting period. According to FAO (2003), sugarcane occupies an area of 20.42 million ha with a total production of 1333 million metric tons worldwide. The plant crop season is 12-18 months in India, 13-14 months in Iran, 16 months in Mauritius, 13-19 months in Jamaica, 15 months in Queensland (Australia) and 20 - 24 months in Hawaii (FAO, 2003) while 18-24 months in Ethiopia.

2.8. Benefits of Hydro- flume irrigation system

Selecting appropriate methods of irrigation and improved irrigation management is obviously a suitable solution to have sustainable water production. Furthermore, on a wide scale, it can save the amount of water energy and other agricultural inputs. Hydro-flume system is a supplement for surface irrigation that can save 30 to 35 % of water in 1950. This system was used in the United States to increase water use efficiency and uniformity of surface irrigation. In Iran, the first time agro-industry company used it in pilot scale in 1980 (Alla *et al*., 2014).

Water conveyance with the traditional method using ditch has a low efficiency. This kind of conveyance causes a significant decrease in water amount along the path. Implementation of hydro-flume method on farms can prevent water wasting. Estate farm had to put fallow same parts due to water logging and water shortage. In the traditional irrigation methods, a large amount of water is lost due to evaporation and seepage and deep percolation in canals and ditches path. Using hydro flume pipe, it can be possible to increase water efficiency more than 70 %; therefore, the hydro-flume method is a simple solution and cost effective way to improve surface irrigation method (Alla *et al*., 2014)

2.8.1. Increasing Water Productivity and land saving by using Hydro-Flume

This method is more effective in fields far from water source, because it can improve water Conveyance efficiency. So farmers are able to cultivate more lands. The lands under cultivation increased about 20 % to 200 % more than before (Alla *et al*., 2009).Increase in land under cultivation means increase in crop production. Crop production and water production can be increased, so that water production is increased about 6.7 % to 80 % more than before. Also, it is considered that the shape of the fields and soil texture can effect on water production by using hydro-flume method. Water production is considerably increased in light texture soil. Overall, the use of hydro-flume in all case study fields increased, but it was more noticeable in land with long water conveyance path because of saving water from evaporation (Alla *et al.*, 2014).

On the other hand, according to Joulazadeh, and Kamali (2011), about 30 % of water, 50 % of labor, 40 % fertilizers and 10 % of land are saved in hydro-flume method compared with traditional methods. Hydro-flume pipes are made of low density polyethylene. Its diameter ranges from 50 to 450 mm. The pipe is simply placed on land and easily connects to any water source, such as pond, well or water channels. It can work with low pressure. There is no impact on applications even if water contains insoluble materials. Hydro-flume pipes can also convey muddy water for irrigation. According to the high hydro-flume resistance against chemicals, it is possible to use fertilizer.

The gated pipe (hydro-flume), gave water saving of 25-28 %, a 19-29 % increase in water use efficiency and 25 % of electricity energy saving compared to conventional basin irrigation. Economic analysis indicated that the PVC gated pipe system has lower investment and higher irrigation efficiency among the conventional ditches, underground pipe, aluminum gated pipe and hand move sprinkler irrigation system. Commercialization and widely extension of this gated pipe irrigation system could reduce agricultural water use (Micheal, 2008).

Improve the water conveyance efficiency: The gated pipe system uses the solid aluminum pipeline to deliver water from the source (riser) to the field boundary, so there is nearly no water loss like seepage and evaporation.

Better distribution uniformity: The uniformity for surface irrigation system is more commonly characterized by the distribution uniformity, and it is a main parameter to evaluate a system.

Water, irrigation time and energy saving: Compared with conventional basin and border strip method, the gated pipe system can reduce the irrigation quota, save time and energy and irrigation water infiltration depth in root zone (Micheal, 2008).

The gated-pipe system of irrigation has a higher value of application efficiency (Ea) (79 % and 88 %) compared with the Ea of the open field head ditch (69 % and71 %).The percent of deep percolation (PDP) for the gated-pipe system is greater than the PDP obtained under open field head ditch irrigation. This is mainly due to the fact that the deep percolation of the soil moisture at infiltration depth below the effective root zone depth at the top of the 11 furrows irrigated by gated pipe was mainly due to the low inflow rate (3 to 4 l/s) and the long irrigation time required to refill the root zone at the field end. The present research also revealed that the percent of runoff (PRO) was higher under the open field head ditch system (20 – 31%) compared with the gated-pipe irrigation system (5 – 9 %). CU for the gated pipe and the open field head ditch methods were equal to 70 – 76 % and 79 % respectively. The low value of CU was mainly due to the longer contact time which leads to spatial and temporal variations of the soil moisture distribution which is more evident at the top part and along the field irrigated with gated pipe (Alla *et al*., 2009).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Geographical location

Metahara Sugar Estate is located about 200 km south east of Addis Ababa along the Addis - Dire Dawa road within the Upper Awash Valley. It is a large state-owned agro industrial company, which was established in late 1960’s .Geographically, it is situated at 8°50’N and 39°55’E.The establishment date of the Metahara Sugar Factory goes back as far as 1965, the time when the Dutch company, named as Hangler Vondr Amsterdam (HVA) had surveyed the area for sisal development. The increasing demand for sugar in Ethiopia and the suitability of the land and climate for sugarcane cultivation attracted HVA to extend the sugar industry to the Metahara Plain. As a result in July 1965 an agreement was signed between the Ethiopian Government and HVA under which the company acquired a concession of 11,000 ha of land. Subsequent to the signing of the agreement, sugarcane cultivation started in 1966. The factory started producing white sugar on November 9, 1969 with an initial crushing capacity of 1,700 tons of cane per day (TCD). Since then, the factory had undergone successive phases of expansion. The first expansion was made in 1973 to raise the crushing capacity of the factory to 2,450 TCD. The enterprise was nationalized in 1975 and organized under the Ethiopian Sugar Corporation. The second and third phases of expansion took place in 1976 and 1981, which raised crushing capacity to 3,000 and 5,000 TCD (Awulachew *et al*., 2007).

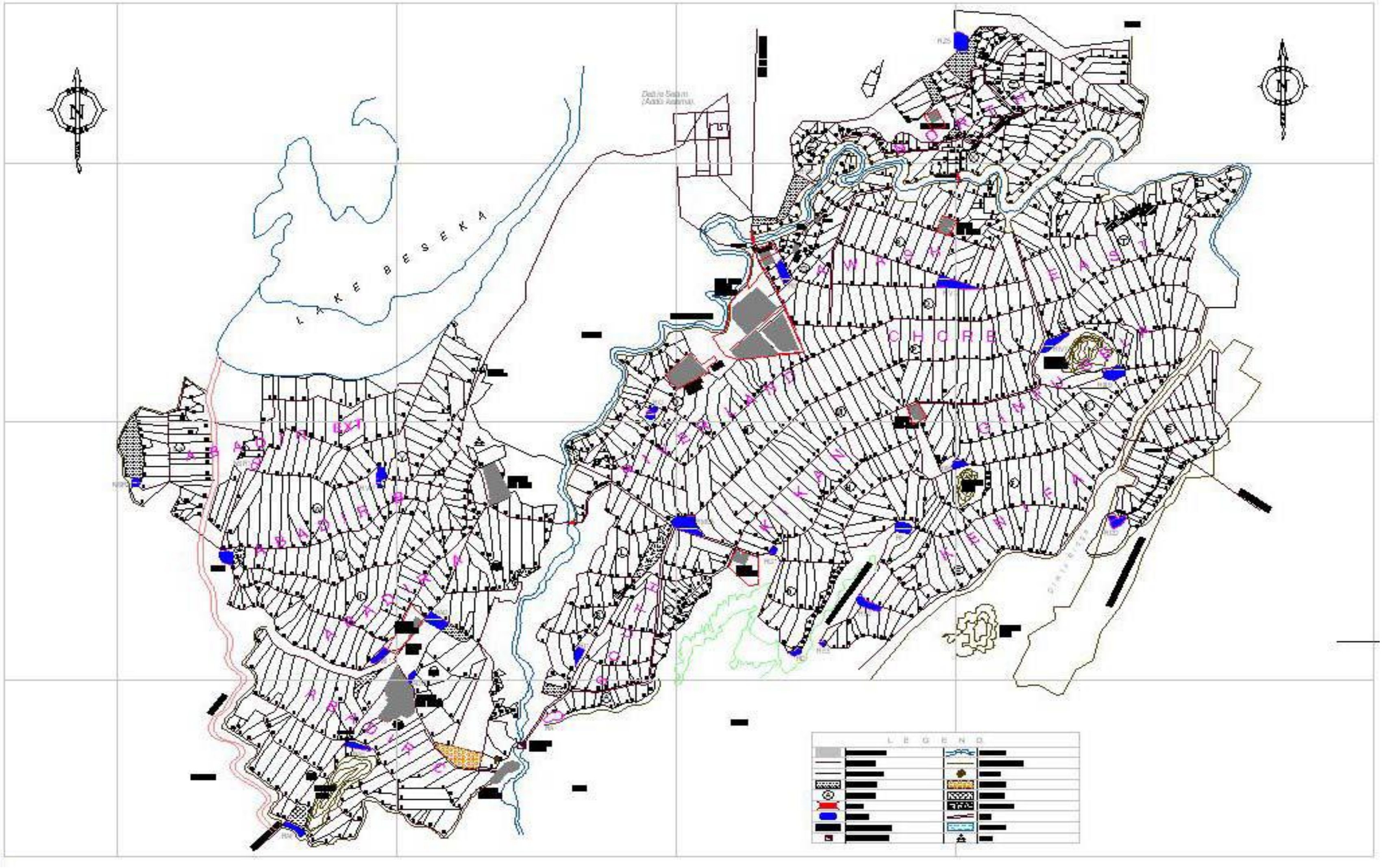

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Figure 1. MSF plantation layout of irrigation blocks and fields

3.1.2. Climate

Metahara, with an altitude of 950 meters above sea level, has a semi-arid climatic condition with a bimodal rainy nature. The area is experiencing on average 610 mm of annual rainfall. The main rainy season is from mid-June to mid-September which accounts for more than 50 % of the annual rainfall while there is small rainy season which occurs from March to May. The average annual effective rainfall and the average pan evaporation of the area are 543 mm and 5.4 mm/day, respectively. The maximum and minimum relative humidity is 67 and 52.8 %, respectively. The mean annual maximum and minimum temperatures are 33.54 and 17.82°C, respectively (Tate, 2009). The hottest period of the year extends from March to June whereas the coldest period extends from September to January.

3.1.3. Soil of the area

Soils of Metahara Sugar Estate were classified into six soil classes: class 1, class 2, class 3, class 4, and class 5 and class 6, (Bishaw, 2015). But Tate (2009) recommends four soil classes for Metahara Sugar Estate instead of existing six classes to be used for irrigation planning. These are heavy (vertic) clay (V); clays (C), clay over loamy (CL); loamy (L) and sandy, very gravelly, pumice.

3.1.4. Irrigation Practice

Water for irrigation and factory is taken in by means of a structure on the Awash River upstream of the estate. Irrigation water is abstracted through two weirs constructed across Awash River with a total discharge of 12 m^3/s (i.e. 8 m^3/s weir at Merti and 4 m^3/s weir at Abadir).From the total plantation area about 7,000 ha is found in the Merti side and about 3, 000 ha is found in the Abadir side. The water is distributed in the plantation area by a gravity system. Night storage reservoirs are included in the system. There are also 3 electrically driven pumping stations in the estate to provide water to areas which are situated too high for gravity irrigation. From these, two are located in Merti side and one in Abadir side. The Estate uses irrigation for 9 to 10 months except July, August and September depending on the weather condition. The conveyance system includes main canal, branches, distributaries (diversion boxes), reservoirs, laterals, sub-laterals, feeder ditches, plastic siphons, and hydro-flumes and furrows (Bishaw, 2015).

3.1.5. Water sources and abstraction

The source of water for the irrigation project is the Awash River. A number of large scale and medium scale state owned commercial irrigation farms in the country are receiving water for irrigation from this river. The Awash River is diverted to the canal by constructing a diversion wall at a location where there is small natural protruding land in the river. The diverted water is then blocked by a weir near the main gate to raise the head of the water in the canal.

Figure 2. Diversion weir and head regulator at Metahara Sugar Plantation

3.2. Field Layout and Experimental Setting

3.2.1. Site selection

Regarding longitudinal slopes, cane fields of Metahara Sugar Factory are categorized as flat (0.5 to 1.0 %) and steep (>1.5 %) slopes. Three representative fields for pressure and discharge relationship determination of pipe out lets, field application of irrigation water, the effect of water logging on sustainability of Estate farm, crop water requirements and scheduling, cane performance as function of application rate, and comparative performance evaluation of open earthen ditch versus hydro-flume were selected and evaluated.

3.2.2. Experimental set up

In order to examine water distribution uniformity along the outlets of gated pipes, each of the selected field was divided into three; upstream, middle and downstream reaches based on their proximity from the inlet box of the pipe. From each compartment three irrigation set were selected to conduct the measurement. Irrigation set comprising 40 pairs of outlets on the opposite sides of the pipe, of which 20 are open at a time while the remains 20 pairs were used for maintaining uniform flow and pressure throughout the measurement. The outlets were numbered from one to twenty starting from the guider (guider is a clamp used as a check dam at each irrigation set located at downstream of the pipe) to the upstream. Hence, labeling of the outlet near the guider was identified as number 1 and the outlet at the upstream numbered 20.

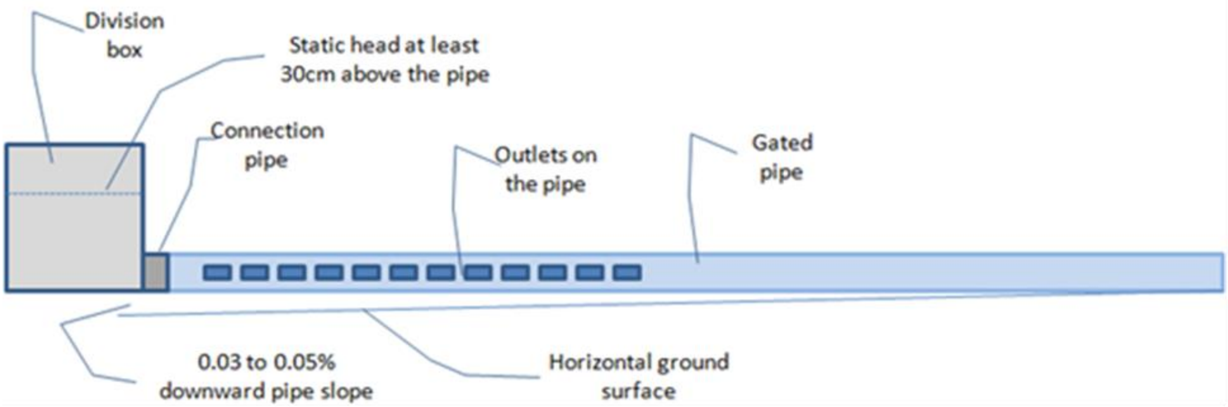

Figure 3. Schematic diagram and slope of hydro-flume

To evaluate design parameters, field Q_5 was selected. The dimension of the field is 500 m by 100 m with an average longitudinal and lateral slope of 0.35 and 0.05 %, respectively. Then field was divided into six equal sized plots i.e. 90 m by 100 m. These plots were randomly assigned for the design slopes. Each plot was separately leveled as per the required lateral slopes for each replication. Each plot was divided into three sets consisting of seventeen furrows spacing 1.45 m apart. For the treatments, furrow length was randomly assigned for each furrow set. Each furrow set was also divided into three sub-sets consisting of five furrows each. Flow rate treatments were assigned to the sub-sets randomly. The middle three furrows were used for monitoring irrigation events and the outer furrows used as a buffer.

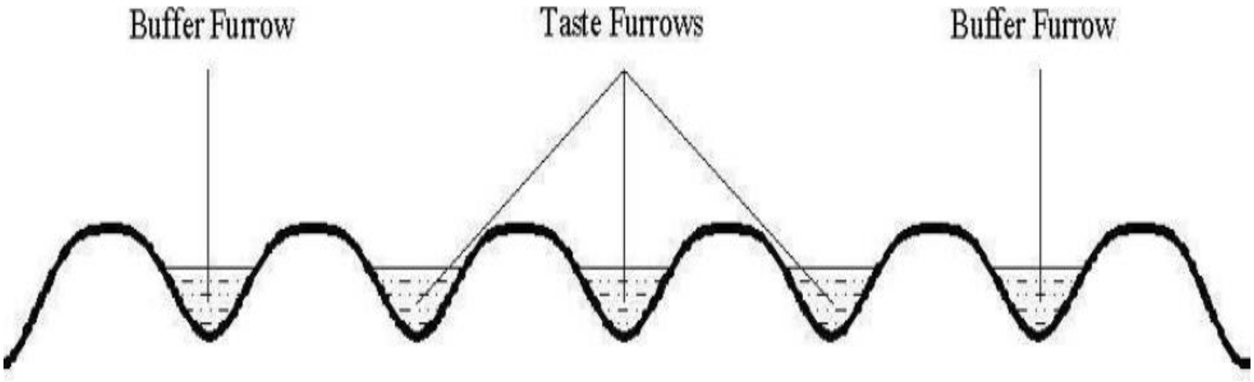

Figure 4. Schematic diagram of the experimental lay out

3.3. Data Analysis

3.3.1. Determination of outlet Discharges and Pressure Heads

To examine water distribution uniformity under fixed outlet area along the length of a pipe and to determine pressure vs outlet discharge relations (under various outlet areas), flexible gated pipe with 425 mm internal diameter and 100 m length is used. The pipe was equipped with the some flow rate of the all outlets. The outlets were located at approximately 1.45 m spacing which is similar to furrow spacing and had a circular shape of 38 mm diameter when fully open. It is a gravity flow system which requires a minimum of 150 mm water head at the inlet (water source).

Both pressure and discharge were measured simultaneously starting from outlet number one to within 20 m interval of the experimental fields. Pressure was measured within 20 m interval of furrow using a tube with a floater. The floater is tied on string which is marked at the length equal to the tube length. During measurement the floater moves up and the string moves down on the tube. The distance between the marked point and the tube end was measured as the pressure head at the outlet. Discharge was measured within 20 m interval at each out let using volumetric method. Discharge is collected for fixed time (five second) and the collected water is measured using measuring cylinders.

3.3.2. Soil analysis

Soils in the experimental area were studied to characterize selected soil physical and chemical properties. Soil samples at two soil depths, 0-30 and 30-60 cm were taken from six random spots from the experimental plots. The composite samples were analyzed for soil texture, field capacity (FC), permanent wilting point (PWP), soil pH, electrical conductivity (EC) and organic carbon (OC) using standard procedures.

Soil texture analysis, determination of bulk density, pH, EC and OC were carried out at Sugar Corporation Research Directorate soil laboratory. The percentage of sand, silt and clay of the composite soil sample were determined by sieve analysis (sand and silt) and hydrometer method (clay).

Soil bulk density (g/cm^3) was determined by the methodology described in undisturbed soil samples were taken at two depths, 0-30 and 30-60 cm, using core samplers of known volume and the samples were weighed and placed in an oven at 105 ^0C for 24 hrs. After 24 hrs.' the oven dried soil was weighed, and then bulk density was calculated. The soil water content at field capacity and wilting point were determined in laboratory using the pressure plate apparatus at -1/3 and -15 arm suction pressure, respectively. Total available water (TAW) is the difference between field capacity (F_c) and permanent-wilting point (PWP) on volume basis moisture contents. It computed using (equation 1) (Walker, 2003)

$$\mathrm{TAW} = (\theta_{\mathrm{FC}} - \theta_{\mathrm{PWP}}) \tag{1}$$

Where;

TAW = Total available soil moisture (mm/m), θ_{Fc}= volumetric soil moisture at field capacity mm/m) and θ_{PWP} = volumetric soil moisture at the permanent wilting point (mm/m)

The design net application depth (readily available water) was estimated using (equation 2)

$$Z_n = RAW = TAW \times P \times R_D \tag{2}$$

Where; Zn = net depth of application P = the allowable depletion. The average value is 0.65 (Michael, 2008), and R_D = effective rooting depth

3.3.3. Determination of bed slope (So)

The bed slope of furrows should be known in order to estimate the maximum non-erosive flow rate. Though slope (S_o) of furrows determined during leveling, it was checked using line level by measuring at 10 m interval.

3.3.4. Maximum allowable flow velocity (V_{max}) and flow rate

It is used to estimate the maximum flow rate (Q_{max}) that can be turned on into the furrows without causing soil erosion. The value of V_{max} depends on soil type and varies in the range of 8 m/min for erodible silt to 13 m/min for stable clay and sandy soils, respectively.

The maximum value of flow rate (Q_{max}) without causing erosion (non-erosive flow rate) computed with the empirical relationship (equation 3) (Cuenca, 1989).

$$Q_{max} = \left(\frac{0.6}{S_o}\right) \tag{3}$$

Where;

Q_{max} = Maximum non-erosive flow rate (l/s)

S_o= furrow slope in the direction of flow (m/m)

3.3.5. Soil moisture determination

Soil moisture was determined gravimetrically. Soil samples were augured from successive stations along the furrows. The soil samples were taken at 0.3 m increments from the soil surface to a depth of 0.6 m before hilling up and three days and after hilling up irrigation. Soil samples oven dried at 105˚C-110˚C for 24 hours, then weighted to determine moisture content as percentage on dry mass basis. Soil moisture measurement for the purpose of performance evaluation was done as follows. Soil moisture samples before irrigation were taken at 20 m interval along the furrow length (L) from each plot at two depths, 0-30 cm and 30-60 cm, using soil auger. Moisture content was calculated using (equation4) (Michael 2008):

$$W = \frac{W_m - W_d}{W_d} \tag{4}$$

Where;

W = soil water content on a dry weight basis (%), W_m = Weight of moist soil (g) and W_d = Weight of oven dried soil (g)

To convert moisture content on dry mass basis as percentage to moisture content on volume basis as percentage and depth basis (cm/m depth) the corresponding bulk density was multiplied by moisture content on mass basis (equation 5) (Walker, 2003).

$$\theta=\gamma bW \tag{5}$$

Where;

θ = Soil water content on a volume basis in percent, and ρ_b = bulk density in gm/cm^3

3.3.6. Manning's roughness coefficient

For this study, the Manning roughness coefficient which is 0.1 and 0.04 were used for before and after hilling up irrigation events (Walker, 1989).

3.3.7. Determination of infiltration

In two point method the selected furrows from each slope, furrow length and discharge were used for the determination of this parameter. The time to advance the mid distance and end of the furrow were recorded and the parameters were determined.

In the inflow- outflow method the infiltration rate is determined by measuring the rates of flow into and out of a section of a furrow when the depth of flow in the furrow is changing slowly, the infiltration equals the difference between the inflow and outflow rates. Flumes were used to measure or weir plates can be used for measuring inflow and outflow (Micheal, 1978), of the simplest techniques is to use small flumes at the head and tail of a furrow length. The greatest concern relates to the amount of backwater resulting from the downstream flume, which would result in more water intake than under normal operating conditions. To alleviate the backwater resulting from installing a constriction in the furrow, the outflow can be measured volumetrically (Walker, 2003).The empirical fitting parameters k and a, were found to be 0.04 and 0.26 for after hilling-up and 0.058 and 0.12 for before hilling-up irrigation events respectively (equations 6). Based on the data, the cumulative infiltration equation was derived from equations of inflow and out flow (Assefa, 2011).

$$Z = 0.04\, t^{0.26} + 0.0000212t \qquad \text{after hilling up irrigation event and} \qquad (6)$$

$$Z = 0.058\, t^{0.12} + 0.0000212t \qquad \text{before hilling up irrigation event}$$

Where,

Z = depth of water infiltrated (mm) and
t = infiltration opportunity time (min).

3.3.8. The required depth of application

The maximum required depth can be determined from the total soil-moisture holding capacity, i.e., the total moisture available between field capacity and wilting point **(TAM),** and the allowable depletion fraction therefor, called the readily available moisture content **(RAM)**, Together with an assumed rooting depth, this gives the maximum depth to which the soil can dry out and the depth the irrigation water supply must reach by the end of an irrigation interval. For given or estimated evapotranspiration rate, this maximum depth fixes the maximum irrigation interval (Jurriëns *et al*., 2001). Irrigation scheduling for sugar cane at Metahara based on 0.6 m root zone. Thus, the maximum effective root depth for scheduling was taken as 0.6 m. Determination of SMD for before and after irrigation events different root depth values was used. For all irrigation events after hilling up, it was taken as 0.6 m (Tate, 2009) and that of before hilling up (up to 3 months) irrigation events it was 0.3m (Dilsebo, 2007).

Soil moisture content determined by equation 7 was used to determine SMD. It is a measure of soil moisture between field capacity and existing moisture content, θ_i, multiplied by the root depth. It was computed using (equation 7) (Michael, 2008).

$$SMD = 10 \times \left(\theta_{Fc} - \theta\right) \times R_D \tag{7}$$

Where;

SMD=Soil moisture deficit (mm), θ_{FC} = Moisture content at field capacity (% volume), θ =Moisture content before irrigation event (% volume), and R_D=Effective root depth (m)

3.3.9. Inflow and outflow measurement

To determine the amount of water applied to the fields, were used three inches (3″) of Parshall Flume was installed at the entrance of each field and frequent readings were taken. During the determination of the amount of water applied to the field, the average water depth irrigation water passing through the flume to the field and respective time intervals were recorded with the sizes of the fields being irrigated. The discharges of the water applied were taken from Appendix Table 16 for corresponding depths of a specific size of Parshall Flume (Hassen, 2004).

Flow rate into and out of the furrow were measured using volumetric method and /or a 3” portable Parshall Flume (a standard flume) which were placed at the upstream, center and tail end of the evaluated furrows. The flow of water into each field was measured using Parshall Flume installed at the entrance of the water flow to the field. Before taking measurements, the Parshall Flume was calibrated using volumetric method of discharge measurement.

The time taken to fill a known volume of container (5 liters bucket) was recorded using stopwatch and the corresponding discharge was calculated dividing the volume of container by the time required to fill it. The Flume was constructed at Metahara Sugar Factory Workshop. As the objective of the evaluation process is to study system performance under a variety of inflow conditions, different stream sizes should be applied to the test furrows. Prior to the test, the three test fields were calibrated at the field by fixing the opening area of the outlet and maintaining the head at the outlet by varying the available head at the inlet. The opening area was determined after several discharge measurement by varying the opening using the sliding gate Full opening (3318 mm^2), 80 % opening (2636 mm^2) and 70 % opening (2309 mm^2) is 5 l/s flow rates respectively.

This inflow maintained to be constant throughout the test. During the test, flow rates were initially measured every 2 min until the flow became stable. After stabilization, measurement intervals increased up to 10 min.

The tail water (run off loss) was collected at the furrow end in drain collector (Plastic bucket in holes which are dug out at the downstream end of every experimental furrow).Run off volume was determined with the help of graduated cylinder and bucket of known volume.

3.4. Measurement of the Irrigation Stream

The outlets were calibrated in situ to estimate their discharge per unit time and to select the suitable irrigation stream size (standard design discharge practice by the Estate 5 l/s with 100 m furrow length). Using the selected irrigation stream size water was applied to each furrow.

3.4.1. Calibration of hydro-flume

The hydro-flume was located on a leveled area (plate 3”). The calibration was made as follows: Holes were dug adjacent to the outlets and a bucket of known volume was installed at each hole separately. The rim of the bucket was kept with the soil surface. The outlets were primed and directed into the buckets where they discharged water. Using a stop watch the time required to fill the bucket was recorded (for this research time to fill bucket was 5 s recorded).The discharge of the outlets in lit/sec was calculated using the following (equation 8)

$$Q = \frac{\mathrm{V}}{\mathrm{t}} \tag{8}$$

Where:

Q = discharge (lit/sec) ,V = volume of water (lit) and t = time required to fill the bucket (sec)
For each outlet three readings were made and their mean was taken to represent the discharge per unit time for that outlet.

3.4.2. Cutoff time

To supply the required amount of water to the full furrows with a given flow rate, cutoff time was determined using (equation 9) (Cuenca, 1989).

$$T_{\mathrm{co}} = \left(\frac{L \times W \times Z_n}{60 \times \mathrm{Q_o} \times \mathrm{Ea}} \right) \tag{9}$$

Where;
T_{co} = time of cutoff (min), L = furrow length (m), W = furrow spacing (m), Zn = net depth of application (mm),Q_o = flow rate (l/s), and Ea = application efficiency (fraction)

For pre-hilling up irrigation events when the crop is fully submerged while irrigated, (equation 9) does not determine the cut off time appropriately. In this condition, besides the drag force the crop resistance resists downward flow. This resistant reduces the flow velocity and slows the advance. Thus this calculated time needs amendment in order to consider sluggish advance.

To determine the adjustment factor side test was made on field O_{90} with the same crop variety with the test field. Cut off time was calculated using (equation 9) and the actual cutoff time for the average 100 m furrow lengths were measured. The cut off time when the advance reach full furrow length of the furrow is 40, mins longer than the calculated cutoff time for furrow length of 100 m. This implies that 60 % increment than the calculated cutoff time for the furrow length of 100 m. This increment was suggested as adjustment factor for cutoff time.

3.4.3. Advance and recession times

Advance and recession times were monitored at selected irrigation events in order to assess the advance and recession rates. Advance time and the total length that the water travelled were used for the comparison of advance and recession rates. Advance and recession times were measured for each furrow irrigation method and application level combinations (plots). Pegs were driven into the soil along the furrows at 20 m intervals. The numbers of stations were six (00, 20 m, 40 m, 60 m, 80 m and 100 m). The time elapsed for water to reach at each peg from the start of water entry to the furrows (advance time) and the time elapsed for water to recede from each peg starting from irrigation cutoff time (recession time), were recorded. The following formula was applied for the computation of advance rate (equation 10).

$$\mathrm{Ar} = \frac{\mathrm{Lt}}{\mathrm{Ta}} \qquad (10)$$

Where:

Ar = advance rate (m/s), Lt = length travelled by water in the furrow (m) and Ta = time taken by water to reach at the measuring point (second).

3.4.4. Crop Water Requirement and Irrigation Scheduling

To estimate crop water requirement and irrigation scheduling, long year’s meteorological data was taken from Metahara Sugar Factory Meteorological Station. Crop water requirement and irrigation scheduling of sugarcane was prepared based on the meteorological data, the soil characteristics of the experimental plot and crop data. CROPWAT 8.0 computer program was used for the preparation of initial scheduling and it was modified as per the local area and climatic information. Meteorological data of minimum and maximum temperatures, relative humidity, wind speed and daily sunshine hours were used as an input for driving the reference evapotranspiration (ETo) using Penman-Monette method (Allen *et al.,* 1998).

Soil characteristics such as soil texture, TAW, infiltration rate, rooting depth were taken as soil input data. Crop data such as length of growth period, crop coefficient (Kc), root depth, management allowed deficit (MAD) and yield response factor (Ky) at different growth stages were taken from (FAO, 2002) and other different sources. All pertinent data were fed into the CROPWAT 8.0 computer program, and then the dates and the net application depths were obtained as output (Tate, 2009). Gross application depth (GIR) was computed by dividing the net application depth to the application efficiency, to achieve at least the design application efficiency (60 %) in respective soils. Thus, they are the maximum amount of water to be applied in respective soils for acceptable performance (Tate, 2009) (equation 11).

$$\mathrm{GIR} = \frac{\mathrm{NIR}}{\mathrm{Ea}} \tag{11}$$

Where:

GIR = Gross irrigation requirement (mm), NIR = Net irrigation requirement (mm) and Ea. = Application efficiency (%)

For net depths of application or perceived application depths for respective soils

$$\mathrm{Dn} = \mathrm{TAW} \times \rho \times \mathrm{Rd} \tag{12}$$

Where,

TAW = total available water (mm/m), ρ = allowable depletion (fraction), Rd=root depth, (m)

For irrigation intervals or frequency of irrigation is determine as follow

$$\mathrm{I} = \frac{\mathrm{Dn}}{\mathrm{ETc}} \tag{13}$$

Where,

I = irrigation interval (days), and ETc = crop evapotranspiration (mm/day)

3.4.5. Sustainability of Irrigation Scheme

The simplest measure of sustainability that quantifies the cumulative effect of negative impacts (like expansion of Lake Beseka, waterlogging, salinity, expansion of community managed small scale farm around estate farm, etc.), is Sustainability of the Irrigated Area (SIA) that was calculated using the following equation (Nelson, 2002) (equation 14)

$$\mathrm{SIA}(\%) = \frac{\mathrm{AC}}{\mathrm{AI}} x100 \tag{14}$$

Where,

AC = current total irrigated area (ha), AI = total irrigated area when the system development was completed (ha)

3.5. Irrigation efficiencies

Even though, there are many performance indicators that can be applied to evaluate an irrigation system which gives the amount of water stored in the soil, water balance method was used in this research work. It requires measuring the amount of irrigation water applied runoff loss and the amount stored in the root zone. These parameters were used as input to estimate the conveyance efficiency, water delivery performance, application efficiency, distribution uniformity and storage efficiency of the irrigation methods.

3.5.1. Conveyance efficiency (Ec)

To determine conveyance efficiency, flows at the field canals were measured using the three Inches Parshall Flumes. Since the flume was not big enough, float (Velocity-Area) method was used at the primary, secondary and tertiary canals to measure the corresponding discharges. Considering only the steady state flow, that is neglecting any spillage or slug losses that can be attributed to management, the conveyance efficiency can be formalized as (equation 15) (Laycock, 2007).

$$\mathrm{E_C} = \frac{\mathrm{Q_{Reaching\ field}}}{\mathrm{Q_{Release\ field}}} * 100 \tag{15}$$

Where,

$Q_{\mathrm{Reaching\ Field}}$ = sum of steady state discharge reaching fields and $Q_{\mathrm{Release\ Field}}$=steady state discharge released at system head

3.5.2. Application efficiency (in-field)

After determining the depth of water actually applied into the fields using a three inches Parshall 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 16) (Laycock, 2007).

$$E_a = \frac{Z_s}{Z} \times 100 \tag{16}$$

Where;

E_a= the application efficiency, (%) Z_s = depth of water retained in the root zone (mm), and Z = depth of water applied to the furrow (mm).

3.5.3. Distribution efficiency

Furrow irrigation is adaptable where soils and topography are reasonably uniform and furrows are sloping channels cut into the soil surface and into which a relatively large initial non-erosive stream of water is turned. The logic behind the evaluation of water distribution uniformity along the furrow is that when irrigation water is applied into a longer furrow with a given discharge, the upper and the lower ends cannot get equal amount of water (Michael, 2008).

To determine the distribution uniformity of irrigation water in these furrows layouts auguring were done at selected points, starting from the initial to the end of the furrows at regular interval. And at each selected points of the furrow soil samples were collected at different 0-30 cm to 30-60 cm depths with a regular interval. And the soil moisture contents of the soils at the selected points were analyzed to determine the depth of water penetration. For calculating the distribution uniformity the root depth of the crop was taken as the zone of distribution and **(**equation 17) (Laycock, 2007).

$$\text{Distribution efficiency} = \frac{\text{minimum water depth applied}}{\text{average water depth applied}} \times 100 \tag{17}$$

3.5.4. Adequacy of irrigation (Water storage efficiency)

The water storage efficiency refers how completely the water needed prior to irrigation has been stored in the root zone during irrigation. 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 75 % moisture depletion level (Allen *et al*, 1998).

After determining the storage and the required depths, the storage efficiency was calculated using (equation18).

$$E_S = \frac{Z_s}{Z_{req}} \times 100 \qquad (18)$$

Where;

E_s=storage efficiency (%), Z_s =actual depth stored in the root zone and Z_{req} = required depth added (mm).

3.6. Irrigation Water Losses

To improve the performance of a surface irrigation system, the measures of uniformity and efficiency may need to be more qualitative. DU gives minimal information about the magnitudes of losses or under-irrigation. Ea. does not allow the engineer to segregate deep percolation losses from tail water losses and it is difficult to assess the degree of under-irrigation. Since these items are important, deep percolation ratio (DPR) and tail water ratio (TWR) are proposed as additional indicator (Walker, 2003). Efficient furrow irrigation requires reducing deep percolation and surface runoff losses. Water that percolates below the root zone (deep percolation) is lost and not available to the crop production, although deep percolation may be necessary to control salinity when required. Improving the evenness of the applied water and preventing over irrigation can reduce deep percolation.

3.6.1. Runoff ratio (RR)

The amount of runoff from each field was collected and measured using known volume of Buckets and three inch Parshall Flume installed at the lower end of each field and RR was Calculated using the following (equation 19) (Michael, 2008).

$$RR\% = \frac{\text{Depth of run off (Dr, mm)}}{\text{Depth of water applied to the field (Da, mm)}} \times 100 \qquad (19)$$

3.6.2. Deep percolation fraction (DPF)

Deep percolation losses occur in the field when irrigation water goes below the root zone and is lost to the plant. When applying water by surface irrigation methods, it can be difficult to get an even distribution of water across the field. In order to get enough water to the end of the field it may be necessary to put too much on at the start of the field, and excessive percolation loss is the result. Similarly, an irrigation application discharge that is too small can lead to excessive percolation loss due to the long travel time across the field (Laycock, 2007).

Deep percolation fraction (DPF) was calculated using the following (equation20) (Walker, 2003).

$$\text{DPF (\%)} = \frac{\text{Deep percolation (mm)}}{\text{Depth of water applied to the field (Da, mm)}} \times 100 \tag{20}$$

3.7. Yield and yield component data

Stalk height measurement was made from twenty randomly selected stalks from the middle two rows by measuring the distance from the soil surface to the top visible dewlap (TVD). Measurement was made at monthly interval from the 8 weeks after the last date of germination count and the measurement taken at harvest was used for statistical analysis while the rest were used to study effect of number of buds, spacing and variety on plant height.

Plant population count was made at monthly interval from five months until harvesting. However, the data taken at harvesting was used for analysis while the rest were used to study the effect of number of buds, spacing and variety on plant population.

Mill able canes in each plot were counted before harvesting from the net plot area (14.5 m^2) at harvesting and then converted to the hectare base as follows (equation 21)

$$\text{MCH} = \frac{\text{MCP} \times 10{,}000}{1.45 \times 10} \tag{21}$$

Where,

MCH = number of mill able canes per hectare (ha), and MCP = number of mill able canes per plot

Girth measurement was taken from 14 sample stalks taken randomly from the middle two rows at harvest. Measurement was made using a caliper on three points of the stalks (upper, middle and bottom part of the stalk) after removal of the sheath.

Weight per stalk was determined by taking 14 samples randomly from the middle two rows and by measuring the weight of each sample using spring balance. Then the average weight per stalk was taken.

Cane yield per experimental plots was calculated by multiplying the number of mill able

Canes per plot by the average weight per stalk as follows;

Cane yield per plot (kg) = Average weight per stalk (kg) x Number of mill able canes per plot

$$\text{CYH} = \frac{\text{CYP} \times 10{,}000}{14.5 \times 1000} \qquad (22)$$

Where,

CYH = Cane yield per hectare (ha) and CYP = Cane yield per plot.

Per cent Brix was determined by hand refractometer. Juice was extracted with sampler mill and screened with a fine copper sieve and then the samples were taken using plastic jar. Then brix value was measured using the hand refractometer.

Percent pol was determined using an automated Polari meter, which is used to determine percent pol by measuring the angle of rotation to the left.

Apparent purity was calculated as the ratio of percent pol to percent brix and multiplied by 100.

Percent recoverable sucrose was calculated using the following model used

Recoverable Sucrose (%) = [%pol-(%brix-%pol) 0.52] 0.75 (23)

Where

0.52 = Non-sugar factor

0.75 = Cane factor.

Then the commercial sugar (t/ha) yield was calculated as the product of cane yield per middle

Rows and recoverable sucrose percent per plot, Then Commercial sugar yield per hectare was calculated as follows:

CCS (t / ha) = CYH (t / ha) x RS (%) (24)

Where

CCS = Commercial cane sugar

RS = Recoverable cane sucrose

3.8. Economic Evaluation of hydro-flume with feeder ditch (open ditch)

In order to see cost benefit analysis of hydro flume with feeder ditch, economic feasibility of the irrigation methods and application levels, profitability of each treatment was assessed based on their relative profit. Costs of bed preparation, rolling and unrolling of hydro-flume, machines efficiency of fertilizer application before and after, machines efficiency, pesticide spraying, cost of weeding, cost of additional labor, water use efficiency and loss, cost of drop box construction before and after, and percentage of land and water saving were considered in this section.

Profit = Revenue – Cost (25)

The area covered by Feeder ditch per 100m or two hectare (99% of all fields are two sides and 1% of the estate farm irrigated by one side) (equation 26 and 27).

A= (width x length) (26)

Lay flat dimension= $[1/2(2\times\pi\times R) + 0.8] \times L$ (27)

Where, R= radius of hydro- flume (m), L= length of hydro-flume (m), $\pi = 3.14$

Since 2005/2006 crop year, this opens earthen canal irrigation system (Feeder ditch) of all cane after cane fields has been started to change open earthen canal /feeder ditch/ by flexible gated pipe. As per the implementation schedule in 2005/2006 and 2006/2007 crop years, flexible gated pipe has been installed on 522.25 and 1113 hectares of land, with 111,780 meters of hydro-flume. In 2015/2016 crop year, flexible gated pipe has been installed on more than 90 % of the total area. The total length of hydro-flume is 821,966.84 m and length of feeder ditch (open earthen ditch) 47,323 m which is 10 % of the total length. The replacement cycle of hydro flume (flexible gated pipe) 5-7 year (monograph of manufacturer).

3.9 Methodologies used

3.9.1 Data collection methodologies

The data collection has been carried out in collaboration with the Research Center workers, Plantation Department and Civil Engineering Department, assigned by the Metehara Sugar Factory Head Office. It was started in April 2015. During the reconnaissance survey; Civil Engineering Department, Research Center workers, professional staff, of Metahara Sugar Plantation and some stakeholders were consulted about the general conditions of large scale irrigations. Based on the survey made and the information gathered; three representatives irrigation fields were selected. The criteria for selection were proximity for, hydro-flume have been started for the first time, nearness to residence station, and the availability of secondary data. Data collected included primary sources at field level in the irrigation fields.

As much as possible, three representatives Plantation' fields were selected from the head; middle and tail water users of each irrigation schemes.

3.9.2. Primary data collection

Frequent field observations were made to observe and investigate the method of water applications, and practices related to water management techniques made by the assigned persons. Measurements of canal water flow at the diversion of the Estate were taken frequently. Based on this average discharge coupled with total flow time total volume of water diverted by the irrigation scheme was estimated.

Moisture contents of the soils of the selected irrigation fields before and after irrigations were determined by taking soil samples at different depths of the profiles.

To determine the pH, ECe, FC, PWP %, sucrose, etc., and texture of each Plantation field, soil samples were collected periodically from different depths. And also using sampling rings undisturbed soil samples were collected and the bulk densities at different depths were determined. Three inches Parshall Flumes were constructed using sheet metal and installed at the entrance, middle, and tail end of the selected Plantation fields to measure the depth of water applied to the specific areas of fields.

3.9.3. Secondary data collection

Secondary data were collected from different, responsible bodies or officials at Sugar Estate, as much as possible. Furthermore, Metahara Sugar Factory Research Centers, Plantation Department, Land Preparation and Cultivation Department, and Civil Engineering Department were visited periodically to gather further information. The Secondary data included total yields, before and after implementation of Hydro- flume, area irrigated per crop per season or per year, machines efficiency before and after implementation of Hydro- flume production cost per season or per year, and cropping pattern. Much effort has been spent through survey and observations of different documents at different places to check the reliability and consistency of these data. Climatic data of irrigation scheme has been collected from, Metahara Sugar Factory Research Center.

4. RESULTS AND DISCUSSIONS

4.1. Physico -Chemical Properties of Soil

Soil physical property analysis of the experimental plot is presented in Table 2. The data revealed that, it has a clay texture with percentage of sand, silt and clay as 20, 22.5 and 57.65 %, respectively. The soil has an average moisture content of 40.75 % at field capacity (FC) and 19.97 % at permanent wilting point (PWP) on weight basis. Bulk density of the soil was 1.32 g/cm^3 at a depth of 0 – 30 cm and 1.31 g/cm^3 at a depth of 30 – 60 cm. The values of bulk density were in agreement with the report by Tate (2009), which ranged from 1.0-1.5 for clay soils and the average value of 1.32 gm/cm^3.

Table 2.Soil physical properties of experimental site

Pit no	Depth (cm)	BD (gm/cm$^{3)}$	FC	PWP	TAW	Sand	Clay	Silt	Textural class
1	0-30	1.18	40.91	20.28	20.63	27.2	53	19.8	Clay
	30-60	1.32	38.95	19.19	19.76	21.2	51	27.8	>>
2	0-30	1.33	41.48	20.59	20.89	27.2	51	21.8	>>
	30-60	1.37	39.92	19.15	20.77	31.2	48.4	20.4	>>
3	0-30	1.32	40.46	20.42	20.04	25.2	56.4	18.4	>>
	30-60	1.29	40.16	20.21	19.95	17.2	62.4	20.4	>>
4	0-30	1.36	41.34	20.49	20.85	16	63	21	>>
	30-60	1.31	40.68	19.12	21.56	18	59	23	>>
5	0-30	1.36	40.33	20.44	19.89	15.7	61.2	23	>>
	30-60	1.31	40.58	20.18	20.4	14.8	59	26.2	>>
6	0-30	1.34	42.29	20.34	21.95	14.8	65	22.2	>>
	30-60	1.27	41.89	19.08	22.81	12	62	26	>>
mean	0-30	1.32	41.14	20.43	20.70	21	58.3	21	>>
	30-60	1.31	40.36	19.50	20.88	19	57	24	>>
	0-60	1.32	40.75	19.97	20.80	20	57.65	22.50	>>

The total available water holding capacity of the soil was found to be 207.80 mm/m (equation 1). The soil had high water holding capacity which is very appropriate for surface irrigation using high application depths and low irrigation frequencies. The readily available water (RAW) was equal to 65 % of TAW (Laycock, 2007) which was equal to 135.07 mm/m. The values of FC, RAW and TAW were found to be in the range (FC=25-40, PWP =12-20 and TAW=200-400) given for clay soil (Dilsebo, 2007).

Table 3.Soil chemical properties of experimental site

Pit no	Soil depth (cm)	pH	EC (ds/m)	OC (%)
1	0-30	7.48	0.248	1.56
	30-60	7.46	0.204	1.13
2	0-30	7.45	0.284	1.40
	30-60	7.52	0.23	1.03
3	0-30	7.47	0.334	0.98
	30-60	7.45	0.264	0.74
4	0-30	7.93	0.26	1.87
	30-60	8.00	0.21	0.85
5	0-30	7.94	0.25	1.57
	30-60	8.12	0.21	0.79
6	0-30	8.00	0.22	1.61
	30-60	8.15	0.23	0.83

4.2. Gated Pipe Characterization

Figure 5 shows the relationship between pressure and discharge per outlet for full open, 3/4 open and 1/2 open for single outlet openings. The value of R^2 indicates that there was strong relationship between outlet pressure and discharge for all the three openings. Discharge per out let depends on the pressure inside the gate. The pressure depends on the slope along gated pipe (bed slope) and area of outlet opening. The resulting lines on the log-log scale are relatively parallel giving similar slope and gave outlet characteristic equations: $y = 1.03x^{0.503}$, $y = 0.06x^{0.51}$, $y = 0.42x^{0.504}$ for outlets with full open , 3/4 open and ½ open, respectively. This suggests relation of the power (0.5) for "h" in the following form (equation 28).

$$q = ch^{0.5} \tag{28}$$

Where "q" is discharge in l/s, "h" is pressure head at the center of the outlet in cm, the coefficient "c" is a function of gate opening area and took different values for different gate openings, This is similar to Power curve regression used to develop depth discharge relations for off-take (sluice gate) and outlets to determine the daily irrigation supplies using expression $Q = \alpha \times H^u$ (Kennedy, 1984).

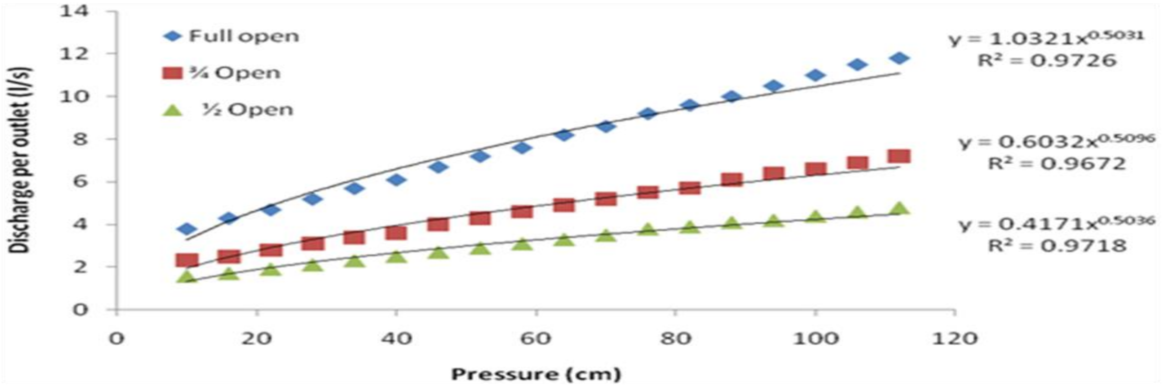

Figure 5. Outlet discharge pressure relationships of gate opening

The results of field characteristics obtained are presented, (Appendix Tables 1, 2 and 3). There was a general increase of outlet discharge and pressure towards the downstream end. Table 4, shows the mean value of discharge and pressure along the fields' were 2.88, 3.45, 3.43 l/s , 98.12, 145.10 and 152.51 mm which is less than the designed discharge of 5 l/s and 150 mm of minimum pressure obtained in two fields due to the slope variation along the fields. Analysis of the discharge measurement made for fields of different bed slopes. The result indicated that the outlet discharge and pressure along the length of the pipe varied differently for each fields. Similar results were found (Assefa, 2011), the mean values of discharge along the length of the pipe is 4.96 l/s.

Table 4.Discharge and pressure distribution along the length of gated pipe (hydro- flume)

	Field experimental work		
Field	0.024%	0.334%	0.172%
Mean discharge(l/s)	2.88	3.45	3.43
Mean pressure(mm)	98.12	145.10	152.51

4.3. Field Experiment measurement Characteristics

4.3.1. Maximum Allowable Flow Velocity (Vmax) and Flow Rate

The soil texture of the experiment site is clay, therefore, V_{max} of 13m/s was used for the study (Walker, and Skogeroboe, 1987) (equation 3), and Qmax for slope 0.05 is 12.6 l /s the levels of flow rate treatment (5 l /s) are suitable for slope in the limits of non-erosive flow rate.

4.3.2.. Infiltration Parameters

The results of field Infiltration Parameters obtained are using the inflow-out flow method to determine the basic infiltration rate of the soil(equation 6), average infiltration rate was found to be 0.0000212 m^3/m/min, which is in the range (0.000011to 0.000035 m^3/m/min) value for clay soil (Walker, 2003).

4.3.3. Inflow Rate Characteristic

The results of field inflow rate characteristics obtained are presented (Table 6), provides inflow measurement made during first irrigation event. The average measured inflows per treatments were 3.20, 3.25 and 3.33 l/s. The values were less than from design discharge 5 l/s, the inflow rates varied differently among treatments. The maximum value was obtained field-3, the reason for high due to suitable longitudinal slope and maximum field water application than the other fields. Similar results were found Assefa (2011), the average measured inflows per treatments were 3.93, 4.94 and 5.99 l/s.

4.3.4. Advance and Recession Times

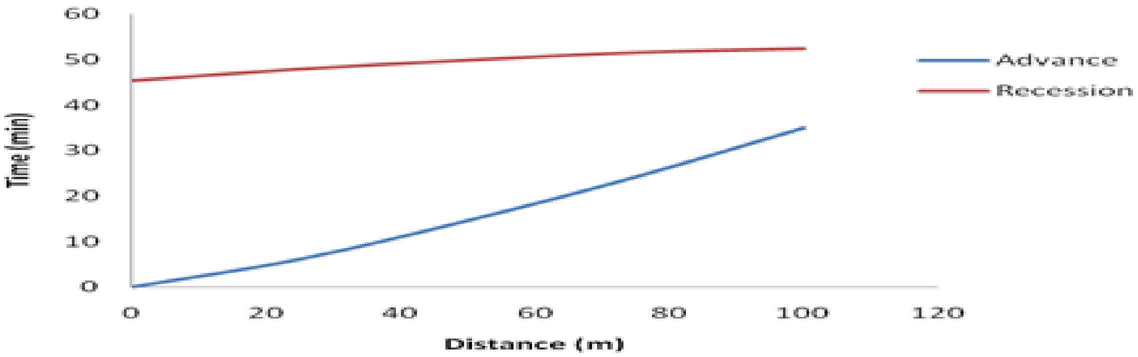

Figure 6. Advance and recession graph for 100 m furrow length and 3.11 l/s flow

Advance and recession curves are presented in Figure 6.The result showed that long advance times and the recession curve is about linear, with relatively small difference between the upstream and the downstream sections. The vertical difference between advance and recession curves at any particular point gives the infiltration opportunity time. The opportunity times were used for determining the average infiltration rates of furrows. Since the furrows were free draining one and the inflow was constant, infiltration opportunity time decreased from the head end to tail end of furrows. This led to variation in the amount of water infiltrated into the soil along the furrow length.

4.4. Irrigation requirement of sugarcane

To indicate the approximate irrigation requirements for each of the four classes' were applied the FAO computer model Cowpat 8.0 Windows to soils and climate data obtained from the Estate meteorological station. Each irrigation to field capacity were depend on net irrigation requirement, calculation of gross water application a field efficiency factor is required (application efficiency 60 % at MSF) , 0.6 m rooting depth and 12 month crop.(Tate, 2009),factor of depletion for different soil groups were heavy (vertic) class (v) 50 %, Clays (C), Clay over loamy (CL) 56 %, Loamy (L) 60 % ,Sandy, very gravelly, pumice 70 %,Total available water of the four soil class were 220, 185, 150 and 116 mm, respectively.

The net application depth (60 cm rooting depth), the required gross application depth, and cut off time (at 5 l/s inflow rate to each furrow, 100 m furrow and its design application efficiency of 60 %) estimated were tabulated below. The correct amount of water to apply-net depth of application at each irrigation varies with soil water holding capacity and soil intake rate, root depth, and soil moisture status. Gross application depends on the net application depth and application efficiency required.

Table 5.Gross application for 100 m furrow at 60 % application efficiency

Soil types	Net depth (mm)	Gross depth (mm)	Cut off time (min)
Heavy clay	66	110	64
Clay, Clay over loam	62	103	60
Loamy	54	90	52
Sandy, very gravelly, pumice	48	80	47

Interval of irrigation - Intervals between irrigations vary with soil, season, and crop growth phase, shorter in light soils and medium in heavy soils during growth. Irrigation interval shortens also during dry season. Irrigation interval that can be achieved is highly dependent on irrigation method, system water delivery capacity, and flexibility and manageability of the field application system.

The net depth of irrigation water application of sugarcane (60 cm rooting depth), the required gross application, net depth of application and cut off time for heavy clay soil, (at 5 l/s inflow rate to each furrow, 100 m furrow and its design application efficiency of 60 %),(Appendix Table 12),were 123 mm, 99 mm, 64 mm for clay, clay over loam 124 mm, 93 mm, 60 mm for loamy soil 108 mm, 81mm, 52 mm for Sandy, very gravelly, pumice, 97 mm,73 mm and 47 mm, respectively. Irrigation water requirement based on crop type, growth stage and soil type of the area**.** interval of irrigation depends on mainly soil type of the farm.

Tate (2009), the soils in irrigation class, Heavy (vertic) clays (V), Clays (C), Clay over loamy (CL), and Loamy (L), sugarcane water requirements and amount of net irrigation water applied (interval) were 1135, 1236 mm, 13 and 36 days, respectively. For the coarse soils in class, Sandy; very gravelly; pumice, the net amount is 1302 mm applied every 10 to 16 days. Water requirement and frequency of irrigation increases soils become coarser textured.

4.5. Sustainability of irrigation scheme

The total size of the scheme was initially designed to irrigate 11, 000ha (Awulachew, 2007), but currently it is irrigating only, 10, 240 ha (Bishaw, 2015). Figure 7, clearly shows that sustainability of the Metahara Sugar Factory irrigation scheme is greatly endangered because only 93 % of the design size is currently under irrigation. This is due to high groundwater and/or salt-affected soils cover 11 % of the Estate. Some of the soils in these areas are also slowly permeable. A further 9 % of the Estate also has slowly permeable soils with an actual or potential water logging problem (Tate, 2009).The problem is wide spread over vast area of sugarcane fields. Out of 37 assessed fields (210.9 ha) most of the fields stagnated water for a prolonged period of time and affects workability to the fields (Bishaw, 2015).The lower altitudes with relatively shallower ground water table depth have severe salinity than the higher altitudes at Metahara Sugar Estate (Olumana *et al*., 2009). Rapid expansion of Lake Beseka, expansions of community managed small scale farm around the Estate farm, water logging, and due to relative shortage of water the command area are the major reasons observed in the field as threats to its sustainability.

Figure 7. The effect of waterlogging at Sugar Plantation fields

4.6. Scheme Water Conveyance Evaluation

The Metahara Sugar Factory irrigation scheme uses the water diverted from the perennial river called awash. The mean water flow into the main supply canal was measured to be 8m^3/s from Merti side main canal and 4 m^3/s from Abadir side. However, as there is high seepage of water through the network of supply canals. As a result, competition for water and conflicts among irrigators are common. Even if construction of the Metahara Sugar Factory irrigation scheme was concluded more than 40 years ago, there are no sufficiently designed and constructed canals and canal structures. The consequence of this poor water delivery and conveyance system results in loss of much water and the corresponding low conveyance. The average conveyance efficiency of the scheme was 65 %. The general texture of the soil where main canal efficiency measured was found to be sandy and the efficiency was 77 % (Mekonnen, 2009).

4.6.1.Canal conveyance efficiency

The results of field canal conveyance efficiencies obtained are presented (Table 8), the average main canal and Supply canal conveyance efficiencies are measured as 94.14 and 90.20 %. During the field work water was leaking from canal, the depth of canal not uniform, flow in canal network was not uniform, most of the canals light soil, canals were heavily vegetated, and water overtops the canal banks.

Checkol and Alamirew (2008), the average main canal and tertiary canal conveyance efficiencies were measured as 92 and 81 %, respectively. (Laycock, 2007), Conveyance efficiency over 90 % is normally considered acceptable for a lined canal, but a well-constructed canal on a small scheme should achieve better than 95 %.

Table 6.Evaluation of the water conveyance efficiency of different canals

Canal type	Inflow (m^3/s)	Average canal inflow (m^3/s)	Average canal outflow (m^3/s)	Conveyance efficiency, E_c (%)
Main average	4.78	4.50	0.28	94.14
Supply canal average	0.51	0.46	0.05	90.20
Scheme E_c (%)				92.17

4.6.2.Water application efficiency

The application efficiencies measured on the three different sugarcane farm fields, selected for this study are presented in (Table 9), the flow rate, furrow length and application efficiency for field-1, field-2 and field-3 were, 2.93 l/s, 100 m and 59.58 % ; 3.27 l/s ,100 m and 58.69 % ; and 3.14 l/s ,100 m and 57.39 %, respectively. The values obtained were close to each other and low, but not very far from what is expected in surface irrigation system. This result is in agreement with the result (Checkol and Alamirew, 2008; Mekonnen, 2009; and Hassen, 2004). They had estimated the application efficiency in the order of 44-57 %, 37-62 % and 50 – 64 %, respectively.

Even with the best irrigation practices, however, field application efficiency values cannot attain 100 %. Nor should that be the aim, since a certain fraction of the water applied must be allowed to seep downwards and leach the salts that would otherwise accumulate in the root zone. However, with careful management, field water application efficiency can achieve relatively high value.

FAO (1989), suggested 60 % attainable water application efficiencies for surface irrigation system. Value below this limit would normally be considered unacceptable (Mekonnen, 2009), whereas Solomon (1998) suggests attainable efficiency of 60-75 % for furrow irrigation.

Table 7.Summary, the effect of furrow length, flow rate and field application efficiency

Experiment fields	Application efficiency		
	Flow rate(l/s)	Application (%)	Average length(m)
Field- 1	2.93	59.58	100
Field-2	3.27	58.69	100
Field -3	3.14	57.39	100
Overall Scheme	3.11	58.55	100

4.6.3. Water distribution and storage uniformity

Distribution uniformity: - measures how evenly water has infiltrated to the soil in an irrigation event. Due to the difference in infiltration opportunity time, variation in the amount of infiltrated depth of water along the length of the furrow is a probable situation which may happen.

The evaluation of water storage and distribution uniformity of each field was conducted using three field irrigation events (Table 10 and , Appendix Tables 5, 6, and 7).The average of the three was taken to compute the distribution uniformity and the results are summarized inTable,10, in field-1, flow rate, furrow length ,distribution, storage uniformity were 2.93 l/s, 100 m ,86 and 99.45 %; field-2, flow rate, furrow length, distribution uniformity and storage uniformity were 3.27 l/s, 100 m, 85.25 % and 99.41 %; Field-3,flow rate, furrow length, distribution and storage uniformity were 3.14 l/s, 100 m, 85.02 and 99.44 %, respectively. From this, it can be concluded that 85-86 % portion of the irrigation fields received and stored equal amount of water to their rooting depth. The higher the value of DU, the better the uniformity of application and the higher the distribution efficiency.

Similar results have been reported by, Abdaldafi (2006); the result shows that the distribution efficiencies for all cycle ratios were similar which are 84 %, 83 % and 85 %, respectively. The distribution uniformity had a similar trend. The high distribution efficiencies obtained may be due to the acceleration of the advance of the surge flow. Similar results have been reported by (Mekonnen, 2009), the DU at the head, middle and tail end fields were 90.34 %, 86.15 % and 88.41 %, respectively. On the other hand, similar results have been reported by Gebre-Egziabiher (2013), the mean distribution uniformity (DU) values obtained were 90.7 % and 89.4 % for AFI (Alternate furrow irrigation) and CFI (Conventional furrow irrigation), respectively. A properly designed system and well managed irrigation field can attain quite high distribution efficiency.

Table 8. Summary, the effect of furrow length, flow rate and field Distribution uniformity

Experiment fields	Distribution uniformity		
	Flow rate(l/s)	Distribution uniformity (%)	Average length (m)
Field- 1	2.93	86.00	100
Field-2	3.27	85.25	100
Field -3	3.14	85.02	100
Overall Scheme	3.11	85.42	100

Storage efficiency: - the evaluation of Es for each field was done based on the mean value of the three irrigation fields and data are summarized in (Table 11 and on Appendix table 5, 6 and 7), the mean storage efficiency (Es) values obtained were 99.45 %, 99.41 % and 99.44 %, respectively. From Table 11, the storage efficiency of the sample fields ranges from 99.41-99.45 % with an average of 99.33 % for the scheme.

(Gebre-Egziabiher, 2013), reported storage efficiency values of 72.1 % for conventional furrow and 64.4% for alternative furrow irrigation system. (Hassen, 2004), reported storage efficiencies of the fields were 100 %, 95.96 %, and 84.58 %, the results are with an average of 93.51 % for the irrigation scheme

According to Ley and Clyma (1981), the overall water storage efficiency of the irrigation scheme (97.63 %), was in line with the range of 85-100 %, which is assumed to be the potential achievable value for furrow irrigation. This shows that irrigation water application successfully met its objective of refilling the root zone to field capacity (Mekonnen, 2009).

Table 9. Summary, the effect of furrow length, flow rate and field storage efficiency

Experiment fields	Storage efficiency		
	Flow rate(l/s)	Storage efficiency (%)	Average length(m)
Field- 1	2.93	99.45	100
Field-2	3.27	99.41	100
Field -3	3.14	99.44	100
Overall Scheme	3.11	99.43	100

4.7. Irrigation water losses

Runoff ratio (RR):-The amount of runoff measured is summarized in (Table 12, and Appendix Tables 8, 9 and10), considering the mean values of the three irrigation field events.

The results of irrigation field water loss obtained are presented the above table, the values of runoff ratio, flow rate and furrow length were 18.53 %, 18.76 %, 18.45 %, 2.93 l/s, 3.27 l/s, 3.14 l/s and 100 m, respectively. The values obtained from research are high; and from field observation, the result of this, the effect of poor irrigation methods on RR was highly significant effect on irrigation water application of the scheme.

Gudissa (2011),reporeted the mean values of runoff ratio were 20.55 %, 20.54 %, 27.69 % and 23.89 %, respectively. According to Gebre-Egziabiher (2013), the mean values of RR were 9.67 and 13.75 % for AFI and CFI, respectively. Assefa (2011), reported that, the mean value of RR were 18.82, 18.14, and 21.79 % for flow rates of 4, 5 and 6 l/s, respectively. According to Ley and Clyma (1981), the acceptable value of runoff ratio for furrow irrigation is 20%.

Table 10. Summary, the effect of furrow length, flow rate and field Run off

Experiment fields	Runoff ratio		
	Flow rate(l/s)	Runoff ratio (%)	Average length(m)
Field – 1	2.93	18.53	100
Field – 2	3.27	18.76	100
Field – 3	3.14	18.45	100
Overall Scheme	3.11	18.58	100

Deep percolation fraction (DPF):-The amount of runoff collected and the application efficiencies of each field were used to calculate the deep percolation fraction and the results are presented in Table 13, the values of deep percolation fraction, flow rate and furrow length were 23.03 %, 22.38 %, 23.35 %, 2.93 l/s, 3.27 l/s, 3.14 l/s and 100 m, respectively. As shown in (Table 13, and Appendix Tables 8, 9 and 10), this is shows that, the largest volume of irrigation water applied per hectare of the field .Therefore, the majority of water lost from the fields was in the form of deep percolation. The Estate tends to evaluate their skill of irrigation practice in terms of runoff loss and waste great quantity of water in the form of deep percolation. Water is relatively scarce; Estate tends to use water more efficiently and minimizing the deep percolation losses.

The overall deep percolation loss of water from the scheme, taken as the average value of the three sample fields was found to be 22.92 %. Therefore, the deep percolation loss is considered as unacceptable FAO (2002).

Table 11. Summary, the effect of furrow length, flow rate and field Deep percolation

Experiment fields	Deep percolation fraction		
	Flow rate(l/s)	Deep percolation (%)	Average length(m)
Field– 1	2.93	23.03	100
Field–2	3.27	22.38	100
Field –3	3.14	23.35	100
Overall Scheme	3.11	22.92	100

Table 12.Mean calculated efficiencies, water losses, and flow rate measurement within 100m furrow length

Experiment fields	Efficiency				Water losses	
	Flow rate(l/s)	Application (%)	Storage (%)	Distribution (%)	Runoff ratio (%)	Deep percolation ratio (%)
Field– 1	2.93	59.58	99.45	86.0	18.53	23.03
Field–2	3.27	58.69	99.41	85.25	18.76	22.38
Field -3	3.14	57.39	99.44	85.02	18.45	23.35
Overall Scheme	3.11	58.55	99.43	85.42	18.58	22.92

4.8. Sugarcane yield

As shown in (Appendix Table 15), the mean cane yields, per flow rate and furrow length obtained were 11.18 t/ha/month, 3.11 l/s and 100 m, respectively. In the experiment field maximum and minimum value obtained are 13.12 and 9.08 t/ha/month. Flow rate was highly significant for maximum cane production, whereas the variability of flow rate per plot reduce its sugar cane yield. Similar results are obtained by Assefa (2011), the mean cane yields per flow rate obtained were 10.75, 11.16 and 11.65 t/ha/month for 4, 5 and 6 l/s flow rates, respectively. Better cane yield was observed at higher flow rates and it increased as the flow rate increased. Flow rate have good yield potential, this happens due to the fact that better irrigation canal conveyance, application and uniformity were attained in higher flow rates.

4.9. Cost- benefit analyses of hydro flume with feeder ditch (open ditch)

4.9.1. Economical advantage of flexible gated pipe on, plantation of sugarcane

Flexible gated pipe irrigation occupies smaller area than earthen canals (feeder ditch). Area covered by Feeder ditch per 100 m or two hectare 350 m^2 using (equation 26),area covered by Flexible gated pipe per 100 m, is 140 m^2(equation 27), Land saving per two hectare, the difference of land save of feeder ditch and hydro flume 210 m^2, and total land saving using two equations are11.69 ha.

1. Siphons supplying water to furrows

2. Hydro flume supplying water to furrows

Figure 8. Siphons with feeder ditch versus hydro flume feeding furrows at Metahara Scheme

4.9.2. Cost saving and benefit obtained after substituting hydro- flume

Table 13.Cost saving and benefit obtained, substituting Feeder ditches by Hydro-flume

Categories/ activity	Cost(birr)
Feeder ditch weeding	63,445.39
Feeder ditch reshaping	13,633.44
Opening feeder ditch crossing (2)	124,141.92
Opening furrow along feeder ditch	23,690.28
Total cost saving and benefit obtained	224,911.03

Additional benefit from land saving

= 11.69ha x1672qt (can)/ha x11% x 800 birr/qt of sugar

= 1,720,019.84 birr

A. Total saving = 1,944,930.87 birr

Table 14.Cost incurred by Hydro- flume implementation

Categories/activities	Cost(birr)
Bed preparation	39,904.38
Flattening and punching	19,985.78
Bed weeding	7005.00
Bed maintenance after mechanical molding	17,014.00
Rolling and unrolling for herbicide	10,773.70
Rolling and unrolling for molding	10,884.60
Total cost incurred	105,567.46

Table15.Comparison of amount of water, Yield, manual tillage and daily labors in different irrigation systems

Irrigation method	Amount of water m^3/ha	Yield qt/ha	Manual tillage/ha	Daily labors /ha
Hydro-flume	1,470	1,672	26.75	96
Open ditch	1,350	1,488.08	26.75	128

Manual tillage cost and cane obtained from saved land

= (11.69 ha x 1672 qt/ha) x1.60 birr/quintal of cane

= 31,273.10 birr

Manual tillage cost /ha = 26.75 birr, 100 kg of cane produce 11kg of sugar, Production cost of 11kg sugar is 88 birr, and cost of 1 kg sugar is 8 birr, respectively.

Mechanical cost for saved land= (4,400 birr/ha) x11.69 ha = 51,435 birr

Mechanical cost /ha = 58.52 birr, and 3.5 birr / 100 kg of cane

B. Total cost=188,275.56 birr

Net cost saving and benefit obtained /A-B/ = 1,756,655.31 birr

4.9.3. Other benefits of hydro-flume

4.9.3.1. Improves irrigation efficiency

Irrigation efficiency is related to water losses but not limited to it. There are many causes for loss of irrigation water such as seepage, run off deep percolation, evaporation and over flow in case of earthen canals. In the case of flexible gated pipe irrigation this losses are minimum or almost nil. In case of earthen canal, feeder ditches need to be kept weed free and reshaped many times within a year as required to ensure adequate siphon head. But in case of flexible gated pipe no weed and silt problem, which affect the pressure head. This improves the irrigation efficiency.

4.9.3.2. Furrowing opening

An area equal to the size of a tractor was not furrowed near the feeder ditch while furrowing into the feeder ditch. In addition during tractor turning at the feeder ditch, furrows are demolished by tractor' wheels. This requires furrow opening along feeder ditch. But this operation is done from one side to the other side of a field without any obstacles after installation of flexible gated pipe and hence, no/little furrow opening is required.

4.9.3.3. Weed control/molding

In these operations tractors are driven backward on the ridge of the furrows without effective work due to the presence of feeder ditch. During backward driving, tractors frequently slide into the cane row and damage the cane. The idle movement in these operations also increases soil compaction. But after the implementation of Flexible gated pipe, the tractors move from one side to other side of the field without idle run and backward movement. So there is no risk of damage and there is minimum compaction.

4.9.3.4. Harvesting operations

In the presence of feeder ditch, it is not possible to run harvesting equipment across the canal to carry out infield haulage. The feeder ditch are being bulldozed with 8.70 m widths and then rebuilt after the completion of haulage. This operation has damaged cane stool, which, in turn, reduces tailoring in the next ratoon cane, and causes water leakage through the rebuilt dike. But such operations are omitted after the implementation of flexible gated pipe. Thus, there are no problems mentioned above.

4.9.3.5. Improves land productivity

In flexible gated pipe system, there is proper irrigation practice, and reduced soil compaction and cane damage. As a result uniform cane growth is observed and hence leads to land productivity.

4.9.3.6. Reduces labor drudgery and increase labor productivity

In earthen canals irrigation, moving of siphon (45) and bison sheets (3) from field to field and /or with in the field is labor intensive and reduces the labor productivity. In the flexible gated pipe irrigation there is no such kind of task. As a result there is any labor drudgery in this system, which ends labor productivity.

4.9.3.7. Allows selective irrigation

In the case of earthen canal, selective irrigation is not possible in fearing of overflow and seepage. But Flexible gated pipe irrigation allows selective or spot irrigation without fearing any risk to adjacent field, which are dry for harvest and ready for tillage operations.

4.9.3.8. Harrowing along feeder ditch

Conventionally harrowing along feeder ditch side was executed to demolish furrow ridges for uprooting operations. In the implementation of flexible gated pipe, only feeder ditch demolishing has been done with the same operation.

4.9.3.9. Furrowing

The tractor had to turn around at the feeder ditch by lifting implement after it reached at feeder ditch during furrowing operation. There were wastage of time in returning and stresses on the tractor parts & drivers.

After implementation of flexible gated pipe, the operation has been executed from one side to other side of a field without returning by crossing the place of flexible gated pipe. Thus, machine performance has increased and stresses on the tractor and drivers have been minimized due to the implementation of Flexible gated pipe.

-Five years average daily machine capacity before implementation	14.08 ha
-Daily average machine capacity after implementation	21.72 ha
-Average area (ha) increased per day	7.64 ha
-Percentage	$\frac{7.64}{14.08} \times 100\%$
	54.00 %

4.9.4.1. Weed control (herbicide spraying)

Idle run was present in 100m from harvest road to feeder ditch for each turn to make the machine ready for work and then a machine spraying when it run from feeder ditch to harvest road. After implementation of flexible gated pipe, idle run in 100m to reach feeder ditch was avoided. As a result, field efficiency of the machines has increased due to the implementation of flexible gated pipe as mentioned below.

- Five years average daily machine capacity before implementation	11.87 ha
- Average field daily capacity after implementation	17.82 ha
- Average of daily capacity increased	5.95 ha
	$\frac{5.95}{11.87} \times 100\%$
Percentage	50.13 %

4.9.4.2. Molding plant cane

Like weed control (herbicide spraying), there were idle run from harvest road to feeder ditch to execute ridge flattening and molding operation before the implementation of flexible gated pipe. This idle run was avoided by executing the operation from one end to other end (harvest road to the next harvest road).

-Average field daily capacity for five years before implementation	6.07 ha
-Average field daily capacity after implementation	9.48 ha
-Average of daily capacity increased	3.12 ha
-Percentage	$\frac{3.41}{6.07} \times 100\%$
	56.20 %

4.9.4.3. Improves driver's working conditions and efficiency

The implementation of flexible gated pipe in place of feeder ditch at cane plantation has improved the working condition (ergonomic) and efficiency of drivers as mentioned above. There was always twisting of neck to see back during operations of all cultivation activities before hydro flume implementation.

After implementation of flexible gated pipe, drivers are relieved from such bad working condition and increase driver’s work rate due to the absence of obstructions at the middle of the field.

4.9.4.4. Minimizes machine stresses

There were short turn of tractor and frequent twisting of steering system to return back during operation at the feeder ditch and hence, caused high wear and tear of machine parts. After implementation of flexible gated pipe, breakage of tractor part is seemed to be reduced.

Table 16.Cost saving obtained by Implementation of Hydro-flume on LPCD Activities as per 2015/2016 conversion rate

No.	Activity	Quantity		Cost of operation per ha		Cost type		Net cost
		Unit	Total (A)	Convectional system (B)	Hydro-flume system (C)	Additional cost (AxC)	Saving (AxB or C)	
1	Demolishing feeder ditch	ha	1113.0		23.62	26,289.06		-26,265.44
2	Harrowing along feeder ditch	ha	1113.0	62.98			70,096.74	70,096.74
3	Furrowing	ha	1113.0	33.78	21.89		13,233.57	13,233.57
4	Ridge flattening	ha	1113.0	90.63	58.13		36,172.50	36,172.50
5	Molding	ha	1113.0	90.63	58.13		36,172.50	36,172.50
6	Herbicide spraying	ha	1113.0	27.09	21.84		5,843.25	5,843.25
7	Additional labor cost	Md	4.0		500.00	24,000.00		-24,000.00
Total						50,289.06	161,518.56	111,253.12

4.9.4.5. Construction of field drop box before and after implementation of hydro-flume

To construct the energy dissipater, the max allowed static pressure head has been given 3m (as per the manufacturer monograph). 3 % slope, which has the big difference when it compared with the slope that has been used in conventional method of irrigation system. The number of energy dissipater that were constructed at 3 m static pressure head was reduced tremendously by using flexible gated pipe as compared to the previous irrigation system which was being used > 0.5 % slope. After implementation of hydro-flume the number energy dissipater or drop box construction was reduced from 280 to 85 in number when it compared with before implementation of hydro-flume.

4.9.4.6. Economic Benefit

In the past 10 years, before implement hydro flume the average maintenance cost for the drop box in a longitudinal profile has been 320 drop structures at different fields by this annual maintenance ,Cost = 650 birr/drop x 320 drops= 208,000 birr, NB**:** 650 Birr/drop includes ,Material cost [Cement (9 bags), sand (3 m^3), stone (4 m^3) and water.] Labor cost [103.50 Birr/drop] , the implementation of flexible gated pipe in 2015/’2016,85 drop structures and160 off take structures were constructed for the same amount of field numbers. The construction cost for the above mentioned items would be: Total amount of construction cost = 85 drop structure x 103.50 Birr drop +160 off take structures x 745.02 Birr / structure =128,000.70: 45.02 Birr/structure individual the material. (Cement, sand, aggregate stone, and sheet metal, etc...), and labor cost which have been required for the construction work. After implementing Hydro-flume, the department has got a benefit from economical point of view, i.e. in 2015/’2016 (208,000 -128,000.70) = 79,999.30 birr has been saved from the operational budget allocated for the department.

Table 17.Net cost saving and revenue obtained by implementation of hydro-flume

Working area	Additional cost due to implementation of hydro flume	Cost saving and Benefit obtained implementation of hydro-flume	Net Cost saving
Plantation Department	188,275.56	1,944,930.87	1,756,655.31
LPCD	50,289.53	161,518.56	111,229.03
Civil Engineering Department	128,000.70	208,000	79,999.30
Total cost	366,565.79	2,314,449.43	1,947,883.64

5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1. Summary

Field assessment to evaluate hydraulic and economic performance hydro flume irrigation in the Estate irrigation scheme has a paramount importance for improving the existing irrigation schemes. This study was initiated with the objectives of investigating the causes of underperformance of the Metahara Sugar Factory large scale irrigation scheme. The study is aimed at evaluating the performance of the scheme in terms of technical indicators, economical analyses and assessing the major water management. The performance indicators that were used to evaluate the irrigation scheme are oriented toward items that directly or indirectly affect water deliveries and water spreading effects.

The field assessment was conducted on three representatives of Metahara Sugar Factory Plantation fields selected from the head, middle and tail end field command area. The total size, lateral and longitudinal slope, flow rate, and furrow length of each field were measured. Determination of soil pH, ECe, FC, PWP, texture of each plantation field. Soil samples were collected periodically from different depths, and also using sampling rings for undisturbed soil samples to measure the bulk densities values at different depths.

Primary field data collection were made and it included: frequent field observations, measurements of canal water flow at the diversions, determination of moisture contents of the soils of the selected irrigation fields before and after irrigations and measuring flow using three inches Parshall Flumes to estimate depths applied to the specific areas of fields.

The secondary field data were collected included total yields, before and after implementation of Hydro-flume, area irrigated per crop per season or per year, machines efficiency before and after implementation of Hydro- flume, production cost per season or per year, and cropping pattern were evaluated. Climatic data of irrigation scheme has been collected from Metahara Sugar Factory Research Center.

Based on the results of inflow and tail water measurements and the determination of moisture contents of the soil samples, technical parameters and economic analyses of hydro-flume of the scheme, and performance indicators like conveyance efficiency, water delivery efficiency, water application efficiency, water spreading uniformity over the fields, water storage efficiency of the fields and water loss measures such as runoff ratio and deep percolation fraction, crop water requirements and irrigation schedule of sugarcane, sustainability of irrigation scheme, sugarcane performance, machines efficiency, amount of land save, construction cost of drop box, additional cost of labor, and bed preparation of feeder ditch (open ditch) were calculated.

The gate pipe (hydro-flume), discharge along the length of the pipe varied differently for each field along the hydro flume length (slopes). The mean values of discharge along the length of the pipe were 2.93, 3.27 and 3.14 l/s respectively, which was less than the designed discharge (5 l /s) .This variation, affects the uniformity of irrigation.

The conveyance efficiencies of the main canal, and supply canal, were found to vary from 94 % (for main canal) to 90.2 % (for supply canal) with 92.17 % as the mean value of the scheme. This indicates that about 7.83 % of the canal water is lost before reaching the target fields, which is unacceptable because this much percentage of water loss difficult due to the shortage of water supply in the scheme.

The water application efficiency of selected three estate farmers, which is a measure of how much volume of the applied water was actually stored in the root zone, value from 59.58 % (at field-1), 58.69 % (at field-2) and 57.39 % (at field-3) with 58.55% as the average application efficiency of the scheme which is unacceptable value. This indicates that once water reaches the fields, major part is lost as runoff and deep percolation and cannot be used by crops. From the results obtained, this study shows that the value found during the research were similar in terms of water application efficiency.

The distribution uniformity, which is a measure of how uniformly water was spread over the field, was found to be in the range of 86 % (at field-1), 85.25 % (at field-2), and 85.02 % (at field-3) with 85.42 % as the average value of the scheme, which can be considered as satisfactory. This means that 85-86 % of the field receives and stores equal amount of water.

As a measure of how well the root zone moisture content is refilled to field capacity level by the applied irrigation water, water storage efficiency was calculated to range from 99.45 %

(for field-1), 99.41 % (for field-2) and 99.41 % (for field-3) with an average value of 99.43 % for the whole scheme. This shows that, irrigation application successfully achieves its purpose of refilling the root zone to field capacity and soil infiltration rate.

In order to account for water lost (in the form of runoff and deep percolation) from the fields, runoff ratio and deep percolation fraction were computed and found to be in the range from 0-18.76 % and 23.03-23.38 %, respectively. The main cause of water loss is therefore found to be deep percolation. Since block-end furrow irrigation is a common practice, only small volume of water is lost as runoff. This study also concludes that more water loss from the fields as deep percolation. As a result, even if the runoff loss is minimal, deep percolation loss is found to be unacceptable.

The trend of sustainability of the irrigation scheme was assessed dividing the current irrigated area by the initial irrigated area when the system was first fully developed. The total size of the scheme was initially designed to irrigate 11,000 ha; but currently it is irrigating only 10,240 ha. This clearly shows that sustainability of the Metahara Sugar Factory irrigation scheme is greatly endangered because only 93.00 % of the design size is currently under irrigation. Rapid expansion of Lake Beseka, expansions of community managed small scale farm around the estate farm, waterlogging, and du to relative shortage of water the command area are the major reasons observed in the field as threats to its sustainability.

To estimate the Crop water requirement, irrigation scheduling and irrigation requirement of the irrigated crops at field levels and the irrigation fields as a whole the Crop Wat for windows computer program (Crop Wat 8.0 Windows Version 8.1) was used.

The net depth of application or perceived application depth (targeting 60cm rooting depth), the required gross application depth, and cut off time (at 5 l/sec inflow rate to each furrow, 100m furrow and its design application efficiency of 60 %) estimated.

These gross application depths are the amount of water to be applied in matured cane (12 months) to achieve at least the design application efficiency (60 %) in respective soils. Thus, they are the maximum amount of water to be applied in respective soils for acceptable performance. Obviously, when the cane is younger the amount should be smaller and when more efficient application practices are followed the amounts would be smaller. Still, targeting the same application efficiency in different soils even under the same furrow length is not advisable.

Depending on the soil type, month of irrigation, and cane growth stages the Estate use the following irrigation intervals. For heavy clay soil, an average irrigation interval of 11, 13, 14, 22 days for respective growth stages can be used. For clay and clay over loamy soils, an average irrigation interval of 10, 13, 14, 21 days for respective growth stages can be used. For loam soil an average irrigation interval of 9, 11, 12, 18 days for respective growth stages can be used. For sandy, very gravelly, pumice soils an average irrigation interval of 8, 10, 11; 16 days for respective growth stages can be used.

Analysis on performance of cane yield and sugar yield were also carried out. The effect of furrow length and flow rate on cane yield was found to be significant. The highest cane yield 13.12 t/ha/month were obtained from the treatment combination of 0.05 % slope (S), 100 m furrow length (F) and 5 l/s flow rate (Q) and the least yield 9.08 t/ha/month were obtained from the treatment combination of 0.05 % slope (S), 100 m furrow length (F) and 5 l/s flow rate (Q). Similarly, the effects of flow rate were significantly different.

Net cost saving and benefit obtained after implementation of Hydro-flume on Plantation Department, Land Preparation and Cultivation Department and Civil Engineering Department of Estate Farm were 1,947,883.64 birr.

5.2. Conclusions

From the field assessment results, the following conclusions are drawn:

- The relationship between pressure and discharge per out let for full area open, 3/4 the area open and ½ of the area open for single outlet openings indicated strong relationship for all three openings. Discharge per out let was dependent on the pressure inside the gate. The pressure depends on the slope along gated pipe (bed slope) and area of out let opening. The gate discharge along the length of the pipe varied differently for each fields, and the mean values of discharge along the length of the pipe 3.11 l/s, which was less than the designed discharge 5 l/s. This variation affects the uniformity of irrigation. Therefore, to maintain uniform application; gated pipe application is best fitted to fields with smaller slopes (<0.5 %).
- Performance of Metahara Sugar Factory Estate large-scale irrigation scheme is considered as unsatisfactory in terms of water application efficiency of the fields (58.55%), deep percolation fraction (22.92 %), runoff ratio (18.58 %), conveyance efficiency (92.17 %) and sustainability of irrigated Area (93 %).This means a lot of water is lost as steady-state and transient losses from the canals. Once reaches to fields, the water is also lost as deep percolation and runoff ratio during application by daily workers due to their poor water management practice that depends mainly on preventing of runoff loss. Because of the rapid expansion of upstream and downstream large-scale farms relative water shortage, more than (10 %) of the total area put under irrigation due to expansion of Lake Beseka, waterlogging, poor maintenances of drainage and salinity of irrigation water, shows sign of declining; meaning that the sustainability of the irrigation scheme is endangered.
- However, the irrigators performed well in uniformly spreading water over their fields, average distribution uniformity (85.42 %); meaning that more than 85 % of the field gets equal amount of water to the root zone. The irrigation schemes also performed well in terms of water storage efficiency (99.43 %).The result of water storage efficiency tells us that about 99.43 % of the moisture depleted below FC evapotranspiration was refilled by irrigation water. Similarly, the Estate has

appreciable technique to prevent runoff loss by using block-end furrow irrigation practice.

- Analysis on performance of cane yield and sugar yield were also carried out. The effect of furrow length and flow rate on cane yield was found to be significant. The highest cane yield 13.12 t/ha/month were obtained from the combination of 100 m furrow length and 5 l/s flow rate and, the least yield 9.08 t/ha/month were obtained from combination of, 100 m furrow length and 5 l/s flow rate. Similarly, the effects of flow rate were significantly different.
- Estate has obtained total, net cost saving and benefit, after implementation of hydro-flume were 1,947,883.64 birr. The result shows that Hydro-flume has made furrow irrigation more efficient, using less area compare to open earthen ditch, easy to operate machines for varies activities, easy to operate and maintain, applied fully at Metahara sugarcane plantation and familiarized for other irrigation schemes.

5.3. Recommendations

The following recommendations are suggested based on the conclusion drawn and the field observations made

- The results of this study, using gated pipe (Hydro-flume) that proper distribution of water in the field, reducing water consumption and increase yield due to increase land and water use efficiency are recommended. In addition to the water crisis, the Estate is facing a lot the evidence showed that in the future not very far, with the energy crisis. Development methods such as irrigation with gated pipe while promoting efficiency, and also high distribution must be considered.
- Under Metahara Plantation field conditions, the gated-pipe (hydro-flume), system is better than the open field head ditch irrigation system, keeping in mind that for more uniform water distribution through irrigated 100 m long furrow length fields of Metahara, increased pressure head at the inlet and/or larger openings of the hydro-flume gates necessary.
- The material was very sensitive and easy to damage, so a more dependable material should be used.
- Metahara Sugar Factory is adopted used 16” diameter flexible pipe for the recommended topography and slope, but for future, the detail topography map will be prepared and accordingly as per the monograph and material property, the order of flexible pipe will be adjusted as per the topo map and longitudinal slope of the field.
- Replace damaged hydro-flumes with new ones in order to reduce water logging and excess infield water losses.
- Hydro-flume has made furrow irrigation more efficient, easy to operate and maintain, it is not applied fully at Metehara Sugarcane Plantation and familiarized for other irrigation schemes due to its high initial investment cost. Therefore, concerned bodies (stakeholders) should give attention to manufacture hydro-flume (flexible gated pipe) in Ethiopia in order to make it affordable for sugar industry.
- The optimum length of furrow is usually the longest furrow that can be safely and efficiently irrigated. If the length is too long, water percolates deep at the head of the furrow, the time stream reaches the lower end. This result in over Irrigation at the

upper end or under Irrigation at the lower end. Short furrows require more Hydro-flume and more land to install which, in turn, demands high initial capital for Implementation. So that it is better to revise proper furrow length depends on the hydraulic conductivity of the soil to maximize our profit.

- Decrease the size of the flexible pipe for steep slope fields and the number of energy dissipater that can resist increasing existed pressure from previous one. Static head pressure.
- Implementing the revised irrigation scheduling in order to improve the water management practice.
- Training mainly based on the importance of irrigation water, how to use the scarce water resource and how to manage it should be given for stakeholder. By doing these it can be reduce over irrigation practices, consecutively reduce effect of waterlogging, maximize production of sugarcane and improve efficiency and uniformity will minimize irrigation water loss.

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7. APPENDICES

Appendix Table 1. Pressure and Discharge Measurement per Outlet field-1

Out let number	River Land Experiment – I		Hydro-flume length (m)
	Pressure (mm)	Discharge (l/s)	
1	42.35	1.98	0
2	169.4	4.20	20
3	108.9	3.63	40
4	112.53	3.11	60
5	113.3	1.54	80
6	24.2	2.98	100
7	60.5	3.52	120
8	48.4	3.75	140
9	145.2	3.52	160
10	121	1.21	180
11	36.3	3.33	200
12	48.4	2.00	220
13	60.5	2.75	240
14	96.8	3.09	260
15	133.1	2.92	280
16	157.3	2.54	300
17	137.5	3.22	320
18	150.5	3.40	340

Appendix Table 2. Pressure and Discharge Measurement per Outlet field -2

out let number	River Land Experiment – II		
	pressure(mm)	discharge(l/s)	Hydro-flume length(m)
1	127.05	3.03	0
2	148.83	3.37	20
3	96.80	2.57	40
4	96.80	2.20	60
5	108.90	2.78	80
6	159.72	3.63	100
7	157.30	3.30	120
8	143.00	2.97	140
9	165.00	4.07	160
10	107.80	2.75	180
11	148.50	3.08	200
12	154.00	3.19	220
13	124.30	2.97	240
14	112.20	2.86	260
15	148.50	3.08	280
16	176.00	4.40	300
17	170.50	4.29	320
18	176.00	4.40	340
19	168.30	4.18	360
20	176.00	4.62	380
21	181.50	4.73	400

Appendix Table 3. Pressure and Discharge Measurement per Outlet field -3

Out Let Number	River Land Experiment– III		
	pressure(mm)	discharge(l/s)	Hydro-flume length (m)
1	150.0	2.31	0
2	140.0	3.3	20
3	130.0	3.74	40
4	230.0	4.0	60
5	94.0	2.31	80
6	124.3	2.75	100
7	104.5	2.97	120
8	159.5	3.3	140
9	140.0	3.30	160
10	130.0	3.74	180
11	120.0	3.50	200
12	115.0	3.10	220
13	150.0	2.30	240
14	160.0	3.40	260
15	170.0	3.70	280
16	163.0	3.50	300
17	174.0	3.80	320
18	160.0	3.30	340
19	150.0	2.40	360
20	147.0	3.70	380
21	180.0	4.10	400
22	187.0	4.3	420
23	190.0	4.70	440
24	192.0	4.90	460

Appendix Table 4. Determination of Net Depth for Irrigation Event Four before and after hilling up

Trail id	FC	soil moisture at			FC-moisture	Average BD	Z	MAD	SMD(cm/m)	RAW(mm)
		0-30	30-60	average						
I-1	40.33	20.77	22.22	21.5	18.83	1.31	0.6	1	14.80	148.00
I-2	40.33	33.93	31.61	32.7	7.63	1.31	0.6	1	6.00	59.97
I-3	40.33	38.21	36.11	37.16	3.17	1.31	0.6	1	2.49	24.92
I-4	40.33	37.96	36.57	37.26	3.07	1.31	0.6	1	2.41	24.13
I-5	40.33	35.03	36.77	35.9	4.43	1.31	0.6	1	3.48	34.82
I-6	40.33	36.4	35.2	35.8	4.53	1.31	0.6	1	3.56	35.61
I-7	40.33	37.2	34.2	35.7	4.63	1.31	0.6	1	3.64	36.39
I-8	40.33	38.1	36.3	37.2	3.13	1.31	0.6	1	2.46	24.60
I-9	40.33	28.3	31.2	29.75	10.58	1.31	0.6	1	8.32	83.16
I-10	40.33	32.5	36.1	34.3	6.03	1.31	0.6	1	4.74	47.40
I-11	40.33	30.2	29.3	29.75	10.58	1.31	0.6	1	8.32	83.16
I-12	40.33	32.5	30.2	31.35	8.98	1.31	0.6	1	7.06	70.58
I-13	40.33	34.8	29.8	32.3	8.03	1.31	0.6	1	6.31	63.12

Appendix Table 5.The effect of flow rate and furrow length on storage and distribution efficiency

Trail id	Average infiltrated depth (mm)	Average min. depth (mm)	Stream size(l/s)	Required Depth(mm)	Average Stored Depth(mm)	Storage efficiency (%)	Distribution efficiency (%)
I-1	95.42	80.6	1.98	74.25	73.1	98.45	84.47
I-2	92.23	82.1	4.20	74.25	73.4	98.86	89.02
I-3	90.8	80.3	3.63	74.25	72.75	97.98	88.44
I-4	106.9	86.8	3.11	74.25	74.04	99.72	81.20
I-5	101.2	86.8	1.54	74.25	73.93	99.57	85.77
I-6	97.3	83.4	2.98	74.25	73.75	99.33	85.71
I-7	114.52	92.1	3.52	74.25	74.25	100.00	80.42
I-8	106.8	90.45	3.75	74.25	74.25	100.00	84.69
I-9	103.4	91.79	3.52	74.25	74.25	100.00	88.77
I-10	108.2	91.67	1.21	74.25	74.25	100.00	84.72
I-11	102.23	89.45	3.33	74.25	74.07	99.76	87.50
I-12	98.5	86.78	2.00	74.25	74	99.66	88.10
I-13	98.14	84.79	2.75	74.25	73.8	99.39	86.40
I-14	94.76	82.2	3.09	74.25	73.4	98.86	86.75
I-15	90.23	80.12	2.92	74.25	73.15	98.52	88.80
I-16	116.61	94.45	2.54	74.25	74.25	100.00	81.00
I-17	108.3	95.4	3.22	74.25	74.25	100.00	88.09
I-18	106.85	94.23	3.40	74.25	74.25	100.00	88.19
Scheme Efficiency (%)			2.93			99.45	86.00

Appendix Table 6.The effect of flow rate and furrow length of storage and distribution efficiency

Trail id	Average infiltrated depth (mm)	Average min. depth (mm)	Stream size(l/s)	Required Depth(mm)	Average Stored Depth(mm)	Storage efficiency (%)	Distribution efficiency (%)
I-1	106.8	89.2	3.03	74.25	74.04	99.72	83.52
I-2	101.9	88.2	3.37	74.25	74.18	99.91	86.56
I-3	98.27	84.83	2.57	74.25	73.64	99.18	86.32
I-4	98.6	83.41	2.20	74.25	73.75	99.33	84.59
I-5	94.71	81.47	2.78	74.25	73.45	98.92	86.02
I-6	91.4	80.53	3.63	74.25	73	98.32	88.11
I-7	114.4	93.01	3.30	74.25	74.25	100.00	81.30
I-8	109.34	90.46	2.97	74.25	74.22	99.96	82.73
I-9	105.76	92.83	4.07	74.25	74.25	100.00	87.77
I-10	114.35	93.07	2.75	74.25	74.25	100.00	81.39
I-11	109.68	93.1	3.08	74.25	74.25	100.00	84.88
I-12	106.03	92.4	3.19	74.25	74.25	100.00	87.15
I-13	105.78	87.4	2.97	74.25	74.07	99.76	82.62
I-14	102.35	86.2	2.86	74.25	73.86	99.47	84.22
I-15	98.95	83.85	3.08	74.25	73.43	98.90	84.74
I-16	97.56	83.02	4.40	74.25	73.75	99.33	85.10
I-17	93.45	84.21	4.29	74.25	73.4	98.86	90.11
I-18	90.62	79.21	4.40	74.25	72.55	97.71	87.41
Scheme Efficiency (%)			3.27			99.41	85.25

Appendix Table 7.The effect of flow rate and furrow length of storage and distribution efficiency

Trail id	Average infiltrated depth (mm)	Average min. depth (mm)	Stream size(l/s)	Required Depth(mm)	Average Stored Depth(mm)	Storage efficiency (%)	Distribution efficiency (%)
I-1	106.78	86.33	3.03	74.25	73.68	99.23	80.85
I-2	102.59	86.38	3.37	74.25	73.64	99.18	84.20
I-3	97.13	83.05	2.57	74.25	73.36	98.80	85.50
I-4	115.01	91.93	2.20	74.25	74.25	100.00	79.93
I-5	108.07	91.46	2.78	74.25	74.25	100.00	84.63
I-6	105.31	93.3	3.63	74.25	74.25	100.00	88.60
I-7	97.9	83.73	3.30	74.25	73.5	98.99	85.53
I-8	93.7	82.5	2.97	74.25	73.5	98.99	88.05
I-9	91.3	79.56	4.07	74.25	72.1	97.10	87.14
I-10	116.03	94.72	2.75	74.25	74.25	100.00	81.63
I-11	108.72	91.79	3.08	74.25	74.25	100.00	84.43
I-12	104.74	92.7	3.19	74.25	74.25	100.00	88.50
I-13	107.56	90.7	2.97	74.25	74.25	100.00	84.33
I-14	103.5	90.03	2.86	74.25	74.18	99.91	86.99
Scheme Efficiency (%)			3.14			99.44	85.02

Appendix Table 8.The effect of flow rate and furrow length on runoff ratio and deep percolation ratio

Trail id	Average DP depth (mm)	Stream size(l/s)	Applied(mm)	Runoff Depth(mm)	Runoff ratio (%)	Deep percolation ratio (%)
I-1	24.6	1.98	115.2	16.7	14.50	21.35
I-2	20.7	4.20	116.4	20.6	17.70	17.78
I-3	21	3.63	121.45	28.8	23.71	17.29
I-4	35.5	3.11	132.4	24.5	18.50	26.81
I-5	29.6	1.54	123.21	22.2	18.02	24.02
I-6	24.4	2.98	116.23	21.2	18.24	20.99
I-7	38.2	3.52	142.33	29.02	20.39	26.84
I-8	32.65	3.75	128.2	20.2	15.76	25.47
I-9	26.7	3.52	120.29	23.46	19.50	22.20
I-10	34.78	1.21	130.16	23.04	17.70	26.72
I-11	29.4	3.33	123.48	21.51	17.42	23.81
I-12	26.55	2.00	119.46	21	17.58	22.23
I-13	26.01	2.75	112.77	15.63	13.86	23.06
I-14	22.32	3.09	116.05	21.3	18.35	19.23
I-15	20.82	2.92	122.3	31.3	25.59	17.02
I-16	40.36	2.54	147.5	27.1	18.37	27.36
I-17	36.03	3.22	130.4	21.32	16.35	27.63
I-18	30.52	3.40	123.45	27.12	21.97	24.72
Scheme irrigation water losses (%)		2.93			18.53	23.03

Appendix Table 9.The effect of flow rate and furrow length on runoff ratio and deep percolation ratio

Trail id	Average DP depth (mm)	Stream size(l/s)	Applied(mm)	Runoff Depth(mm)	Runoff ratio (%)	Deep percolation ratio (%)
I-1	33.81	3.03	133.23	20.45	15.35	25.38
I-2	27.61	3.37	124.51	21.31	17.12	22.17
I-3	24.3	2.57	119.98	22.4	18.67	20.25
I-4	26.4	2.20	122.6	22.97	18.74	21.53
I-5	21.12	2.78	112.3	19.81	17.64	18.81
I-6	20.47	3.63	119.51	26.81	22.43	17.13
I-7	40.11	3.30	144.62	26.2	18.12	27.73
I-8	33.87	2.97	130.91	22.77	17.39	25.87
I-9	39.51	4.07	124.78	19.02	15.24	31.66
I-10	40.14	2.75	147.9	27.25	18.42	27.14
I-11	33.54	3.08	131.56	22.3	16.95	25.49
I-12	29.77	3.19	126.43	26.11	20.65	23.55
I-13	33.43	2.97	135.46	25.65	18.94	24.68
I-14	25.87	2.86	127.78	26.02	20.36	20.25
I-15	24.18	3.08	120.61	24.9	20.65	20.05
I-16	24.11	4.40	121	23	19.01	19.93
I-17	20.1	4.29	111.52	17.3	15.51	18.02
I-18	15.98	4.40	120.42	32	26.57	13.27
Scheme irrigation water losses (%)		3.27			18.53	23.03

Appendix Table 10.The effect of flow rate and furrow length on runoff ratio and deep percolation ratio

Trail id	Average DP depth (mm)	Stream size(l/s)	Applied(mm)	Runoff Depth (mm)	Runoff ratio (%)	Deep percolation ratio (%)
I-1	34.14	3.03	135.31	24.67	18.23	25.23
I-2	29.42	3.37	123.5	19.9	16.11	23.82
I-3	20.68	2.57	117.2	23.64	20.17	17.65
I-4	40.05	2.20	146.13	25.42	17.40	27.41
I-5	33.71	2.78	132.8	23.62	17.79	25.38
I-6	30.06	3.63	126.9	20.57	16.21	23.69
I-7	25.18	3.30	121.59	22.7	18.67	20.71
I-8	20.47	2.97	113	18.31	16.20	18.12
I-9	19.77	4.07	121.01	28.72	23.73	16.34
I-10	40.78	2.75	147.9	27.49	18.59	27.57
I-11	33.47	3.08	132.93	23.2	17.45	25.18
I-12	35.45	3.19	126.35	26.16	20.70	28.06
I-13	35.11	2.97	137.79	24.76	17.97	25.48
I-14	28.59	2.86	128.41	24.41	19.01	22.26
Scheme irrigation water losses (%)		3.14				

Appendix Table 11.Theoretical intervals of sugarcane plantation at Estate Farm

Growth stage	Jan.	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
	Heavy clay soils											
0-3 months	12	11	10	10	10	8	9	10	11	11	12	13
3-6 months	13	13	13	12	11	8	17	25	13	12	12	12
6- 15 months	14	14	14	13	12	9	17	23	15	13	14	14
>15 months	23	24	24	23	20	15	-	-	26	22	21	21
	clay, clay over loamy soils											
0-3 months	12	10	10	9	9	7	8	10	10	10	12	12
3-6 months	12	12	12	11	10	8	16	24	13	11	12	12
6- 15 months	13	13	13	12	11	9	16	22	14	13	13	13
>15 months	21	23	23	21	19	14	-	-	24	21	20	20
	loamy soils											
0-3 months	10	9	8	8	8	6	7	8	9	9	10	10
3-6 months	10	11	10	10	9	7	14	20	11	10	10	10
6- 15 months	12	12	11	11	10	8	14	19	12	11	11	11
>15 months	18	20	20	19	17	12	-	-	21	18	18	18
	Sandy, very gravelly, pumice soils											
0-3 months	9	8	7	7	7	6	7	8	8	8	9	9
3-6 months	9	10	9	9	8	6	13	18	10	9	9	9
6- 15 months	10	10	10	10	9	7	13	17	11	10	10	10
>15 months	17	18	18	17	15	11	-	-	19	16	16	16

NB. Sign (-) indicates no irrigation is required

AppendixTable12 .The effect of flow rates and furrow length on application efficiency (%)

Irrigation method	Average length(m)	Stream size(l/s)	Applied Depth(mm)	Stored Depth(mm)	Application efficiency (%)
Gravity(furrow)	100	1.98	115.2	73.1	63.45
<<	100	4.20	116.4	73.4	63.06
<<	100	3.63	121.45	72.75	59.90
<<	100	3.11	132.4	74.04	55.92
<<	100	1.54	123.21	73.93	60.00
<<	100	2.98	116.23	73.75	63.45
<<	100	3.52	142.33	74.25	52.17
<<	100	3.75	128.2	74.25	57.92
<<	100	3.52	120.29	74.25	61.73
<<	100	1.21	130.16	74.25	57.05
<<	100	3.33	123.48	74.07	59.99
<<	100	2.00	119.46	74	61.95
<<	100	2.75	112.77	73.8	65.44
<<	100	3.09	116.05	73.4	63.25
<<	100	2.92	122.3	73.15	59.81
<<	100	2.54	147.5	74.25	50.34
<<	100	3.22	130.4	74.25	56.94
<<	100	3.40	123.45	74.25	60.15
Scheme application efficiency (%)	100	2.93			59.58

Appendix Table 13.The effect of flow rate and furrow length on application efficiency (%)

Irrigation method	Average length(m)	Stream size(l/s)	Applied Depth(mm)	Stored Depth(mm)	Application efficiency (%)
Gravity(furrow)	100	3.03	133.23	74.04	55.57
<<	100	3.37	124.51	74.18	59.58
<<	100	2.57	119.98	73.64	61.38
<<	100	2.20	122.6	73.75	60.15
<<	100	2.78	112.3	73.45	65.41
<<	100	3.63	119.51	73.00	61.08
<<	100	3.30	144.62	74.25	51.34
<<	100	2.97	130.91	74.22	56.70
<<	100	4.07	124.78	74.25	59.50
<<	100	2.75	147.9	74.25	50.20
<<	100	3.08	131.56	74.25	56.44
<<	100	3.19	126.43	74.25	58.73
<<	100	2.97	135.46	74.07	54.68
<<	100	2.86	127.78	73.86	57.80
<<	100	3.08	120.61	73.43	60.88
<<	100	4.40	121	73.75	60.95
<<	100	4.29	111.52	73.4	65.82
<<	100	3.03	120.42	72.55	60.25
Scheme Application Efficiency (%)	100	3.27			58.69

Appendix Table 14.The effect of flow rate and furrow length on application efficiency (%)

Irrigation method	Average length(m)	Stream size(l/s)	Applied Depth(mm)	Stored Depth(mm)	Application efficiency (%)
Gravity(furrow**)**	100	2.31	135.31	73.68	54.45
<<	100	3.30	123.5	73.64	59.63
<<	100	3.74	117.2	73.36	62.59
<<	100	4.0	146.13	74.25	50.81
<<	100	2.31	132.8	74.25	55.91
<<	100	2.75	126.9	74.25	58.51
<<	100	2.97	121.59	73.5	60.45
<<	100	3.30	113	73.5	65.04
<<	100	3.30	121.01	72.1	59.58
<<	100	3.74	147.9	74.25	50.20
<<	100	3.50	132.93	74.25	55.86
<<	100	3.10	126.35	74.25	58.77
<<	100	2.30	137.79	74.25	53.89
<<	100	3.40	128.41	74.18	57.77
Scheme Application Efficiency (%)	100	3.14			57.39

Appendix Table 15.The effect of irrigation water application on sugar cane performance

Trail ID	No of Stalk per plot	stock weight (kg)	Cane field yield	Sucrose % cane	Sugar yield (t/ha)	Brix%	Pol%	Purity (%)
I-1	92	2.12	11.61	9.22	0.96	17.53	16.26	92.73
I-2	100	2.2	9.08	9.65	1.05	15.39	13.35	86.75
I-3	96	2.14	10.13	10.72	1.18	16.92	15.63	92.37
I-4	92	1.99	11.44	9.44	1.08	16.02	13.89	86.70
I-5	89	2.15	12.02	9.17	1.10	15.97	13.64	85.41
I-6	96	2.18	13.12	8.26	1.08	14.78	12.44	84.17
I-7	89	2.04	11.36	10.78	1.22	17.73	15.64	88.21
I-8	82	2.25	11.60	10.51	1.22	17.36	15.28	88.02
I-9	86	2.21	11.94	11.25	1.34	17.83	16.07	90.13
I-10	74	2.2	10.15	10.56	1.07	17.20	15.26	88.72
I-11	74	2.28	10.56	11.29	1.19	18.01	16.17	89.78
I-12	82	2.11	10.82	10.26	1.11	17.25	15.03	87.13
I-13	90	2	11.25	10.94	1.23	18.13	15.93	87.87
I-14	94	1.93	11.41	10.66	1.22	17.61	15.50	88.02
Mean			11.18		1.15			

Appendix Table 16.Free flow discharge values for different size of Parshall flumes

Head (cm)	Thought width (inches)				
	1	2	3	6	9
	Discharge (l/s)				
2	0.140	0.281			
3	0.263	0.526	0.772	1.496	2.504
4	0.411	0.822	1.206	2.357	3.889
5	0.581	1.162	1.705	3.354	5.471
6	0.771	1.541	2.261	4.473	7.232
7	0.979	1.957	2.872	5.707	9.155
8	1.205	2.407	3.532	7.047	11.231
9	1.446	2.889	4.239	8.489	13.448
10	1.702	3.402	4.991	10.027	15.801
11	1.973	3.943	5.786	11.656	18.281
12	2.258	4.513	6.621	13.374	20.885
13	2.557	5.109	7.496	15.177	23.605
14	2.868	5.731	8.408	17.062	26.440
15	3.191	6.377	9.358	19.027	29.383
16	3.527	7.048	10.342	21.070	32.433
17	3.875	7.743	11.361	23.188	35.585
18	4.234	8.460	12.413	25.38	38.837
19	4.604	9.200	13.499	27.643	42.186
20	4.985	9.961	14.616	29.976	45.630
21	5.376	10.744	15.764	32.379	49.167
22		11.547	16.942	34.848	52.794
23			18.151	37.384	56.510
24			19.389	39.984	60.312

Appendix Table 17. Determination of Cutoff time and applied depth for irrigation event 1& 2

Trail code	Furrow		SMD	Q	Ea	cut off time	Applied depth (mm)
	length	width					
	1	2	3	4	5	F=(1*2*3) / (60*4*5)	
I-1	100	0.9	89.44	4	0.65	51.6	137.6
I-2	100	0.9	90.53	3.3	0.65	63.31	139.28
I-3	100	0.9	89.62	3.3	0.65	62.67	137.88
I-4	100	0.9	111.55	3.3	0.65	156.01	171.62
I-5	100	0.9	109.95	3.06	0.65	165.84	169.15
I-6	100	0.9	110.39	2.75	0.65	185.27	169.83
I-7	100	0.9	90.97	2.75	0.65	76.34	139.95
I-8	100	0.9	89.01	2.97	0.65	69.16	136.94
I-9	100	0.9	87.85	2.31	0.65	87.76	135.15
I-10	100	0.9	111.01	2.34	0.65	218.95	170.78
I-11	100	0.9	114.13	2.75	0.65	191.55	175.58
I-12	100	0.9	113.44	2	0.65	261.78	174.52

Appendix Table 18.Computation of hydro-flume with earthen open ditch (feeder ditch)

S/no	Descriptions of system components	Hydro- flume	Feeder ditch(open earthen ditch)
1	water conveyance efficiency	98% water conveyance efficiency i.e. no water loss due to seepage, evaporation, and over flow	90% conveyance efficiency, Very high water loss due to seepage, evaporation, leakage and over flow
2	Annual maintenance cost	Minimum annual maintenance cost	high annual maintenance cost
3	Machinery efficiency	Increase machinery efficiency	Decrease machinery efficiency
4	Farm area	Less farm area are occupied with this method	Large farm area are occupied with this method
5	Ergonomic advantages	high	low
6	Soil compaction	Reduce soil compaction	High soil compaction
7	Cane damage	Minimize cane damage	maximize cane damage
8	Accumulation of salts in soil and root zone	Preventing the accumulation of salts in soil and root zone	High accumulation of salts in soil and root zone
9	Control on the flow of water input to furrow	Full control on the flow of water input to furrow	Difficult to control the flow of water input to furrow
10	Labor requirement	Minimum labor requirement, 3 labor /ha	Maximum labor requirement,4 labor /ha
11	The possibility of collecting tubes during usage of farm machinery and field preparation	Highly important	Less important
12	Water use per hectare	1.470 m^3/ha, only 2% of water loss	1.350 m^3/ha, 10% of water loss