



**PERFORMANCE EVALUATION OF FIELD WATER
APPLICATION ON FURROW IRRIGATION AT WONJI SHOA
SUGAR ESTATE, ETHIOPIA**

MSc THESIS

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HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

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EXAMINERS' APPROVAL SHEET

We, the undersigned, members of the Board of Examiners of the final open defense by **TSIGE MOHAMMED AHMED** have read and evaluated her thesis entitled **“PERFORMANCE EVALUATION OF FIELD WATER APPLICATION ON FURROW IRRIGATION AT WONJI SHOA SUGAR ESTATE, ETHIOPIA”**, and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree **Masters of Science in Water Resource Engineering with Specialization in Irrigation and Drainage Engineering**.

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STATEMENT OF AUTHOR

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

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LIST OF ABBREVIATIONS AND ACRONYMS

σ_Y	Surface Shape Factor
σ_z	Sub-Surface Shape Factor
ALARC	Arid-Land Agricultural Research Center
ATVET	Agricultural Transformation Vocational Education Training
DPR	Deep Percolation Ratio
DU	Distribution Uniformity
Ea	Application Efficiency
EIA	Ethiopian Investment Agency
Es	Storage Efficiency
FAO	Food and Agriculture Organization of the United Nations
FC	Field Capacity
FDRESC	Federal Democratic Republic of Ethiopia Sugar corporation
FN	Field Number
Fn	Furrow of Number
ILRI	International Livestock Research Institute
IWMI	International Water Management Institute
MARC	Melkassa Agricultural Research Center
MAE	Mean Absolute Error
RMSE	Root Mean Square Error
Mha	Million hectare
MoARD	Ministry of Agriculture and Rural Development
MoAFRA	Ministry of Agriculture, Food and Rural Affairs
MoWR	Ministry of Water Resources
NRCS	Natural Resources Conservation Service
NSW	New South Wales
PWP	Permanent Wilting Point
R^2	Coefficient of Determination
RD	Depth of the Root Zone

SIRMOD	Surface Irrigation Simulation, Evaluation and Design Software
SMD	Soil Moisture Deficit
SMIS	Small Scale and Micro Irrigation Support Project
TAW	Total Available Water
TWR	Tail Water Ratio
USAID	United State Agency for International Development
USDA	United States Department of Agriculture
V_z	Volume of Infiltrated
WinSRFR	Surface Irrigation Analysis, Design, and Simulation Software
WSSF	Wonji Shoa Sugar Factory
Z	Depth of Infiltrated
Z_{av}	Average infiltrated depth of water over entire field
MBE	Minitab Blog Editor
Z_{lq}	Low quarter average infiltrated water of the field
Z_{req}	Required Depth

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ABSTRACT

Furrow irrigation is dominantly used method of surface irrigation in the large sugar cane irrigation projects in Ethiopia. This research was conducted to evaluate the performance of furrow irrigation with SIRMOD software by two point method and evaluate current performance of furrow irrigation system, identify the performance gaps and recommend means of performance improvement at Wonji Shoa Irrigation Estate. Three fields were selected according to soil type, furrow length and workability for measurement with field code 15, 52,108 which had furrow length of 64 m, 48 m and 32 m which was practice in the sugar estate. Different performance indicators were used to evaluate performance of furrow irrigation they were application efficiency, storage efficiency, application uniformity and deep percolation ratio. The estimated and simulation result obtained from the average application efficiency of the three selected fields (15, 52, and 108) were 74.42%, 41.19% and 64.12% and 74.39%, 50.20% and 75.18% respectively. The storage efficiency values for three selected fields were 100% for estimation and 99.11%, 99.67% and 99.65% for simulation respectively. The estimation and simulation average distribution uniformity of the three selected fields were 91.86%,90.78% and 89.86% and 92.44%,91.38% and 93.26% respectively and the deep percolation ratio for estimated and simulation were 25.35%,58.81% and 35.88% and 25.35%, 49.48% and 24.5 respectively . From the selected fields, filed 15 and 108 had better application efficiency with furrow length 64 and 32 respectively than the filed 52 with furrow length 48 m and the field 52 had low application efficiency and high deep percolation ratio. The result obtained from sensitivity analysis; discharge, cutoff time and length of furrow were highly sensitive to application efficiency and deep percolation ratio, whereas the slope of furrow had no effect on performance indicator in this study. The amount of water applied during irrigation event were more than the irrigation water required which indicates that large amount of water was being wasted due to poor irrigation water management practice. From the result of this study, it can be concluded that there were over irrigation problems.

Key Words: Furrow Irrigation, Performance evaluation and SIRMOD Model

1. INTRODUCTION

1.1. Background

Different types of surface irrigation projects are found in Ethiopia. Wonji Irrigation Estate is considered as the first commercial large-scale irrigation project in Ethiopia (WSSF, 2011). It was introduced in the 1950s for the production of sugar using water from the Awash River (Awulachew *et al*, 2007). The area developed at Wonji Shoa irrigation estate is 7050 hectares (5930 hectares estate and 1120 hectares out grower farms) capable of producing 80,000 tons of sugar per annum and Sugarcane plantation is continuously expanding and reaches more than 10,000 ha (Yusuf, 2015). The estate farm is cultivated by furrow irrigation system and the out grower land irrigated is by center pivot sprinkler system (EIA, 2012).

If the surface irrigation is to be a sustainable and positive social and economic force in the 21st century, it shall evolve into an efficient, cost effective, and environmentally agreeable technology (Adugnaw, 2017). According to Walker, (1989) surface irrigated agriculture faces a number of problems in the future. One of the major concerns is the poor water use efficiency with which water resources have been used for irrigation, relatively safe estimate is that 40 percent or more of the water diverted for irrigation is wasted at the farm level through either deep percolation or surface runoff.

Improved the management of water resources is needed to ensure the equitable distribution of water to competing users. There are especially significant opportunities for conservation and more effective water use for largest user of agriculture in the worlds. Accurate delivery of the necessary amounts of water at the correct times can both conserve water and improve the quantity and quality of agricultural products (*Bos et al*, 2008). Because of the uncertainty associated with the soil infiltration characteristics, the performance of surface irrigation systems is not predictable without assessing the individual system. Even when a level of performance is dictated by design practices, there is no assurance that the field system will perform as planned (Walker, 2003).

Well-managed furrow irrigation system provides better on-farm water management capabilities for most surface irrigation conditions. Flow rates per unit width can be substantially reduced and topographical conditions can be more severe and variable and

provides operational flexibility for achieving high efficiencies for irrigation throughout a season. Furrow irrigation has one of the lowest application efficiencies among irrigation methods, the least amenable to consistently high levels of performance in furrow irrigation (Walker, 2003). The rate at which water will be absorbed through the soil surface is a nonlinear process which varies both temporally and spatially, and affected by changes in cropping patterns, cultivation, the weathering due to climate, and many other environmental influences. As a result, it is difficult to correctly predict the uniformity and efficiency of irrigation before it occurs. When furrows are too long, deep percolation can occur at the upstream end of the furrow by the time the downstream end is watered adequately (Hubner, 2016).

Monitoring and evaluating of irrigation performance is the first measure that has to be taken to improve irrigation efficiency at field levels (Adugnaw, 2017). From the available literature in that area the Existing furrows irrigation performance of Wonji Showa sugar estate is not yet studied. Therefore this study is focused on evaluation of the performance of furrow irrigation at Wonji Showa sugar estate, evaluating the field irrigation performance in terms of application efficiency, storage efficiency, distribution uniformity and deep percolation ratio, but tail water ratio not evaluated since the downstream Condition is blocked-end. Performance evaluation had now become very important not only to point out where the problem lied but also helps to identify alternatives that may be both effective and feasible in improving system performance

1.2. Statements of the Problem

The main problem that enforcing to this research was Wonjii Showa Sugar Factory which is one of the largest irrigation projects but the incoming flow rate in to the furrow had been used for irrigation not measured and the performance of field water application of furrow irrigation at sugar estate was not been done for long time. Thus this study would be conducted for the purpose of identifying the existing level of field water application efficiencies using appropriate field irrigation performance indicators such as, application efficiency, storage efficiency & distribution efficiency, deep - percolation ratio and to determines the decision variable such as cutoff time, advance & recession of water across the field length and flow rate. Therefore, this study set to solve the management & operational practice of furrow irrigation problem and also evaluations were useful,

particularly to those essential to improve management and control water resource in the study area. In addition, irrigation scheme performance evaluation was vital to evaluate the impacts of irrigation practices, to identify performance gaps and to improve system performance (Solomon, 2016).

In addition to test the concept of the performance that influence on the furrow irrigation system related with field parameters & decision variables of irrigation efficiencies, define irrigation water losses and controlling for irrigation management options for irrigator at Wonjii Shoa Sugar Estate.

1.3. Objective

1.3.1. General objective

The general objective of the study was to evaluate the performance of field water application through furrow irrigation at Wonjii Sugar Estate

1.3.2. Specific objectives

Specific objectives were to:-

1. To evaluate the determinants of field water application for furrow irrigation at Wonjii Shoa Sugar Estate
2. To evaluate the current performance indicators of furrow irrigation at Wonjii Shoa Sugar Estate
3. To test the sensitivity of those determinants of field water application for selected field and furrow length
4. To compare performance indicators values of three selected fields

1.4. Research Questions

- What was the existing furrow irrigation efficiency at Wonjii Shoa Sugar Estate?
- What were the existing performance gaps?
- What were the highly sensitive decision variable to performance indicator?
- Which field (furrow lengths) had better performance

1.5. Scope of the Study

This Msc research was conducted at Wonjii Shao Sugar Estate on performance evaluation of field water application of furrow irrigation for two irrigation event from March 2020-May 2020. The study was focus mainly on the determinants of field water application of furrow irrigation at Wonjii Shoa Sugar Estate.

1.6. Significance of the Study

This study would provide indicative information about the present performance level of the furrow irrigation at Wonjii Shoa Sugar Estate. The performance evaluation of the scheme would help to improve the efficiency of furrow irrigation system in terms of farm water management, checking the effectiveness of the irrigation scheme and to identify the cause's inefficient irrigation management and recommend a remedial measure that improves the performance of the furrow irrigation. The paper was used as a reference for those who will do a research on the performance of furrow irrigation methods on wonji Shoa Sugar Farm Estate or every other area.

2. LITERATURE REVIEW

2.1. Overview of Irrigation

Irrigation is the artificial processes of water application to the land in accord with the irrigation requirement of crop throughout the crop period for full-fledged nourishment of the crops (Garg, 2006). The practice of irrigation is older than civilization and originated certainly in the semi-tropical and arid regions (Asawa, 2008). Irrigation makes a major contribution to agricultural production by making a whole range of crops practice and helping insure against drought, however irrigation does not automatically guarantee profit and approval. It is a high cost exercise, using water from increasingly limited supplies, and raises environmental concerns in the community (Southorn, 1997).

Irrigation in Ethiopia is considered as a fundamental strategy to improve poverty and food security, It is useful to transform from the rain-fed agricultural system which depends on rainfall into the combined rain-fed and irrigation agricultural system and help to promote the most prominent way of sustainable development in the country. However, the development of irrigation practices in Ethiopia has to be studied as to seriously know the history of irrigation emergence and its subsequent developments (Gebremedhin, 2015)

The irrigation potential of Ethiopia is 5.3 Mha of which 3.7 Mha from surface water and 1.6 Mha from ground water and rainwater management and Irrigation development in Ethiopia about 0.7 Mha but the performance of the existing schemes is not well known (Seleshi and Mekonnen, 2011).

A reliable and suitable irrigation water supply can result in vast developments in agricultural production and assure the economic grown of the region. Many civilizations have been dependent on irrigated agriculture to provide the basis of their society and enhance the security of their people (Walker, 1989).

2.2. Importance of Irrigation in Ethiopia

The increment of irrigation and agricultural water management play significant role to improve productivity and minimized environmental change in any country (Seleshi, 2010).

Although Ethiopia has abundant rainfall and water resources, its agricultural system not that much benefit from the technologies of water management and irrigation (SMIS, 2016).

According to Seleshi, (2010) the development of irrigation is an important means for achieving food self-sufficiency in many arid and semi-arid countries, including Ethiopia; the main problem to enhance food security is caused by water scarcity, Water storage structures such as dams, diversions, wells and ponds have become an option to be used for increased agricultural production, including in Ethiopia is a means both to improve the livelihoods of rural people and the sustainability of the economy; agriculture is cover 85% of the Ethiopian population and accounts for 43% of the Gross domestic product (GDP) of the country and over 80 percent of export value.

The first large scale irrigation scheme was introduced in the 1950s at Wonji to develop a sugar cane farm for the production of sugar using water from the Awash River controlled by the Koka Dam (Awulachew *et al*, 2007).

2.3. Irrigation Management

The main aim of irrigation water management in the field level is give irrigation decision makers and understanding of conservation irrigation principles by viewing them how can judge the effectiveness of their own irrigation practices, make good water management decisions, recognize the adjustments and improvements in existing systems or to install new systems (USDA , 1997).

Irrigation management is often designed to increase efficiencies and decrease the labor and capital requirements of that particular irrigation system where as maintaining a favorable growing environment for the plant. Improved and efficient water management practices can support to maintain farm profitability in an area of increasingly limited and more costly water supplies (Ali, 2011 and Walker and Skogerboe, 1987).

Management decisions which were common to all systems are the frequency of irrigation, depth of water to be applied, and measures to increase the uniformity of applications such as land leveling or shaping, individual systems can be manipulated to significantly increase application efficiencies. In furrow irrigation some growers will use two siphon tubes per furrow to increase the efficiency by reducing water lose; at the start of irrigation

two siphon were used (advance phase) and when the water has reached the end of the row, one tube is removed (wetting phase) but it requires an additional labor input(Walker,2003).

Monitoring the performance of irrigation system continuously enables to whether the targets and objectives are being met or not and by improving system performance it help to achieve maximum efficiency (Mintesinot *et al* , 2004). Improper irrigation practices bring inefficient water distribution, non-uniform crop growth and excess leaching or insufficient leaching, so that performance evaluation of irrigation system in the field of irrigation system management is the key point (Dinka , 2017).

2.4. Irrigation Efficiency

The efficiency indicates a ratio of something in to something out (Ali, 2011). Water utilization efficiency was used throughout the data processing as the characteristic of performance (Bos and Nugteren,1990). Irrigation efficiency is a critical aspect for irrigated agriculture and a key constraint due to the competition for water resources (Mangrio *et al*, 2015). Irrigation efficiency implies that how the available water supply is efficiently used, based on different methods of evaluation. The aim of efficiency concept is to indicate where improvements can be made, the outcome in efficient irrigation (Sharma and Yadav,2008).

The irrigation system efficiency is dependent on the level of management during operation and management process in the system (Savva and Frenken, 2002). According to Sharma and Yadav,(2008) the low value of irrigation efficiencies indicate that, land, water and the crops are not being managed properly; Low water application efficiency means wastage of water in the form of deep percolation or runoff losses. Poor storage efficiency means inadequately application of water and poor distribution efficiency, due to uneven land surface. Low water use efficiency also due to over application of water or inability of the crops to utilize the applied water due to poor vegetative growth or adverse chemical properties of root zone soil and water as result, the general effects of poor irrigation efficiencies are crop loss and wastage of water and nutrients. High levels of uniformity and efficiency are being achieved by precise and careful field preparation,

irrigation scheduling, regulation of inflow discharges and tail water runoff restrictions, reduction, or reuse (Walker, 1989).

Irrigation efficiency used to express the performance of irrigation system. Irrigation efficiency was recognized, with water savings, cost savings and production from having highly performing irrigation systems (Wigginton, 2008). It also ensures the highest amount of water that delivered to the farm that used by the crop rather than being lost to groundwater or off the farm as drainage (NSW, 2002).

2.5. Surface Irrigation Management

Relatively large amount of water is applied with large irrigation interval in surface irrigation method; because it is difficult to apply a small amount of water with any evenness and also difficult to give precise control over a small depth of watering due to surface irrigation methods require a certain depth of water to provide the driving force causing the water to flow (Southorn, 1997). One of the most important ways for improvement of irrigation efficiency is development of better instruments to measure the amount of soil water in the field.

surface irrigation evaluation system will identify management practices and field layouts that can be carry out to improve the irrigation efficiency and uniformity of the system, the evaluation indicate that achieving better performance requires a reduction in the flow and duration of flow at the field inlet or it may also show that improvements require changes in the field size and topography (Walker, 2003).A properly designed and conducted irrigation evaluation is an critical tool to improve on farm irrigation efficiencies (Surt, 1995).A well-managed surface irrigation system on a uniform soil application efficiency approach 90% with reused tail water and Efficiency of surface irrigation system varies extremely because of variation in soli type, field uniformity, crop type and management (Bjornerberg, 2013). Improved irrigation practices are important to pollution control, water and energy conservation, increased food and fiber production (Walker and Skogerboa, 1982).

2.6. Management of Furrow Irrigation

According to Yonts *et al*, (2007) Proper practices of furrow irrigation can reduce water application lose, irrigation costs and salt leaching and resulting in high crop yields, the goal of furrow irrigator irrigating the whole field as rapidly as possible, although the irrigators get the water at end of the furrows and also consider how much water is applied and how it is distributed.

The two major sources of Furrow irrigation systems inefficiency are deep percolation and surface runoff or tail water. To minimize deep percolation lose the advance phase should be completed as quickly as possible so as to the intake opportunity time over the field will be uniform and then cutoff the inflow when enough water has been added to refill the root zone. This practice maximizing the tail water problem because the flow at the end of the furrow must be maintained until a sufficient depth has infiltrated. The higher inflow reaches the end of the furrow faster but it increases both the duration and the magnitude of the runoff (Savva and Frenken, 2002). To solve this kind of problem, at least partially dyke the downstream end to prevent runoff in case of basin irrigation; minimize the inflow discharge to a rate more closely approximating the cumulative infiltration along the field next to the advance phase, a practice of 'cutback'; select a discharge which reduces the sum of deep percolation and tail water losses, (Walker, 1989).

One potential for improving the efficiency and performance of furrow irrigation systems by use of simulation models to predict furrow irrigation performance and assess changes in management variables, which can bring the improvements in irrigation efficiency (Hornbuckle *et al*, 2001).

2.7. Factors Affecting the Performance of Irrigation at field level

According to Irmak *et al*, (2011) performance of irrigation can be found from three main points of view: - water application performance, irrigation system performance, and the response of crop for irrigation, the performance of irrigation is mostly varied spatially and temporarily due to different factors like wind, water source, agronomic factors like crop growth stage, soil properties.

Water application performance is affected by rate of infiltration of water into the soil, inflow rate of water, slope of the field, time of irrigation, time of recession of water from soil surface, soil moisture prior to irrigation, spatial variability of the soil, climatic condition and Furrow shape (Holzapfe *et al*, 2010).

The performance of an irrigation system at field scale depends on several design variables, management variables, and system variables or factors. Irrigation performance vary from irrigation event to irrigation event, based on the dynamics of certain factors such as infiltration characteristics, roughness coefficient, root zone depth, soil water deficit (Ali, 2011).

According to Waskom, (1992) furrow length, soil depth, subsoil characteristics and land leveling are also the factors of irrigation performance and when irrigation water runs too long result in overwatering at the top of the furrow by the time the lower end is adequately watered. Land leveling can improve irrigation uniformity whenever non-uniform slopes contribute to runoff or deep percolation and changes in root depth, soil moisture status, and the soil intake rate, the irrigation set size;(stream size, set time, and length of run) can be optimized by irrigators to improve, a well-designed and properly managed surface system also factors affecting the performance of irrigation at field level.

The performance of an irrigation scheme is influenced by socio-economic, agronomic, environmental & technical constraints. Factors are often interlinked, so the causes & effects may not be easily distinguishable. Physical defects may be more easily identified, but their removal will not necessarily solve problems under performance (Adugnaw, 2017 and Koech, and Langat, 2018).

2.8. Factors Affecting Efficiencies of Furrow Irrigation

Furrow irrigation efficiencies described as a function of intake characteristics, surface roughness, water holding capacity of soil, initial soil moisture content, slope, furrow cross-section, application rate and duration of irrigation, and crop condition, many farm

irrigation systems are poorly adapted (Irmak *et al*, 2011). Furrow irrigation also affected by cropping patterns, lack of standardized equipment for regulation and automation, cultivation, the weathering due to climate, and others influences (Walker, 2003).

In addition, advance time, cutoff time, depletion time, and recession time affect the efficiency of furrow irrigation (Eldeiry *et al*, 2005). And also physical conditions such as soil texture, soil structure and the amount of crop residue cover have some impact on the performance of the furrow irrigation system (Cahoon *et al*, 1993). Furrow shapes and compaction of bottom of furrow have also effects on the efficiencies of furrow irrigation. Water movement was increment under compacted bottom of furrows (Meselhy and El-Hagarey, 2014).

2.9. Parameters for Furrow Irrigation Evaluation

According to Jurriens *et al*,(2001) evaluation stands for assessment of irrigation performance, the performance indicators being adequacy, efficiency and uniformity of irrigation. The evaluation can cover quality of design and method of operation. Also used to analysis of an existing situation from known data that are field parameters, field dimensions, flow rate and cutoff time. Then, evaluation indicates the measure of the appropriateness of situation and the modifications that improve irrigation performance evaluation variables are basically measured for determining the combination of decision variables and field parameters that produce the best irrigation performance.

According to Ali, (2011) performance evaluation is the systematic analysis of an irrigation system and management based on measurements taken at field conditions and practices used and comparing the same with an ideal one. The evaluation of furrow irrigation system is limited to a single or small number of adjacent furrows due to intensive measurement process. Complete inflow, advance, and runoff measurements are used to accurately determine soil infiltration rate for a small number of furrows. Evaluation of furrow irrigated fields has generally been based on analysis of a single analysis, have then been used to describe the entire field (Wallender, 1989).

According to Walker, (1989) the principal objective of evaluating furrow irrigation systems is to recognize management practices and system configurations that can be effectively implemented to improve the irrigation efficiency. Evaluations used in the number of analyses and operations that are essential to improve management and control. In the evaluation, data can be collected occasionally from the system to fill the gap of management practices and identify the changes in the field that occur over the irrigation season due to complex and dynamic hydrologic system; hence, to optimize the use of water resources the evaluation processes are very important (Walker and Skogerboe, 1987).

A number of parameters in furrow irrigation evaluations were measured including furrow geometry, slope, width, and length, infiltration characteristics, advance time, cutoff time and recession time (Eldeiry *et al.*, 2005, Magwenzi, 2000).

2.9.1. Performance Indicators

The design and operation of surface irrigation schemes are to satisfy the irrigation water requirements of each field whereas controlling deep percolation, runoff, evaporation and operational losses. The performance of the irrigation system is determined by the efficiency with which water is conveyed to the scheme from the head works, distributed within the scheme and applied to the field, and by the adequacy and uniformity of application in each field (Savva and Frenken, 2002).

Efficiency and uniformity are the most common among the factors used to judge the performance of an irrigation system or its management. There is no a single parameter which is sufficient for determining irrigation performance. Theoretically, the adequacy of irrigation depends on how much water is stored in the crop root zone, percolating losses below the root zone, tail water losses, the uniformity of the applied water, and the remaining deficit or under-irrigation within the soil profile next to irrigation. The important aspect for both management and design are the evaluation of surface irrigation at the field level. Field measurements are important to characterize the irrigation system in terms of most important parameters to identify problems in its function, and to develop different means for improving the system (Walker,1989).

Performance measures how close an irrigation event is to an ideal one or reference irrigation is apply the right amount of water over the entire area of interest without loss (Ali ,2011). The importance of irrigation efficiency is widely recognized, with water savings, cost savings and production gains all possible from having highly performing irrigation systems. But maximizing performance of surface irrigation systems can be a complex process (Wigginton, 2008). The performance of furrow irrigation affected by changing cropping patterns, lack of standardized equipment for regulation and automation, cultivation, the weathering due to climate , and many other unknown influences (Walker, 2003)

The principal measure of irrigation performance for irrigating fields at farms and irrigation units is in term of irrigation efficiency. Application efficiency relates to the actual storage of water in the root zone to satisfy the crop water demand in relation to the water applied to the field (Mangrio *et al*, 2015). To determine the water application and water storage efficiencies of furrow irrigation, it is important to know the soil moisture deficiency in the root zone before irrigation, the amount of water delivered by the irrigation and the soil moisture content of the root zone after the irrigation (Irmak *et al*, 2011).

To evaluate irrigation practices, estimate the gross depth and uniformity of application, the gross depth of water applied can be determine by measuring the discharge enter in each furrow with time it take (Yonts *et al*, 2007).

2.9.1.1 Application efficiencies

Water application efficiency is the amount of irrigation water that available to the plants' root zone, to the amount of water that delivered to the farm boundary. Application efficiency will play role to a lower economic return, as costs will be higher than they need to be (Southorn, 1997).The primary furrow irrigation system design and management's criteria is application efficiency and also need detailed analysis of the application efficiency of furrow irrigation (Zerihun *et al*, 2001)

The water application efficiency can be applied to a project, a farm or a field to evaluate irrigation practices, field irrigation efficiency, designated when measurement taken at the

field (Irmak *et al*, 2011). It is a measurement of how effective the irrigation system is in storing water in the crop root zone and the percentage of the total volume of water delivered to the field that is stored in the root zone to meet crop evapotranspiration (ET) needs (Hubner, 2016)

Application efficiency relates to the actual storage of water in the root zone to fill the crop water demand in relation to the water applied to the field (Mangrio *et al*, 2015). It is the most important in terms of design and management then it reflects the overall beneficial use of irrigation water. A design and management strategy will be proposed in which the value of application efficiency is maximized subject to the value of requirement efficiency being maintained at 95-100 % (Walker, 1989). The furrow irrigation application efficiency ranges from 50-90% (Danny *et al*, 1997). Well designed and managed furrow-irrigation systems have the potential to operate at application efficiencies above 90% (Mehana *et al*, 2009).

Properly blocked-end furrow irrigation can minimized water application, irrigation costs and Leaching of agrichemical below the root zone (Yonts *et al*, 2007). The difference application efficiencies in inter-row furrow irrigation (water flowing between cane rows) ranged from 70% to 75% and in-row furrow irrigation events (water flowing in the cane row), 48% and 57%. The in- row irrigation result, that this type of furrow irrigation is inefficient; this is mainly attributable to increased resistance to water flow by the crop plants (Magwenzi, 2000). According to Adugnaw, (2017) the application efficiencies range from 60% to 75% and the average 65.3% for sugar cane. Well managed irrigation system of application efficiency of furrow (conventional) range 45-65% (Hubner, 2016). On field water application efficiency varies in b/n 40.28% to 76.91% with average 56.57 % (Tadesse , 2017). And according to Griffiths (2006) application efficiency of furrow irrigation is (50 -70) % with average 57%. The variation between consecutive irrigation events were happened because of the variations in inflow rate and cutoff time and afield parameters (soil moisture depletion, soil infiltration characteristics and flow resistance.

2.9.1.2. Distribution uniformity

The objective of starting design stage, it is desirable that all plants within the field receive the same amount of water (Southorn,1997). Application uniformity concerns the

distribution of water over the actual field is equal and distribution uniformity (DU) is a measure of how evenly water infiltrates across a field. A number of technical sources suggest that Christiansen coefficient as a measure of uniformity. The distribution uniformity is defined as the average infiltrated depth in the low quarter of the field, divided by the average infiltrated depth over the whole field (Walker, 1989).

Distribution uniformity is indication of the magnitude of the uneven distribution and the percent of average application amount in the lowest quarter of the field (Tadesse, 2017). Distribution efficiency is the performance irrigation parameter that can express the conditions of either deficit or over-application of water in furrow irrigation (Holzapfel *et al*, 2010). An irrigation uniformity of 100% would mean that every point within the irrigated area received the same amount of water as every other point. The assessment of irrigation uniformity is an important component of the evaluation of in-field irrigation performance (Ali, 2011).

2.9.1.3. Requirement efficiency

According to Walker, (2003) Storage efficiency is an indicator of how well the irrigation meets its objective of refilling the root zone; it is important when 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.

Storage or requirement efficiency is the most directly related to the crop yield so it will reflect the degree of soil moisture stress. It is an index used to measure irrigation adequacy and is ratio of the quantity of water stored in the root zone during irrigation event to that to be stored in the root zone. After determining the storage and the required depths, the storage efficiency will be calculated (Muhammedziyad *et al*, 2019).

2.9.1.4. Deep percolation Ratio

The deep percolation ratio (DPR) indicates that the amount of water which percolate below the crop root zone, which is considered as water losses to the farmer. The loss of water through drainage beyond the root zone is reflected in the deep percolation ratio (DPR). High deep percolation losses can cause the following problem such as waterlogging, salinity problems, and leaching valuable crop nutrients from the root zone.

It is extremely difficult to eliminate deep percolation losses completely because of variations of intake opportunity time & soil intake properties which generally result in over irrigation, a significant fraction of the field depend on soils, crop, water salinity, type of irrigation system and the level of management and Deficit irrigation strategies can reduce deep percolation loss (Walker,1989).

Blocked the lower end of a field is common practice on gently slope (less than 1%) in furrow irrigation, blocking furrow ends can result in excessive deep percolation at both the upstream and downstream end of the field, percolation below the active root zone can occur at any point in the furrow and excessively, long application time, large stream size, low application rates can cause excessive ponding at the downstream end of blocked end field (Yonts *et al*, 2007)

2.10. Furrow Irrigation Design Variables and Parameters

Different parameters and variable involved in the surface irrigation practices can be categorized as field parameters and decision variable or evaluation variables (Aljoumani, 2012)

2.10.1. Field parameters

Field parameters are restricted data which describe the field situation and not variables because engineer cannot assign them with another value. Field parameters include the infiltration characteristics, the surface roughness or flow resistance and the required irrigation depth in furrow irrigation, the shape(filed slope),furrow geometries and spacing of the furrow are limited-choice of field parameters (Jurriens *et al*, 2001).

1. Soil infiltration characteristics

The infiltration function is importance in order to describe the hydraulics of a surface irrigation event. The soil infiltration characteristic is usually out of the management of the irrigator; it varies between soil types even in a single field over the course of a season (Wigginton, 2008, Walker and Skogerboe, 1987).

Infiltration is the most crucial factor affecting surface irrigation because; this parameter essentially controls the amount of water entering the soil and the advance rate of the overland flow (Walker, 2003). Infiltration is the movement of water into the soil and it determines the time the soil should be in contact with water (the intake opportunity time or the contact time). The infiltration rates of soils are influenced by the soil texture. Heavy soils have low infiltration rates by feature of their small pore sizes, whereas light soils have high infiltration rates because of larger pore sizes (Savva and Frenken, 2002). The magnitude of infiltration or the entries of water in to soil profile affect the rate of flow of water along the surface. The higher the infiltration rate, the slower the advance of water down the furrow and rapid recession (Koech *et al*, 2010).

The infiltration rates are an unknown variable in irrigation practice; it essentially controls the amount of water entering the soil storage, as well as the advance and recession of the overland flow. First Irrigations have high an infiltration rate which decreases with time until it becomes fairly steady, which known as the basic infiltration rate (Walker and Skogerboe, 1987).

Infiltration is a complex process that depends upon physical and hydraulic properties of the soil moisture content, soil structure layer and air entrapment (Walker, 1989). The different amounts of water infiltrating throughout the field (non- uniformity) during soil used to transport irrigation water; due to both time differences water is in contact with the soil (intake opportunity time) and differences in the field's infiltration characteristics or spatial variability of infiltration (Wallender, 1989).

According to Mazibuko,(2003) In surface irrigation, the soil serves as a medium for infiltration and for conveying water from the upstream to the downstream end of afield, so that soil infiltration characteristics are extremely important for surface irrigation design and management, it is one of the most dominant factors affecting irrigation performance, particularly in surface irrigation and soil infiltration characteristics have asignificant effect on the water advance and recession relationships and infiltrated depth.infiltration characteristics of soils are the most important parameters in the design,evaluation and Management of furrow irrigation.

2. Flow resistance

One of the most significant considerations in surface irrigation evaluation and design is the changes that occur on the field surface irrigated system (USDS NRCS, 2012).The flow resistance usually described by the Manning equation, which relates the flow rate (Q), to flow area (A), the hydraulic radius(R) (area over wetted perimeter), the friction slope and the manning roughness coefficient (Clemmens, 2007).

Flow resistance (n) is a basic input parameter in simulations of surface irrigation, which has a direct influence on flow velocity and, as a result, on advance time, infiltration pattern and total irrigation performance. Higher the flow resistance, the longer advance time. The longer the advance times the more non-uniform infiltrated-depth distribution. Manning's roughness coefficient meant for steady uniform flow in canals is also commonly used for surface irrigation (Jurriens *et al*, 2001). The roughness of the soil surface and the vegetation cause the water to flow slower than if water was moving over a smooth surface (Gillies *et al.*, 2008). Newly made furrows typically have 'n' values of about 0.03 to 0.05, depending on the soil mass and irrigated furrows without crops growing in the furrow itself will have considerably lower 'n' values (USDA NRCS, 2012).

The field slope often has very little impact on performance but variable slope within a field may have a greater impact on poor performance caused by other factors such as changes in soil type (Wigginton, 2008). The maximum recommended furrow slope is 0.5% to avoid soil erosion, if the land slope is steeper than 0.5% then furrows can be set at an angle to the main slope or even along the contour to keep furrow slopes within the recommended limits (Brouwer *et al*, 2001). Furrow irrigated fields generally have slopes in both the direction of the flow and the lateral direction and these slopes can vary within a field; the slope in the direction of flow should not vary significantly unless it is flattened at the end of the field to improve uniformity (USDA NRCS, 2012).

3. Furrow geometry

The furrow shape mainly depends on the available of farm equipment and local practice (Jurriens *et al*, 2001). The furrow cross-sectional area and wetted perimeter must be specified as a function of flow depth (Clemmens, 2007). The furrows are generally V-shaped or U-shaped in cross section and the shape of the furrow depends on the soil type and the stream size, furrow irrigation requires regular field shapes, use of the same stream size for the same furrow lengths (Savva and Frenken, 2002).

According to USDA NRCS (2012) flow shape is used to estimate flow depths and describe the shape of the flow cross section. It is necessary to describe the actual shape in terms of depth and area and wetted perimeter in furrow irrigation. Furrow shapes are nearly always irregular, but can be described using a series of power functions.

In the furrow irrigation evaluation process the measurement of the cross-sectional geometry of furrow and corrugations are important, the cross-sectional geometry should be measured at two to three stations before and after the irrigation for each furrow. A profilemeter are used for determining the cross-sections of furrows, each scales on the rods of the profilemeter provide data to plot furrow depth as a function of the lateral distance the data numerically integrated to develop geometric relationships such as area verses depth, wetted perimeter versus depth and top-width verses depth (Walker, 1989).

2.10.2. Decision variables

Decision variables are those parameters or variables that a design engineer can manipulate to find the best irrigation performance for given or selected field parameters. The decision variables in surface irrigation are normally the field dimensions (length and width), the flow rate and the cutoff time (Jurriens *et al*, 2001). Cutoff time and stream size are the most manageable irrigation parameters and that accommodate the field conditions will improve the irrigation efficiency and water distribution efficiency (Yonts *et al*, 2007).

1. Field dimension (furrow length and furrow spacing)

For basins and borders, the field dimensions are width (W) and length (L). For furrows irrigation, there is only one field dimension that is furrow length, Furrow spacing is the

distance from center to center of two adjacent furrows, is mainly used to convert depth to volume. It is important only in the context of field parameters (Jurriens *et al*, 2001).

Furrows must be related with slope, soil type, stream size, irrigation depth, and cultivation practice and field length. Furrow lengths may vary from 10 meter to 500 meter although, 100 meters to 200 meters are the desirable lengths and more common (Asawa, 2008). Furrow length equal to the length of the field is more practical (Brouwer *et al*, 2001).

2. Flow Rate

The flow rate onto the farm limits how quickly water can be applied, and how much area can be irrigated in a given time. The volume delivered divided by the time taken to deliver it gives flow rate (NSW, 2002). Inflow rate has a major impact on performance and can be varied by changing the number or size of siphons or the height of water in the head of ditch, whereas faster advance is often more desirable on high infiltration soils, it is very important that the time to cutoff is accurately matched, A faster inflow demands much more accurate management (Wigginton, 2008).

According to Jurriens *et al*, (2001) flow rate is a key variable that affects the outcome of an irrigation event because it influences the advance time of the inflow and consequently, the irrigation uniformity, efficiency, and adequacy. The flow rate should not be low, because it will not reach the end of the field, for furrows, the flow rate should not be too high to prevent scouring.

The appropriate combination of cutoff time and stream size depends on a fields slope, intake rate and length of run, the combination of set size (stream size) and cutoff time must be balanced to achieve efficient, uniform irrigation and to limit deep percolation (Yonts *et al*, 2007). Flow of water in a furrow can be measured in several different ways. The measuring device should be easy to build, install, move and carry in the field. Accuracy must be within a range of ± 3 to 5 % (Heiner, 2009). Parshall flume is the most commonly used flow measuring device in irrigation system and operated under free flow conditions (Walker and Skogerboe, 1987). Because of these, par shall flume was chosen

for measuring the inflow of water in the furrow. Under free flow condition the required measurement is height of water to determine the flow rate (Kandiah, 1981).

3. Advance and Recession of water across the field surface

According to Walker, (1998) the time required for the water to advance to the end of the furrow length or to cover the field completely is a significant consideration in managing surface irrigation system

When water is applied onto the field at the head ends and when it reaches end of the field is called advance time. The stream size applied at the head of the furrow should be greater. It means that part of the water advances over the soil surface to the end of the field and part of the water infiltrates into the soil greater than the soil infiltration rate. Advance phase is the time between the start of irrigation and water advancement to the end of the field after water starts receding from the head end and it continues to the tail end (Savva and Frenken, 2002).

Whether the furrow are blocked or every other furrow directly affected by soil texture, slope and surface condition and the speed of advance is directly related to how uniformly irrigation water is distributed to the soil profile (Yonts *et al*, 2007).Blocked-end fields will requires the recession time to be noted when the ponded water disappears (USDA NRCS, 2012). The time when water starts to disappear at the head end until it eventually recedes from the whole field is called the recession phase. The intake opportunity time or contact time is the time-difference between the recession and advance curve and for high irrigation uniformity, the opportunity time must be same throughout the field (Walker, 1989).

4. Cutoff time

The amount of time that elapses from the start of irrigation to the cutoff of the inflow is cutoff time (T_{co}). Cutoff time for all three irrigation methods occurs usually after the end of the advance time which used to obtain infiltration to the required depth at the downstream end of the field. If cutoff time is considerably later than advance time, this

may have a clear effect on the deep percolation and surface runoff losses. If cutoff happens too early, infiltration to the required depth will often not occur at the end of the field. This clearly shows that there are limits to the value that you can choose for the cutoff time, to achieve good irrigation performance (Jurriens *et al.*, 2001). Time to cutoff and inflow rate is a key variable which can be easily managed by the irrigator (Wigginton, 2008). It is important to switch off the irrigation water at the appropriate time to reduce the volume of water lost as deep percolation and for the alluvial soils on average more than 10% of applied water would be saved by more accurate timing of irrigation cutoff time (Raine and Derk, 1996).

Water was delivered into the furrows until it reached the end of the furrow when the gate was closed. The advance and recession distances including the time the water reached at the end of the furrow were measured (Issaka *et al.*, 2015). In furrow irrigation management, operation and design variables (inflow rate, furrow length and cutoff time) were highly correlated and if the cutoff time increased the application efficiency is decreased (Holzapfel *et al.*, 2010).

Cutoff time is used to improve irrigation management under blocked-end furrow irrigation, for blocked-end furrow irrigation choosing the appropriate cutoff time depends on soil factors and field slope (Yonts *et al.*, 2007).

2.11. Surface Simulation Models

To provide a management tool and to improve the operation of surface irrigation systems, surface irrigation simulation models have been developed. These simulation models have been based on a variety of hydraulic principles, but mostly determined application uniformity based on differences in intake opportunity time throughout a field (Wallender, 1989). Surface irrigation simulation models are useful tools both at the design and management stages of the surface systems, the heart of simulating various surface irrigation configurations and operational schemes is the numerical solution at the Saint-Venant Equations for conservation of mass and momentum for conservation of mass (Singh *et al.*, 2018).

Different models used for surface irrigation simulation and optimizations are SIRMOD III (Walker, 1997), WinSRFR (Bautista *et al.* 2009) and SURDEV (Jurriens *et al.*, 2001). SIRMOD III is comprehensive software package for simulating the hydraulic of surface irrigation system at the field level, selecting a combination of sizing and operational parameters that maximize application efficiency and a two-point solution of the inverse problem allowing the computation of infiltration parameters from the input of advance data (Walker, 2003). One of the most commonly used models is SIRMOD, developed by Utah State University, has wide use and evaluation throughout the world particularly by researchers and has been shown to the potential for increasing surface irrigation water use efficiencies. The use of the SIRMOD model as a management tool for improving irrigation efficiencies was found to be a valuable aid (Mehana *et al.* ,2009).

According to ALARC,(2006), WinSRFR is the successor to irrigation modeling software developed over 20 years ago by USDA-Agricultural research service and an integrated hydraulic analysis application for surface irrigation evaluation ,design and operational analysis. It is a software package for the hydraulic analysis of surface irrigation systems and a central component of the software is the unsteady flow modeling system SRFR. WinSRFR have only two simulation approach which are Zero-inertia and Kinematic wave approach, in the WinSRFR the simulation model automatically selected to the given hydraulic condition. WinSRFR selects a method for particular data taking in to account the downstream boundary condition and field slope.

According to Jurriens *et al.*,(2001) SURDEV is the program package that accompanies three programs BASDEV(for level basins),BORDEV(for sloping borders) and FURDEV (for graded furrow) enables the user to design ,operate and evaluate surface irrigation systems. FURDEV is a computer program developed to solve problems in the design,operation and evaluation of furrow irrigation systems and it deals with the flow in one furrow does not provides for field layout design. The FURDEV program is based on the volume balance method and is not able to calculate the advance and recession curve for blocked-end furrow condition unless it used for free-drain furrow.

2.11.1. Model Selection Criteria's

Simulation models have the potential to improve the efficiency of irrigation systems and provide significant water savings. This can be achieved by optimizing the design and management decisions at the field level. Surface irrigation simulation models are useful tools both at the design and management stages of the surface systems (Koech *et al*, 2010). Due to the good relationship between the predicted and measured infiltration depths obtained from SIRMOD model which has high accuracy degree for furrow irrigation management decisions (Mehana *et al*, 2009). SIRMOD provides the option for simulating furrow irrigation systems, for open or closed end boundary conditions and provides detailed output on irrigation performance evaluation (application and storage efficiencies, distribution uniformity and deep-percolation ratio), advance trajectory, recession trajectory, infiltrated water depth profile, total volume of water applied, Infiltrated and run-off (Kalwij,1997). The two – point method based on the advance time of irrigation needed to reach half of the furrow length, the two-point method in the SIRMOD model accurately simulate blocked-ended continuous flow irrigation in short furrow length which is less than 100 m (Ismail and Depeweg 2005).

The main reason for selecting SIRMOD III MODEL for this research was that the model has to use full hydrodynamic model and widely used and evaluation throughout the world particularly by researchers and has been shown to deal potential for increasing surface irrigation water use efficiencies. The SIRMOD model adequately describes advance and recession times and infiltrated depth under experimental site conditions for the furrow irrigation practice (Mehana *et al*, 2009).In the SIRMOD III an error less than 5% is acceptable and most simulation will have errors of about 1 % (Walker, 2003).

2.11.2. Modeling approaches

In SIRMOD III software the most common models approaches that used to design and simulate furrow irrigation systems are hydrodynamic, zero-inertia, kinematic wave model (Eldeiry *et al*, 2005).The default is hydrodynamic model, whereas the kinematic wave model assume that the friction or energy slope is equal to the bed slope; these models are not suitable for systems with zero or small slope. The Kinematic Wave Model cannot

simulate the blocked-end condition (Ebrahimian and Liahat, 2011). Zero _inertia models include pressure friction and gradient component and assume negligible water acceleration, the most complex and accurate is the full hydrodynamic numerical simulation model, which uses the full form of the Saint-Venant equations, i.e. both equations of conservation of mass and momentum (Khatri, 2007). From the common modeling approaches that used in this research to simulate furrow irrigation was full hydrodynamic approach in the SIRMOD software because, these models, if properly implemented, should provide simulations that are more accurate over a wide range of field conditions when compared to the other mathematical models and Due to their accuracy, they are often used for the calibration and evaluation of simpler models (Ebrahimian and Liahat, 2011).

The SIRMOD simulation model was found to adequately predict furrow irrigation characteristics on soil conditions and comparisons of infiltrated volumes providing that the SIRMOD model able to adequately model furrow irrigation system (Hornbuckle *et al*, 2001). The Full hydrodynamic models for surface irrigation developed to simulate the depth of flow, advance time, recession time, infiltrated volume, runoff volume, deep percolation and performance indicator (Eldeiry *et al*, 2005). According to Ebrahimian and liaghat, (2011) all measured data that are collected from the furrow of the research field will be analyzed by using the SIRMOD III software irrigation modal (hydrodynamic modal).

The input data requirements for the simulation component include the field length, slope, infiltration characteristics, and advance data, target application depth, water application rate, Manning's resistance, furrow geometry and hydraulic section (furrow shape fitting parameters).The output includes a detailed advance–recession trajectory, the distribution of infiltrated water, volume balance, runoff hydrograph, depth of water flow at the end of the field, application and requirement efficiencies, distribution uniformity, irrigation efficiency, deep-percolation ratio and tail water ratio.

2.12. Review of similar works

Adugnaw, (2017) conducted a study to evaluate performance of furrow irrigation system at Tana Belus Sugar Factory. In order to determine the existing performance's indicator of furrow irrigation and certain parameters were measured before, during and after an irrigation event during the irrigators performing their normal irrigation practice. The results showed that for each performance indicators the average values for estimation, SIRMOD and WinSRFR simulation were 65.3, 62.1 and 68.5, of E_a , 32.8%,24.2% and 26.4% of E_s , 90.4%,92.4% and 95.5% of DU and 34.1%,37.9% and 31.2% of TWR respectively for 100 m furrows length and 1.8% furrow slope. The downstream condition of furrow irrigation was open end.

Tadesse, (2017) conducted a study to evaluate the performance of field water application at Tendaho sugar estate. In order to evaluate the performance of water conveyance of tertiary canal system and to assess the performance of field water application of furrow irrigation system parameters were measured (furrow inflow, furrow cross-section, advance and recession and infiltration) before, during and after an irrigation event. The average field water application efficiency of the study area 56.57%, 70.30% of storage efficiency and 91.93% of distribution uniformity at target application depth.

Muhammadziyad *et al*, (2019) conducted to evaluate the performances of selected field surface irrigation schemes in Kacha Bira Woreda. In order to evaluate the irrigation water use efficiency at field level and with nine famer fields were selected from each irrigation schemes based on their location (from head, middle and tail end water users) in relation to their location. The result showed that the internal performance indicators (Conveyance efficiencies, application efficiencies, deep percolation, storage efficiencies irrigation uniformity were (61.15 and 65.63%), (58.75 and 71.7%), (41.25% and 28.3%), (36.91% and 23.9%) and (98.32 and 97.79%) for Gemesha & Ufute respectively.

Biru, (2018) evaluated the existing hydraulic performance parameters to determine the optimal design or advance and recession water front of furrow irrigation at Melkessa Agricultural Research Center. The primary data were generated by field measurement, the field measurement were carried out on four existing furrows. The parameters were

collected from field and used as an input to the models, the collected data that used as input parameters were analyzed by using SIRMOD and WinSRFR software models. These software's models were analyzed from field tests conducted on 3.5 m running width and 42 m furrow length with slope of 0.2% and 2l/s inflow rate. This slope 0.2% was not suited on 42 m furrow length under blocked end boundary condition. The optimum furrow length of 100 m was selected to realize the efficiency and uniformity with rate of 3 l/s with cutoff 0.89 hr, the maximum attainable water application efficiency was 77% in SIRMOD and 78% in WinSRFR softwares under zero inertia models. The application efficiencies were obtained with optimum inflow rate of 4 l/s and slope of 0.1% in SIRMOD and WinSRFR under zero inertia models respectively. Furrow inflow rate of 4 l/s a recommended furrow slope of 0.1% was suitable with optimal cutoff time of 0.67 hr in SIRMOD and 0.57 hr in WinSRFR.

Fitsum *et al*, (2019) evaluated the hydraulic performance of small scale irrigation scheme in Wolaita Zone. The parameter considered in the study was inflow discharge and cutoff time. The study consisted of field experiments and simulation modeling. Performance indicator including Application efficiency, potential application efficiency, adequacy and distribution uniformity, runoff ratio and deep percolation ratio of two irrigation events were evaluated using surface irrigation evaluation and simulation model WinSRFR. The hydraulic performance of the study area had a value of application efficiency (55% to 73%), low quarter adequacy (0.96 to 1.28) and low quarter distribution uniformity (0.89 to 0.96), runoff ratio (7% to 38%) and deep percolation ratio (1% to 38%) on farms.

Valipour, (2012) evaluated the ability of full hydrodynamics, zero inertia and kinematic wave models has been studied in surface irrigation simulation model, using SIRMOD software. Their performance were compared, the results indicate that full hydrodynamic and zero inertia models were very power full in simulation process, for field slope until amount of 0.01 full hydrodynamic and zero inertia models had not any different but for more increased slope of due to the increasing of velocity, Accuracy of zero inertia model dropped. In full hydrodynamic and zero inertia models for increase in manning's roughness coefficient amount of error was increased until $n=0.15$, error remained constant thus $n=0.15$ determined critical discharge. Accuracy of kinematic wave model reduces in clay and heavy clay soil, high discharge and high manning roughness coefficient.

3. MATERIALS AND METHODS

3.1. Descriptions of the Study Area

The study was conducted at Wonji Shoa Sugar Estate which is situated in the Central Rift Valley of Ethiopia 110 km Southeast of Addis Ababa and 12 km South of Adama geographically located at latitude of $8^{\circ} 21' 0''$ to $8^{\circ} 27' 30''$ N and longitude of $39^{\circ} 12' 0''$ to $39^{\circ} 20' 0''$ E at an altitude of 1540 m. Wonji Shoa Sugar Estate farm area (5,800 ha) were covered by sugarcane, the water application system were furrow irrigation system with Blocked-end downstream condition (Hiwot, 2018). Range of soils with textures from very heavy clays to sands soils of the whole furrow irrigation system is categorized very heavy clays to light sandy loams (WSSF, 2011)

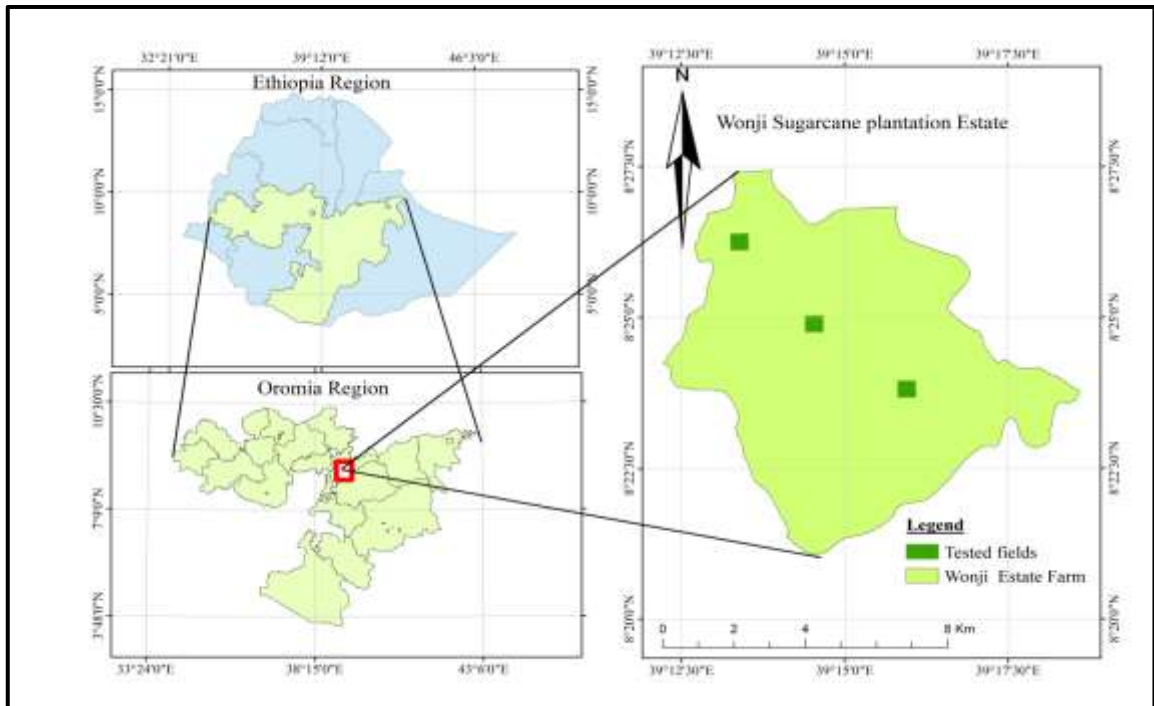


Figure 1: The geographical location map of the research area

3.1.1. Climate

The area receives major rains during June to September and lesser rains during March, April, May and October. The estate has a semi-arid climate and receives an average annual rainfall of 802 mm; mean maximum and minimum temperature of the area is 27.72°C and

13.88 °c respectively and Mean evapotranspiration reading of the area is around 4.32 mm/day.

Figure 2 indicated that the monthly distribution of reference evapotranspiration (ET_o) and effective dependable rainfall of the study area for 30 years (1986-2015). The potential evapotranspiration of the study area were determined by CROPWAT model, is more than the effective dependable rainfall in most of the months and at this period rainfall was insufficient to replace for the water lost by evaporation. This shows that the planted sugar cane in these months needs supplemental irrigation. The effective rainfall is more than ET_o during July and August meaning that no irrigation was required during this months.

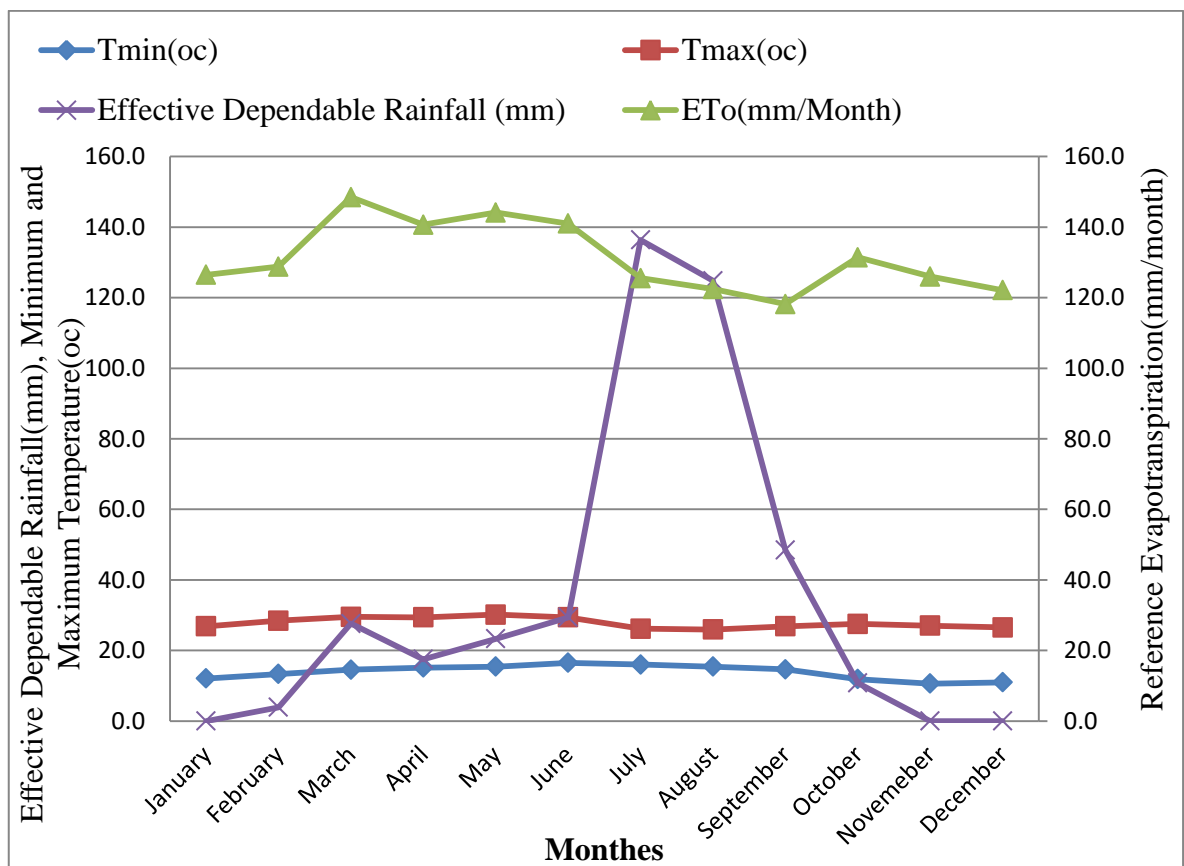


Figure 2: Monthly Distribution of Reference Evapotranspiration and Effective Dependable rainfall of the study area

3.2. Data collection methods

Three tested fields were selected based on soil type and workability for filed measurement with field code of 15, 52 and 108 with their exist furrow lengths 64, 48 and 32 m respectively and had the same furrow spacing 1.45 m. The furrow length practice in the estate depends on the gradients of farm.

Water was pumped from Awash River through a pumping station at Wonji and almost the entire estate was fed from this pumping station through an extensive earthen canal system and storage facilities. Pumped water stored in ponds, which were spread at various locations in the estate, and the estate was irrigated partly from the water supplied directly by the pumps and the rest from the reservoirs (Hiwot, 2018).

Due to intensive measurement processes, three furrows from each field were selected for data collection purposes. Two buffer furrows which were left & right of the test furrows were used to minimize horizontal movement of water (Eldeiry et al, 2005 and Adugnaw, 2017). The measurement was made when the irrigator irrigate six furrow the measurement taken at one furrow from the six furrow. The representative furrows were selected from middle of each selected field and tagged by using pegs. The advance and recession time and also moisture content data were taken at 8 m interval of each furrow length which was marked by pegs.

Primary and secondary data were collected through observation, measurements and from documented file. The primary data were collected from selected field of furrows and secondary data were collected from Wonjii Shoa Sugar factory and Wonjii Sugar Cooperation Research Center. The primary data, used as basic input for full hydrodynamic model simulation in the SIRMOD Software, were collected from the selected field of furrows. They were field topography (furrow geometries, length of furrow and furrow spacing), inflow rate, application depth, basic infiltration rate (f_o), the kostiakov infiltration parameters (a and k) and cutoff time. The collected data from three selected fields of furrows were soil moisture content, furrow slope, furrow geometry, application depth, and advance and recession time, cutoff time and inflow rate and composite soil sample was prepared to determine field capacity, permanent wilting point and bulk density from undisturbed soil sample.

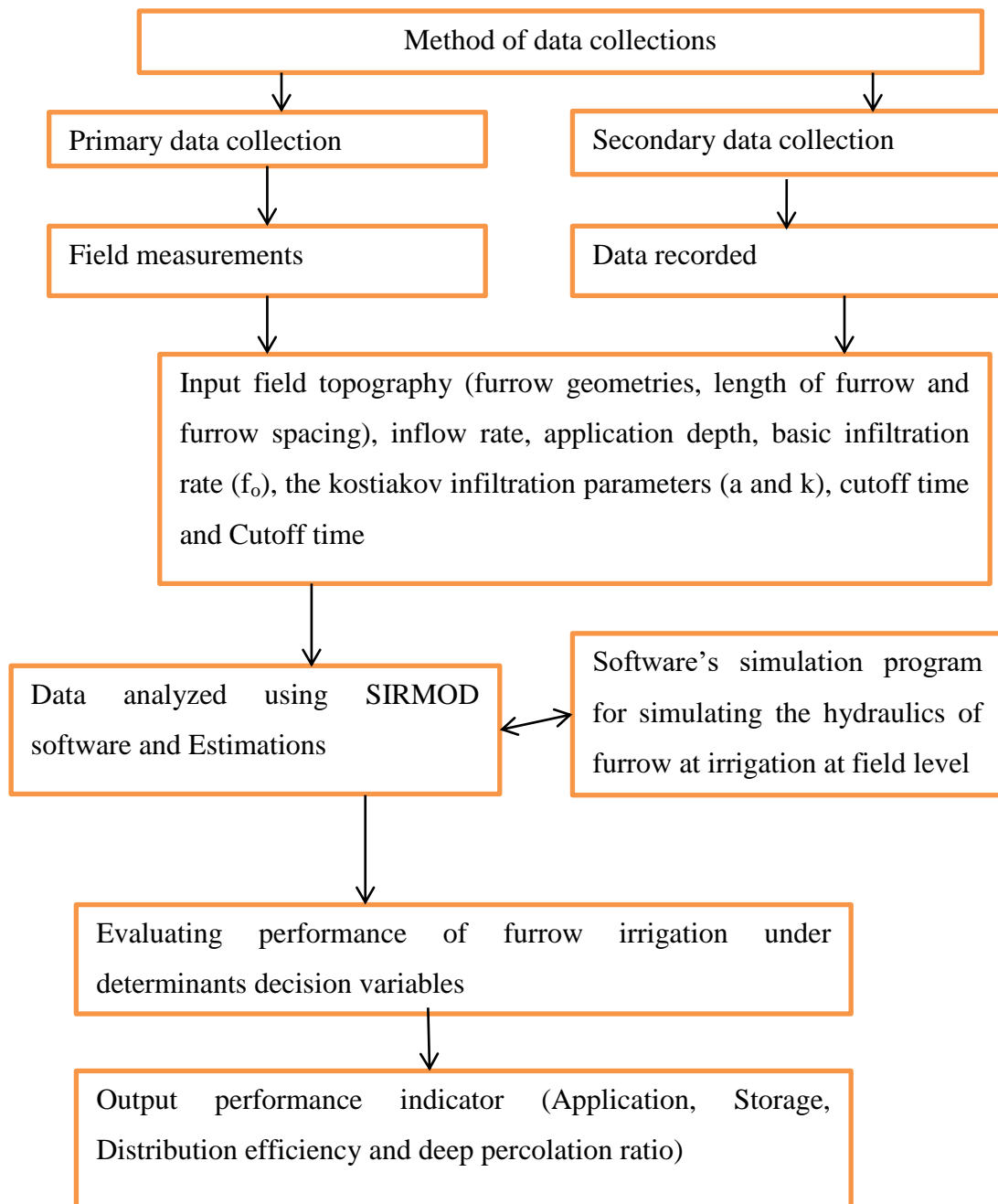


Figure 3: Methodological flow chart of the study

3.2.1. Soil Characteristics

The effective rooting depth of sugarcane of Wonji Shoa Irrigation Estate was from 50 cm-60 cm, due to the presence of perchedground water in the soil (FDRESC, 2014). Shallow water tables can restrict effective root depth (Holden and McGuire, 2014). Soil samples

were collected from three selected fields through zigzag soil sampling methods with the depth interval of 0-30 cm and 30-60 cm by using auger and core sampler. Zigzag sampling method is the best way to ensure a representative sample of the field (MoAFR, 2002). Sampling data were taken to Wonji Sugar Cooperation Research Center and Melkasa Agricultural Research Center for laboratory work.

Soil texture: - Soil samples were collected from 10 sampling points with 50 m interval of each selected field of Wonji Shoa Sugar Estate and composite samples were taken to Wonji Sugar Cooperation Research Center and samples were air dried, weighed, crushed and the particle size distribution was analyzed using hydrometer method. After the percentage of sand, silt and clay was measured, the soil had assigned a textural class using the USDA textural triangle (Savva and Frenken, 2002).

Bulk density: - Undisturbed soil sample from each field were taken from the depth interval of 0-30 cm and 30 cm- 60 cm by using core sampler which had known volume. The weight of the sample was measured before taken into the oven dry and measured after taken off from the oven dry (Walker, 1989), bulk density (g/cm^3) determined by equation (3.1)

$$\text{Bulk density}(\gamma_b) = \frac{\text{oven dry weight of soil}}{\text{volume of soil sample}} = \frac{w_s}{V_s} \text{----- (3.1)}$$

Moisture contents at field capacity (Fc) and permanent wilting point (PWP):-Soil sample were taken to Melkasa Agricultural Research Center. Fc and PWP were determined after soil samples were saturated for 24 hour using the pressure plate apparatus. Field capacity was determined by applying a suction of -1/3 bar to a saturated soil sample. When water was no longer leaving the soil sample, the soil moisture at field capacity whereas the moisture content at a pressure of -15 bars from pressure plate test was PWP (Kirkham, 2005). Field capacity and permanent wilting point result were used to determine total available water (TAW).

Total available water (TAW):- total available water to the plants was determined by the difference between the volumetric moisture contents at field capacity and at permanent wilting point multiplied by effective root zone depth, (RD) (Walker, 2003), Calculated using by equation (3.2).

$$TAW = (\theta_{fc} - \theta_{pwp})RD \text{ ----- (3.2)}$$

Where; θ_{fc} is volumetric soil moisture at field capacity (%), θ_{pwp} = volumetric soil moisture at permanent wilting point (%), TAW=total available water (mm) and RD= Depth of the root zone (mm).

Soil moisture content determination:-To determine the soil moisture content before and after irrigation and to calculate irrigation requirement before irrigation and soil moisture storage after irrigation. Soil samples were collected before and two day after irrigation with 8 m interval along the furrow length from each furrow in the selected field at depth of 0-30 cm and 30-60 cm which was effective root zone for sugar cane in Wonji Shoa Sugar Factory. The samples were taken by moisture Can and weighed at field condition and placed in an oven at a temperature of 105 °C and dried for 24-hours. After 24-hour the soil samples were re-weighed to determine the amount of water removed and the gravimetric water content was calculated and converted to volumetric moisture content according to Walker, (2003) by equation (3.3) and (3.4) respectively.

$$w = \frac{\text{weight of soil} - \text{weight of oven dry}}{\text{weight of oven dry}} * 100 \text{ ----- (3.3)}$$

The volumetric moisture content was computed by multiplying the gravimetric content (w) by the ratio bulk density of soil and density of water (g/cm^3).

$$\theta = w * \frac{\gamma_b}{\gamma_w} * 100 \text{ ----- (3.4)}$$

Where; θ =Volumetric soil moisture content (%), W= Gravimetric soil moisture content (%), γ_b =Bulk density and γ_w =density of water

3.2.2. Measurements of furrow irrigation performance parameters

The methodology used for performance evaluation of furrow irrigation follows (walker 2003). The Measurements was including irrigation depth, furrow inflow, furrow cross-sections (furrow geometry), advance and recession times and cutoff time and infiltration characteristics was calculated from advance time.

3.2.2.1. Required depth

The soil moisture deficit (SMD) is the depletion of soil moisture below field capacity at the time that particular soil moisture content (θ_i) (USDA NRCS, 2012 and Walker, 2003). Soil

moisture deficit was estimated between volumetric water content at field capacity and volumetric water content of soil before irrigation(θ_i) multiplied by the root depth; which represent the depth of water should be supplied (Aljioumani, 2012). It was calculated by equation (3.5)

$$SMD = (\theta_{fc} - \theta_i)RD \text{ ----- (3.5)}$$

Where; θ_{fc} =volumetric soil moisture at field capacity (%), θ_i = volumetric water content before irrigation (%), SMD = Soil moisture deficit (mm) and RD = effective root zone (mm)

3.2.2.2. Inflow measurements

Flow rates were measured with Parshall flumes in furrows (NSW, 2002). Irrigation water was applied from the inlet of the furrow and passed through 2 inch Parshall flumes were placed at the field width for each selected irrigated furrow by measuring the vertical distance (water depth from the zero reference at the bottom of flume to the water surface level (Adkins, 2006) and respective time were recorded. The water flows to each furrow were controlled by filling feeding ditch first and allow flowing water at the same time in each furrow, the downstream condition of furrow was closed-ended and tail water was zero.



Figure 4: Inflow measurement with parshall flume

3.2.2.3. Advance and recession times

Advance and recession times requires determining points (stakes) along the furrow in order to determine the intake opportunity time and it was important to record the advance

and recession data at each point .These were measured for each furrow at the selected field. A common spacing of these stakes is 30 m, except for small fields (<2ha), where the spacing would be reduced to 1/6 to 1/10 of the field in order to provide a sufficient number of measuring points (six or more) (Walker,2003).

In this study the advance and recession points were established along the furrows at 8 m interval using pegs. Pegs were driven into the soil along the furrow at fixed interval before irrigation events. Station at 0+00 was the inlet of the furrow. Advance time was recorded at the time when water front reaches at each pegs from the start of water entry to the furrows and also recession time was recorded at the times when water was fully infiltrated into the soil at the observation sections.



Figure 5: Measurement of advance and recession time

3.2.2.4. Cutoff time

Cutoff time is the amount of time that elapses from irrigation starts until it is cutoff inflow. Blocked-end furrow irrigation was used to irrigate the sugar cane fields in the estate; the water applied to each furrow was cutoff as it reaches the end of the furrow which was blocked-end and bonds up with in the furrow.

3.2.2.5. Furrow Geometry

The evaluation procedure begins by defining the cross-sectional area of flow at the field inlet using furrow geometry parameters computed from the geometry data. According to Walker, (2003) for each furrow selected for evaluation, the cross-sectional geometry

should be measured at two to four stations according to furrow length along flow direction with installed the local wooden pieces in furrow and measured with meter, which was before irrigation. Field geometry and topography were described by length, width, furrow shape and slope. The data obtained from measurements of geometry of furrows were top width, middle width, base and maximum depth used to derive the relationship between the depth of water in furrow and the corresponding top width were computed (Mehana *et al*, 2009). The measurements of the furrow cross-section were made to calculate the area of flow at the inlet.



Figure 6: The measurement of furrow geometry

The flow cross-section was computed with fitting parameter for shape $\text{Rho}(\rho)_{1,2}$, Sigma $(\sigma)_{1,2}$, Gamma $(\gamma)_{1,2}$, which were automatically computed as follows (Walker and Stogerboe, 1987).

$$A = \sigma_1 y^{\sigma_2} \text{-----} (3.6)$$

$$\sigma_2 = \frac{\log \left[\frac{Y_{\max} \left(\frac{\text{Base}}{2} + T_{\text{mid}} + \frac{T_{\max}}{2} \right)}{Y_{\max} \left(\frac{\text{Base}}{2} + T_{\text{mid}} \right)} \right]}{\log_2} \text{-----} (3.7)$$

$$\sigma_1 = \frac{Y_{\max} \left(\frac{\text{Base}}{2} + T_{\text{mid}} + \frac{T_{\max}}{2} \right)}{Y_{\max}^{\sigma_2}} \text{-----} (3.8)$$

Where:-, σ_1 , σ_2 are fitting parameters of furrow shape, Y_{\max} = maximum depth of furrow (cm), T_{mid} = middle width of furrow (cm), T_{\max} = top width of furrow (cm) and base width of furrow (cm)

The wetted perimeter (W_p), fitting parameter γ_1 & γ_2 were obtained using the following equation 3.9, 3.10 and 3.11 respectively; which relates the wetted perimeter with flow depth.

$$wp = \gamma_1 Y^{\gamma_2} \text{-----} (3.9)$$

$$\gamma_2 = \frac{\log \left[\frac{\left[\text{Base} + \sqrt{Y_{\max}^2 + (T_{\text{mid}} - \text{Base})^2} + \sqrt{Y_{\max}^2 + (T_{\max} - T_{\text{mid}})^2} \right]}{\left[\text{Base} + \sqrt{Y_{\max}^2 + (T_{\text{mid}} - \text{Base})^2} \right]} \right]}{\log_2} \text{-----} (3.10)$$

$$\gamma_1 = \frac{\left[\text{Base} + \sqrt{Y_{\max}^2 + (T_{\text{mid}} - \text{Base})^2} + \sqrt{Y_{\max}^2 + (T_{\max} - T_{\text{mid}})^2} \right]}{Y_{\max}^{\gamma_2}} \text{-----} (3.11)$$

Where: - y = flow depth (m), w_p = wetted perimeter and γ_1 & γ_2 = fitting parameter of furrow wetted perimeter

According to Walker, (2003) the cross-sectional flow area at the field inlet, A_o ' will be determined for any flow, Q_o in $m^3 \text{ min}^{-1}$ & for field slope > 0.0001 as follows.

$$A_o = \left[\frac{Q_o^2 n^2}{3600 s_o \rho_1} \right]^{\frac{1}{\rho_2}} \text{-----} (3.12)$$

$$\rho_2 = \frac{10}{3} - \frac{4\gamma_2}{3\sigma_2} \text{-----} (3.14)$$

$$\rho_1 = \frac{\sigma_1^{10/3}}{\gamma_1^{4/3}} \text{-----} (3.15)$$

Where n = manning roughness coefficient; s_o = field slope (m/m); ρ_1 & ρ_2 = furrow shape parameter, A_o = area at the field inlet (m^2) and Q_o = discharge at inflow (m^3/min).

Manning's value for vegetative interferences ranges 0.09-0.14 and average 0.12 (Mittelstadt, 1995). In this finding based on the density of sugarcane plant surface roughness coefficient of 0.2 was used during two irrigation event. Because of the selected fields were not newly established and irrigated previously before the data were collected. Therefore, surface roughness coefficient of 0.2 was used for both events.

3.2.2.6. Infiltration

The most commonly used equation to describe the soil infiltration characteristic for surface irrigation is the kostiakov- lewis equation (Koech *et al*, 2010).The kostiakov- Lewis the most applicable equation for furrow irrigation system because it consider the final or basic intake rate (f_o) (USDA NRCS ,2012). And infiltration characteristic of furrow were represented in the SIRMOD model with the kostiakov-lewis infiltration equation (Mehana *et al*, 2009).

The soil infiltration parameters (a and k) were obtained from two-point method using volume balance equation stated in Walker and Skogerboe , (1987) and the infiltration rate and cumulative infiltrated depth computed by modified Kostiakov (Kostiakov-Lewis) equation stated in (Gillies *et al*, 2008). Two-point method depends on the time required to advance the water to half of the furrow length (t0.5L) as well as on the time required to advance the water to the end of the furrow (tL). It has been developed to determine the exponent (a and k) value for continuous flow (Ismail and Depeweg, 2005). This method is based on Power function representing relation between time and distance water has advanced across furrow (USDA NRCS, 2012). For a wide furrow the two-point method showed better to determine infiltration parameter (Holzapfel *et al*, 2004).

$$Z = k\tau^a + f_o\tau \text{-----} (3.16)$$

Where Z =cumulative infiltration in m³/m, f_o=the basic intake rate in m³/min/m τ= intake opportunity time in (min) and k (m³/m/min^a) & a = infiltration fitting parameters.

The infiltration rate was computed by Modified Kostiakov (kostiakov –Lewis) equation.

$$I = ak\tau^{a-1} + f_o\text{-----} (3.17)$$

Where; I = infiltration rate (m³/m/min)

According to Walker, (1989), it was necessary to segregate the volume of water on the soil surface from the volume which had infiltrated into the soil during the advance phase in order to evaluate the field infiltration parameters. The volume balance method was used to determine the infiltration fitting parameters ‘a’ and ‘k’ based on the volume of water entering to the field (Q*t) being equal to the volume of surface water(v_{sur}) plus the volume of infiltrated water (v_{inf}).

$$Q * t = V_{sur} + V_{inf} \text{-----} (3.18)$$

Where, Q = the inflow, m³ min⁻¹ per unit width or per furrow; t = the time, when the water reach the point in min, v_{inf} = the volume of infiltrated water, v_{sur} =the volume of surface water.

The two-point method is on the volume balance in which the measurement of advance time at two points, the preferable point, one at the middle & the other at the end of furrow, was used to calculate values of infiltration parameters (Walker and Skogerboe, 1987).

$$Q_0 t_L = \sigma_y A_0 L + \sigma_z K t_L^a + \frac{f_0 t_L L}{(1+r)} \quad \text{----- (3.19)}$$

Final or the steady infiltration rate was computed by equation 3.20 (Khatri, 2007).

$$f_0 = \frac{Q_0}{x_{max}} \quad \text{----- (3.20)}$$

Where, Q_0 = discharge at inflow (m^3/min), x_{max} = the maximum possible advance distance and f_0 = the steady infiltration rate ($m^3/min/m$). The furrow irrigation system that going to be evaluated was blocked- end furrow.

Measured advance data were also used to evaluate ‘K’ & ‘a’ and computing cumulative infiltration (Z), ‘a’ and ‘K’ computed by equation 3.21 and 3.22 respectively.

$$a = \frac{\log \frac{V_L}{V_{0.5L}}}{\log \frac{t_L}{t_{0.5L}}} \quad \text{----- (3.21)}$$

$$K = \frac{V_L}{\sigma_z t_L^a} \quad \text{----- (3.22)}$$

$$V_L = \frac{Q_0 t_L}{L} - \sigma_y A_0 - \frac{f_0 t_L}{1+r} \quad \text{----- (3.23)}$$

$$V_{0.5L} = \frac{2Q_0 t_{0.5L}}{L} - \sigma_y A_0 - \frac{f_0 t_{0.5L}}{1+r} \quad \text{----- (3.24)}$$

Where, $0.5L$ =Furrow length of furrow middle, L =length of furrow at end, $t_{0.5L}$ =Advance of time at half-length, t_L =Advance time at full length of furrow, V_L = volume of water at full length, $V_{0.5L}$ = volume of water at half length, σ_y = surface flow shape factor and σ_z =subsurface shape factor.

The value of σ_y is the surface flow shape factor , it assume to be constant during the advance is in the range of 0.7-0.8, However the values may change with field slope, flow shape, slope of advance trajectory and field length. So in this study the surface flow shape factor was determine by using equation 3.25 (USDA NRCS, 2012).

$$\sigma_y = \frac{0.778}{1+0.363e^{-12.07 \frac{r p t_L^{1-r}}{Q_0 * A_0}}} \quad \text{----- (3.25)}$$

Where, σ_y =surface shape factor, Q_0 =discharge at the inlet (m^3/min), r and p =advance power fitting parameter, t_L = advance at full length (min) and A_0 =area at the inlet (m^2)

The sub surface shape factor, the power advance, the total volume of infiltrated and the cumulative intake at i^{th} point that means it is a function of ‘a’ and ‘r’ as indicated in equations (3.26) bellow (Walker and Skogerboe, 1987).

$$\sigma_z = \frac{a+r(1-a)+1}{(1+a)(1+r)} \text{-----} 3.26$$

According to USDA NRCS, (2012), the following equations (3.27-3.33) were computed as follows. Two simple equations of advance and recession can be developed. For the advance trajectory, a simple power relationship is sufficient. The advance trajectory was computed by equation (3.29)

$$X = P t_a^r \text{-----} 3.27$$

$$r = \frac{\log\left(\frac{L}{0.5L}\right)}{\log\left(\frac{t_L}{t_{0.5L}}\right)} \text{-----} 3.28$$

$$t_a = \left(\frac{X}{P}\right)^{1/r} \text{-----} 3.29$$

Where, X= distance from the field inlet to the advancing front (m), t_x = time from the beginning of irrigation until the advancing front reaches the point x (min), $t_{0.5L}$ = time from the beginning of irrigation until the advancing front reaches the field mid-point (min), t_a = advance time (min), p and r = advance power fitting parameters.

The recession trajectory was computed by equation 3.30

$$\bar{t}_x = h + i * x + j * x^2 \text{-----} 3.30$$

$$h = \bar{t}_d$$

$$i = \frac{m^2 \bar{t}_L - \bar{t}_{0.5L} - \bar{t}_d(m^2 - 1)}{L(m^2 - m)} \text{-----} 3.31$$

Where, $m=0.5L/L$

$$j = \frac{t_L - t_d - i * L}{L^2} \text{-----} 3.32$$

Where \bar{t}_x = time of recession at a distance x from the field inlet (min), \bar{t}_d = time of recession at the field inlet (min), $\bar{t}_{0.5L}$ = time of recession at the field mid-point (min) and \bar{t}_L =time of recession (min).The intake opportunity time (τ) at any point was computed by equation 33.

$$\tau = \bar{t}_x - t_x \text{-----} 3.33$$

According to Walker and Skogerboe, (1987), the evaluation of furrow irrigation was done by involving the trapezoidal rule by the sub surface flow profile, thus calculated the total infiltrated volume by equation 3.34

$$V_z = \frac{L}{2N} (Z_i + 2Z_1 + 2Z_2 + Z_{32}) \text{-----} 3.34$$

Where, L= the furrow length (m), Z_i = Cumulative intake at the i^{th} point (m^3/m)

N=number of increments used to subdivide the furrow values for cumulative intake and the individual values for field 15. To determine the infiltrated volume water, the distribution of water applied to the root zone, the length furrow should be subdivided in to 2m increment and depth infiltrated water computed for each increment by equation 3.35.

$$z_i = k[t_{ri} - t_{ai}]^a + f_o[t_{ri} - t_{ai}] \quad \text{----- 3.35}$$

Where, t_r = the recession time in minutes, $(t_a)_i$ = the advance time to the i^{th} station in minutes. If the recession is to be neglected the cut off time, t_{co} is used instead of t_r

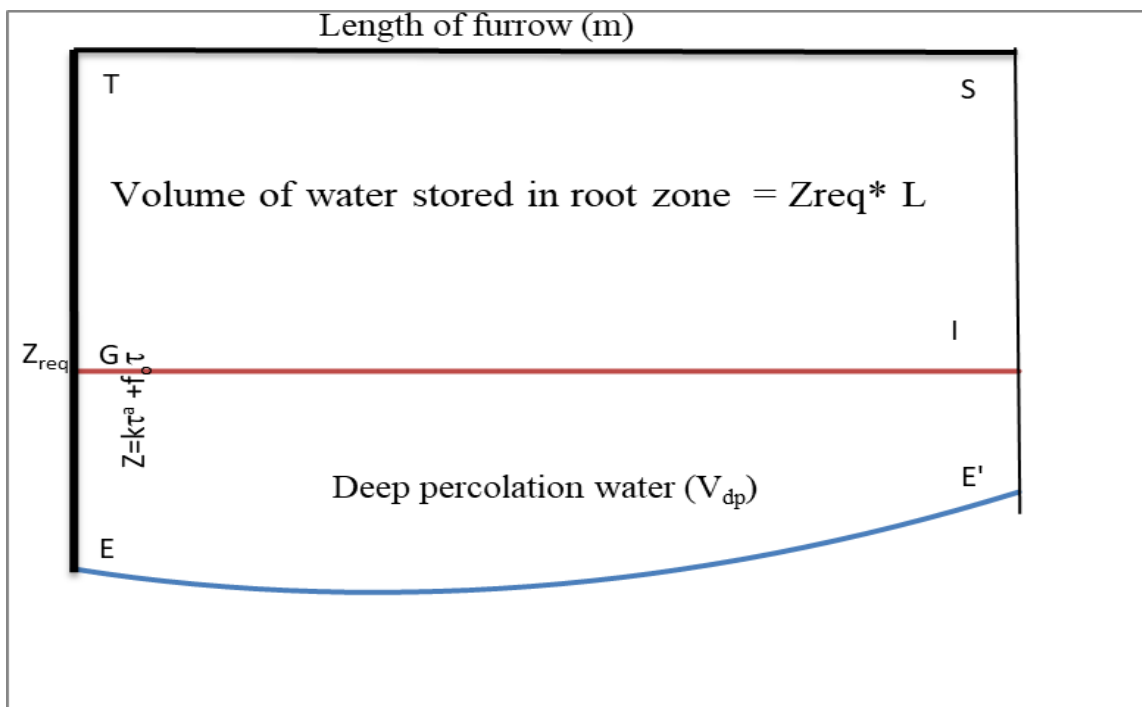


Figure 7: Subsurface infiltration water profile in blocked end furrow irrigation

Where: $-V_z = TSIE'EGT = \text{Total volume of water infiltrated (m}^3\text{)}$; $V_{req} = TSIGT = \text{Volume of water required (m}^3\text{)}$ and $V_{dp} = GIE'EG = \text{Volume of water deep percolated (m}^3\text{)}$ for field code 15

3.2.2.7. Performance measurements

Many performance indicators were suggested, they were application efficiency, storage efficiency, application uniformity, deep percolation ratio and tail water ratio. In this case, tail water ratio was not determine because of the furrow downstream condition were closed end and assume that all the water entering to the field did infiltrated to the soil.

According to Walker and Skogerboe, (1987) for over irrigation practice; application efficiency, storage efficiency, and deep percolation ratio were computed as follows.

a. Application efficiency: - which evaluate only how well the irrigation water was stored in the root zone. Application efficiency indicate a management performance indicators (Horst *et al* ,2005). The application efficiency was calculated by using equation 3.36.

$$E_a = \frac{z_{req} * L}{Q_o * t_{co}} * 100 \text{-----} (3.36)$$

b. Deep percolation ratio: - deep percolation ration is the loss of water through drainage beyond the root zone. Volume of deep percolation determined by subtracting the volume of water required from the total volume of water infiltrated in to the soil. Equation 3.37 was used to calculate deep percolation ratio.

$$DPR = \frac{V_z - z_{req} * L}{Q_o * t_{co}} * 100 \text{-----} 3.37$$

c. Er = Water requirement efficiency is 100%

The volume of water required (volume of potential soil moisture storage) was calculated by equation 3.38 (Walker, 2003).

$$V_{req} = z_{req} * L \text{-----} 3.38$$

Where:- z_{req} = the required depth of application to the furrows in m^3/m , DPR = deep percolation Ratio (%), E_r = water requirement efficiency (%), V_z = total volume of infiltrated (m^3), L = length of furrow and t_{co} = cutoff time (min)

d. Distribution uniformity: Application or distribution uniformity concerns the distribution of water over the actual field. It was determined based on after irrigation measurement depth of water infiltrated in to the soil (Adisu, 2018). It is ratio of the infiltrated depth in the least irrigation 25 % of field to average infiltrated depth of water over the whole field (USDA NRCS, 2012). Distribution uniformity was calculated by equation 3.39.

$$D_u = \frac{z_{lq}}{z_{av}} * 100 \text{-----} 3.39$$

Where, z_{lq} = the low quarter depth of infiltrated water of the field, z_{av} = average infiltrated depth of water over the entire field.

In order to know the continuity of irrigation practice during irrigation time on performance, the measurement were taken during two irrigation events for each furrows in the selected field performance indicator (Appendix table 4).

3.3. Model Performance

To compare the model output performance indicator with the estimated values, the statistical criteria were chosen to analyses the degree of the goodness of fit and were computed by the following equation (Adugnaw, 2017 and Ebrahimian and Liahat, 2011).

$$R^2 = \frac{(\sum_{i=1}^n (o_i - \bar{o})(s_i - \bar{s}))^2}{\sum_{i=1}^n (o_i - \bar{o})^2 * (\sum_{i=1}^n (s_i - \bar{s})^2)} \text{-----} 3.40$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (o_i - s_i)^2}{n}} \text{-----} 3.41$$

$$MAE = \frac{\sum_{i=1}^n |o_i - s_i|}{n} \text{-----} 3.42$$

Where, o_i = i^{th} value of the observed measurement; \bar{o} =mean of the observed values; n = Number of observations/measured; s_i = corresponding value simulated by models; \bar{s} =average of the simulated values; R^2 =coefficient of determination; RMSE= Root mean square errors; MAE= Mean absolute error

3.4. Sensitivity Analysis

Simulation models used to simulate and predict furrow irrigation performance and assess changes in management variables, which improvements in irrigation efficiency (Mehana *et al*, 2009). Because of the uncertainty of field properties and system inputs, sensitivity analysis needed to be conducted to assess the better the performance. The sensitivity analysis was done for all decision variables by varying one and keeping the other constant. If decision variables (cutoff time, inflow rate, length of furrow and slope of furrow) were correctly determined, better furrow irrigation management will be achieved (Wallender, 1999). The performance of irrigation parameters were best correlated with furrow irrigation variable (furrow length, inflow discharge and cutoff time) (Holzapfel *et al*, 2010).

4. RESULTS AND DISCUSSION

4.1. Soil physical properties of study

The soil data samples were taken from the fields for determination of the soil physical properties (textural classes, bulk density, field capacity, permanent wilting point and moisture content). As the results obtained for the three fields (15, 52 and 108) which were presented in Table 1 the soil textural class were clay soil type with 58.9%, 57.9% and 59.0% of field capacity (θ_{fc}) and 34.3%, 26.7% and 25.6% of permanent wilting point (θ_{pwp}) respectively.

The average bulk densities of the selected fields (15, 52 and 108) were 1.14, 1.1 and 1.13 g/cm^3 at the depth of 0 - 60 cm respectively. The average bulk density of each field was in agreement with the work of Booker (2009) who found that value of bulk density ranges from 1-1.7 g/cm^3 for clay soil. This result also similar with Adugnaw (2017) work and he cited Sundra (2000) report indicating the bulk density of soil for sugarcane with a range of 1.1-1.4 g/cm^3 .

4.2. Irrigation required depth

Total available water holding capacity of the soil of the selected fields 15, 52 and 108 were found 147.7 mm, 187.0 mm and 200.7 mm respectively which had 98.8 mm, 37.8 mm and 51 mm respectively for first irrigation and 54.3 mm, 28.6 mm and 57 mm respectively for second irrigation, soil moisture deficit or required irrigation water for sugarcane crops was indicated in Table 1. From three tested fields, field 52 had low soil moisture deficit in both irrigation event than the other two remaining fields. This could be because of the tested furrow located at the downstream of the field; the downstream fields get water not only from irrigation it also receive moisture from the drainage canal passing nearby and the soil texture class more near to heavy clay relative to other tested field as indicated table 1.

Table 1: Soil physical property and soil laboratory analysis of selected field

Parameters	Field 15			Field 52			Field 108		
	0-30	30-60	Avg	0-30	30-60	Avg	0-30	30-60	Avg
Soil depth(cm)									
Sand (%)	15	13	14	9	5	7	13	5	9
Silt (%)	19	22	20.5	21	20	20.5	32	38	35
Clay (%)	66	65	65.5	70	75	72.5	55	57	56
Texture Class	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay
Db(g/cm ³)	1.21	1.06	1.14	1.11	1.09	1.1	1.17	1.08	1.13
θ_i^1 (%)	43.5	41.4	42.5	49.1	54.0	51.6	50.2	50.8	50.5
θ_i^2 (%)	51.1	48.6	49.9	52.5	53.8	53.1	48.3	50.7	49.5
θ_{fc} (%)	60.7	57.2	58.9	55.9	59.8	57.9	61.5	56.5	59.0
θ_{ppp} (%)	36.0	32.6	34.3	26.9	26.6	26.7	27.1	24.0	25.6
TAW(mm)	74.1	73.6	147.7	87.2	99.7	187.0	103.2	97.5	200.7
SMD(mm) ¹	51.5	47.3	98.8	20.4	17.4	37.8	34.0	17.0	51.0
SMD(mm) ²	28.6	25.7	54.3	10.4	18.2	28.6	39.6	17.4	57.0

Where θ_i^1 = soil moisture content first event before irrigation, θ_i^2 = soil moisture content second event before irrigation, θ_{fc} = moisture content at field capacity, θ_{ppp} = moisture content at permanent point, ρ_d = bulk density, TAW = total available water, SMD¹ = soil moisture deficit at first irrigation, SMD² = soil moisture deficit at second irrigation and Avg = average

4.3. Evaluation of Furrow Geometries

The result of average obtained furrow slopes of selected fields (15, 52 and 108) were 0.172%, 0.172% and 0.182% respectively. The slopes of selected fields were suitable for furrow irrigation. These findings were similar with Jurriens *et al*, (2001) who conclude that slopes of furrow irrigation normally vary between 0.05% and 1%. The obtained results were also in line with USDA NRCS, (2002) which reported that slopes of furrow irrigation ranges from 0.05% to 2%. Slope of less than 1% are mostly used for furrow irrigation (Holden and Mcguive, 2014).

The furrow cross-sections of the selected fields were presented in Table 2. The result of the measurement showed that typical furrow geometry before irrigation was like trapezoidal in shape (figure 3).

Average maximum depth, top width, middle width and base width of furrow geometry values of each selected fields were 27 cm, 99 cm, 53 cm and 29 cm for field 15; 27 cm ,99 cm, 52 cm and 28 cm for field 52 and 22 cm, 90 cm, 45 cm and 22 cm for field 108 respectively. In terms of furrow geometry, field 108 had smaller dimensions relative to field 15 and 52 which may be due to silting soil in furrow (Table 2). The field 108 was located the downstream of the estate farm relative to the tested field. Silting had occurred at the downstream of the field other than position of field (Dibal *et al* , 2015)

Table 2: Furrow Geometry

Furrow Geometry parameters	Average Measured value(cm)		
	Field 15	Field 52	Field 108
Maximum depth(y_{max})	27	27	22
Top width(T_{max})	99	99	90
Middle width(T_{mid})	53	52	45
Base width (B)	29	28	22

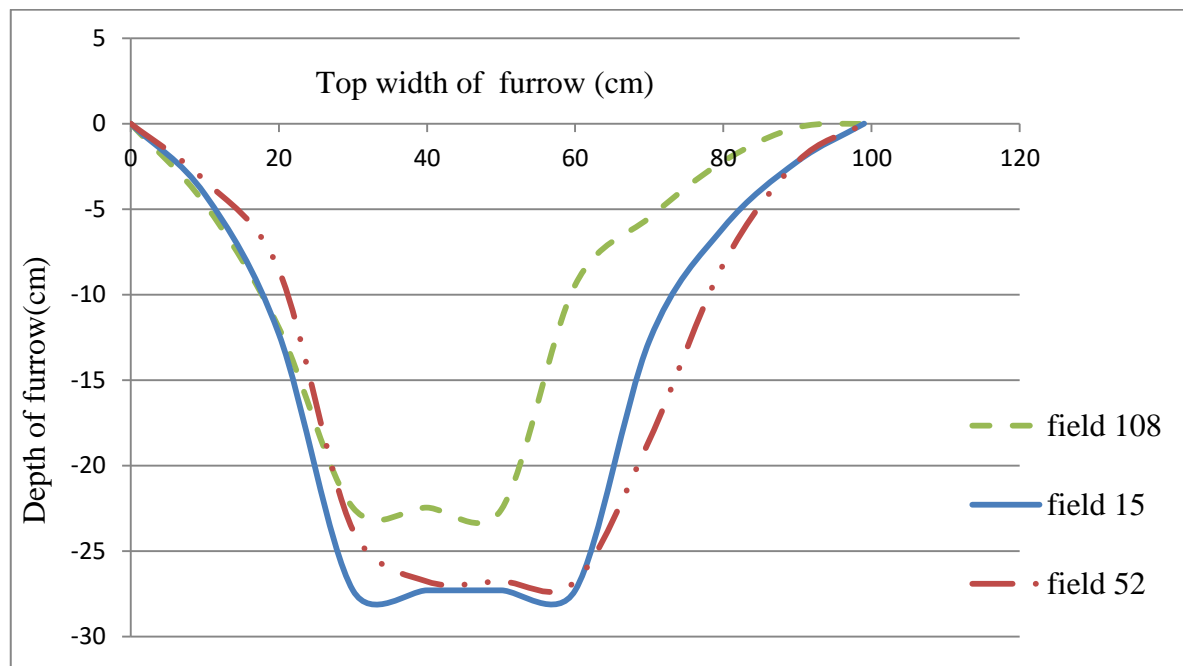


Figure 8: Average cross section of furrows fields for 15, 52 and 108

4.4. Estimation of soil infiltration

The result of infiltration parameters based on measured values found in each fields (15, 52 and 108) were the average basic infiltration rate (f_o) 0.00281, 0.00339 and 0.00416 $m^3/min/m$ respectively. The average kostiakov-Lewis parameter's 'a' values of each selected field were estimated to be 0.196, 0.195 and 0.193; and the 'k' values were estimated to be 0.0024, 0.0007 and 0.002($m^3/min/m$) respectively. The typical infiltration characteristics for the infiltration volume balance method were presented in the Appendix table 1.

The functions for cumulative infiltration (Z) and infiltration rates (I) for selected fields were derived and were indicated below respectively. Also figures such as figure 4, 5 and 6 shows the cumulative function and infiltration rate of fields 15, 52 and 108 respectively. The vertical difference between advance and recession at any particular point gives the infiltration opportunity time, which used to determine the average infiltration rate of furrows (Wallender, 1989).

$$Z = 0.0024\tau^{0.196} + 0.00281\tau$$

$$Z = 0.0007\tau^{0.195} + 0.00339\tau$$

$$Z = 0.002\tau^{0.193} + 0.00416\tau$$

$$I = 0.196 * 0.0024\tau^{0.196-1} + 0.00281$$

$$I = 0.195 * 0.0007\tau^{0.195-1} + 0.00339$$

$$I = 0.193 * 0.002\tau^{0.193-1} + 0.00416$$

Where Z =cumulative infiltration in $m^3/m/m$, τ = intake opportunity time in minutes and I= infiltration rate (mm/min)

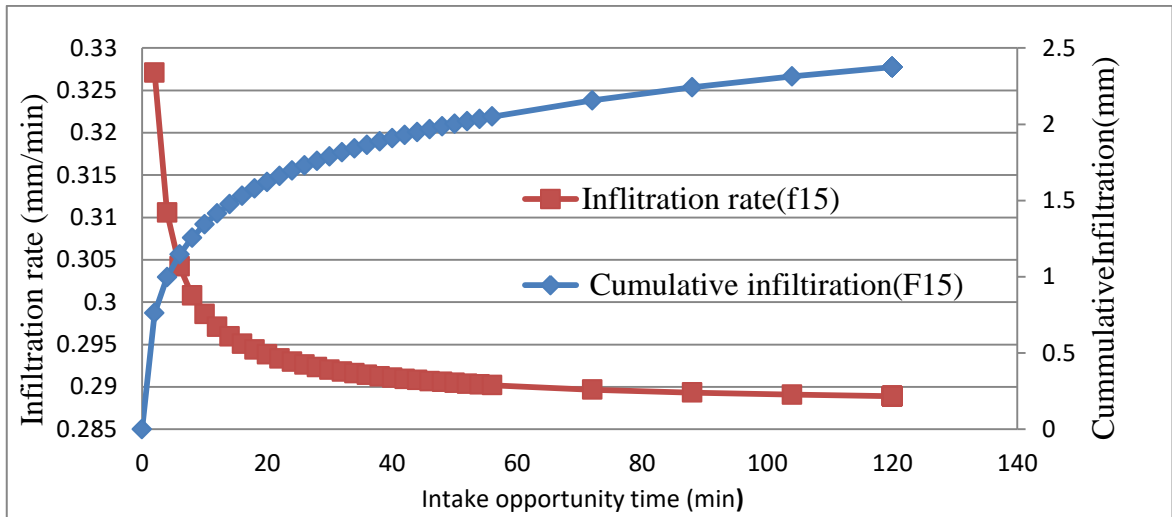


Figure 9: The average infiltration rate and cumulative infiltration of three furrows at field 15

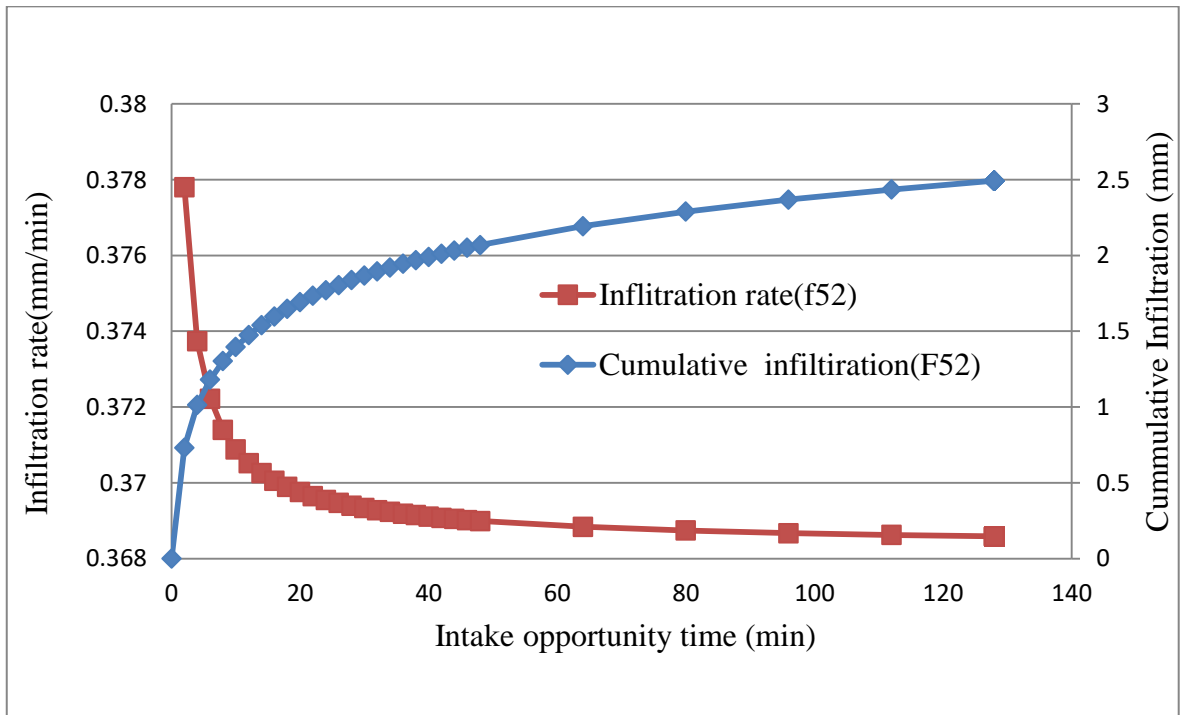


Figure 10: The average infiltration rate and Cumulative infiltration of three Furrows in field 52

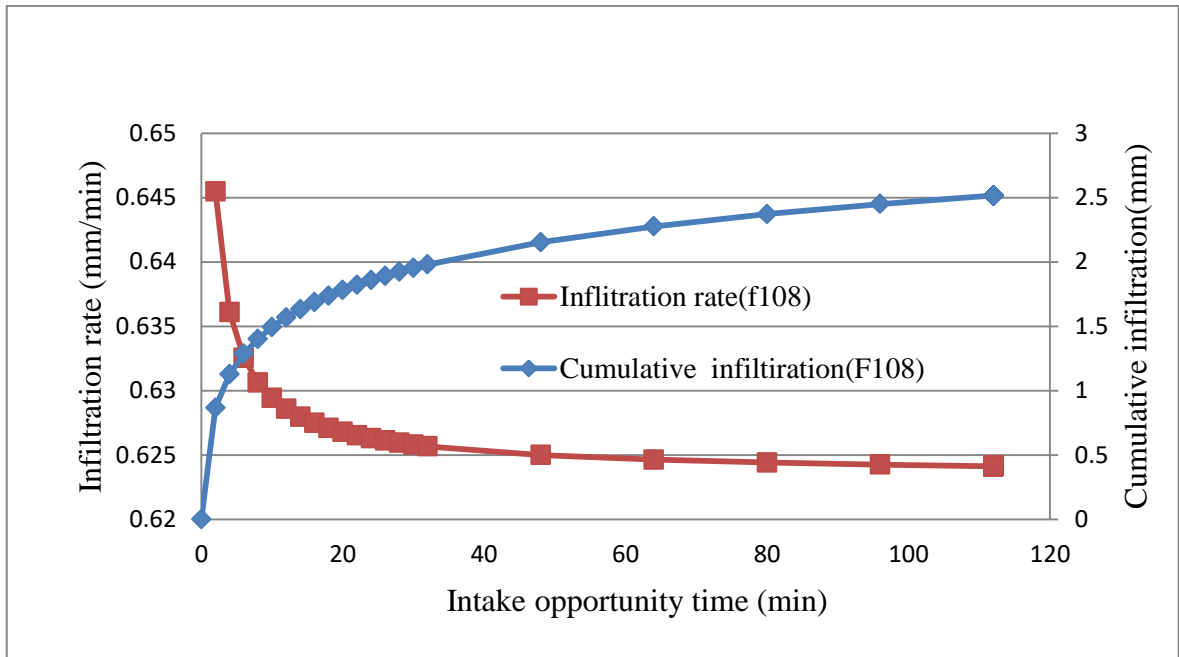


Figure 11: The average infiltration rate and cumulative infiltration of three Furrows in field 108

4.5. Advance and Recession times

The estimated and simulated curve of the advance and recession for the average of 3 furrows in each three field of length 64, 48, and 32 m with two irrigation events were presented bellow figures 9, 10 and 11 and 12,13 and 14 respectively. The estimated curve results showed in figures bellow had large advance times which may result due to large surface roughness of the study area, where furrows were not newly established and rattoned crops were found. This statement was supported by Desta *et al*, (2013) who reported that the advance time becomes longer when there is high surface roughness. But the simulated curve result showed that the advance time was shorter than the advance time of the estimated one. This result was in line with the findings of Ismail and Depeweg, (2005) who reported that the simulation show that the advance reaches the end of the furrow faster than the measured value.

The relationships were developed for both of advance time and recession time with respect to distance and the power function was found as the best fit giving higher values of coefficient of determination both advance and recession in terms of distance for average furrow in the selected field. The power equation results of both advance and

recession value of each selected fields were presented in table 3. As presented in Table 3, the result of power function values of advance time for each field were fit giving higher values of coefficient of determination which was equal to 1. The recession time of R^2 values were less than one as indicated in table 3 may be because of depression. It shows a high correlation ($R^2 \geq 0.89$) for all relationships between measured and predicted advance and recession times.

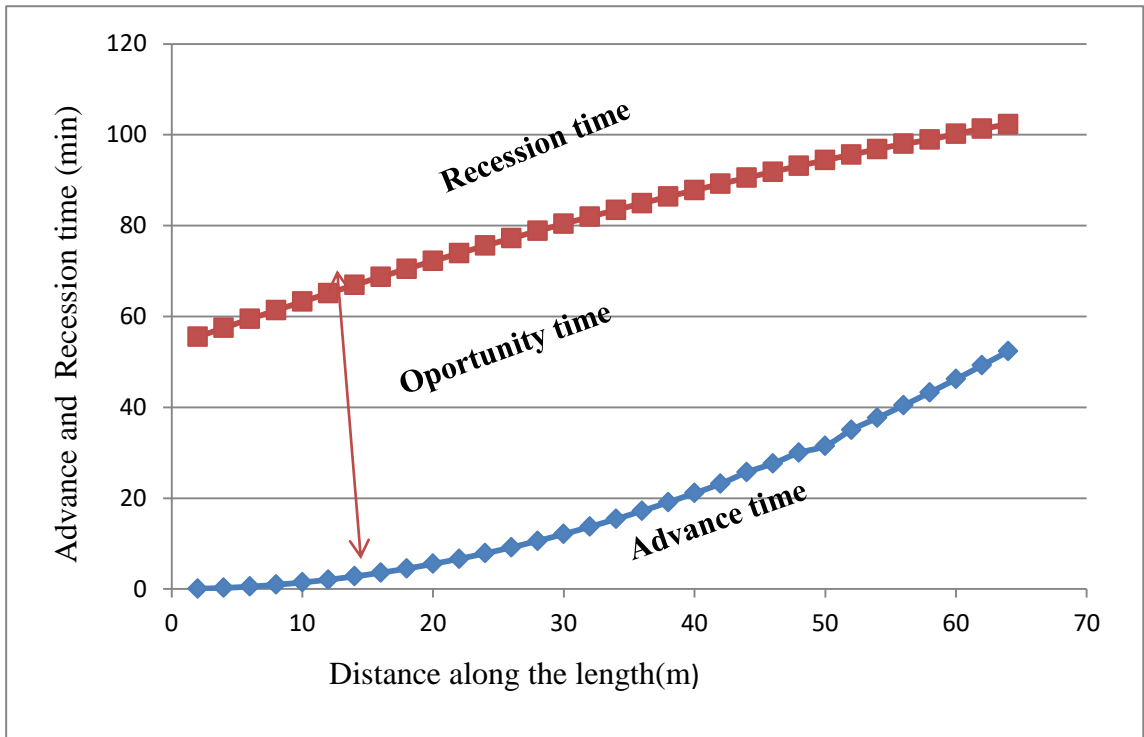


Figure 12: The average advance and recession time graph of estimated for field 15

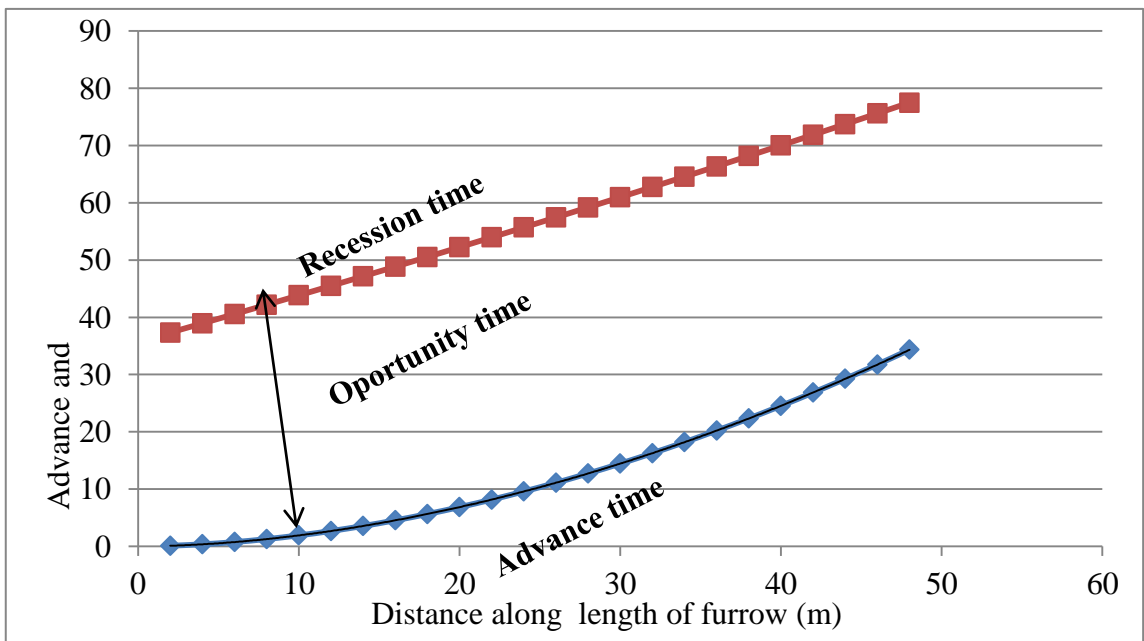


Figure 13: The average advance and recession time graph of estimated for field 52

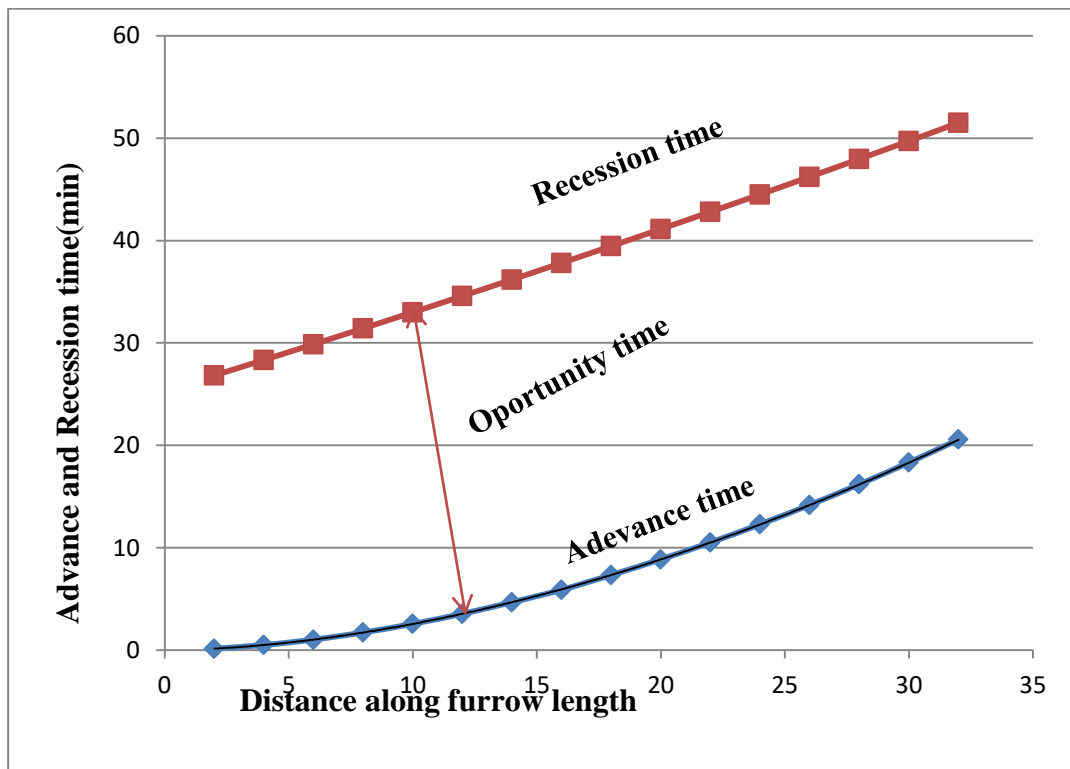


Figure 14: The average advance and recession time graph of estimated for field 108

Table 3: Evaluation of advance and recession time

Field	15	52	108
Advance time	$t = 0.017x^{1.931}$	$t = 0.0275x^{1.8416}$	$t = 0.0415x^{1.79}$
	$R^2 = 1$	$R^2 = 1$	$R^2 = 1$
Recession time	$t = 41.118x^{0.2056}$	$t = 26.03x^{0.2548}$	$t = 19.842x^{0.249}$
	$R^2 = 0.9325$	$R^2 = 0.9017$	$R^2 = 0.9154$

Where; x = Distance along the furrow (m) and t=time taken by the water front to move the distance

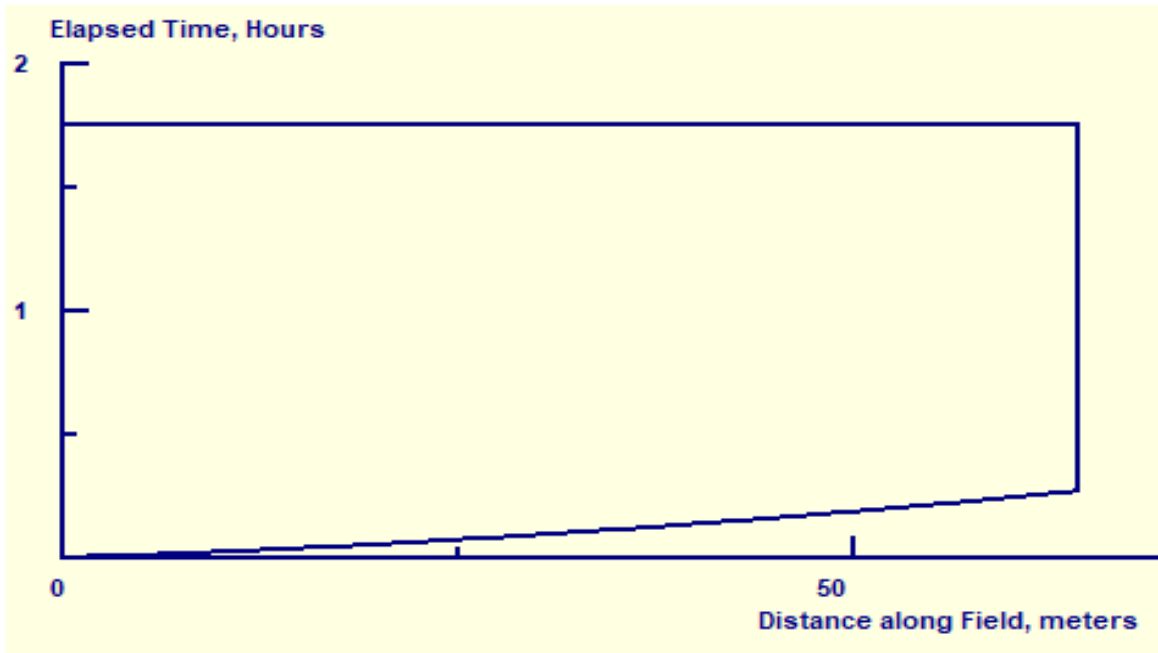


Figure 15: The average advance and recession time graph of Simulation for field 15

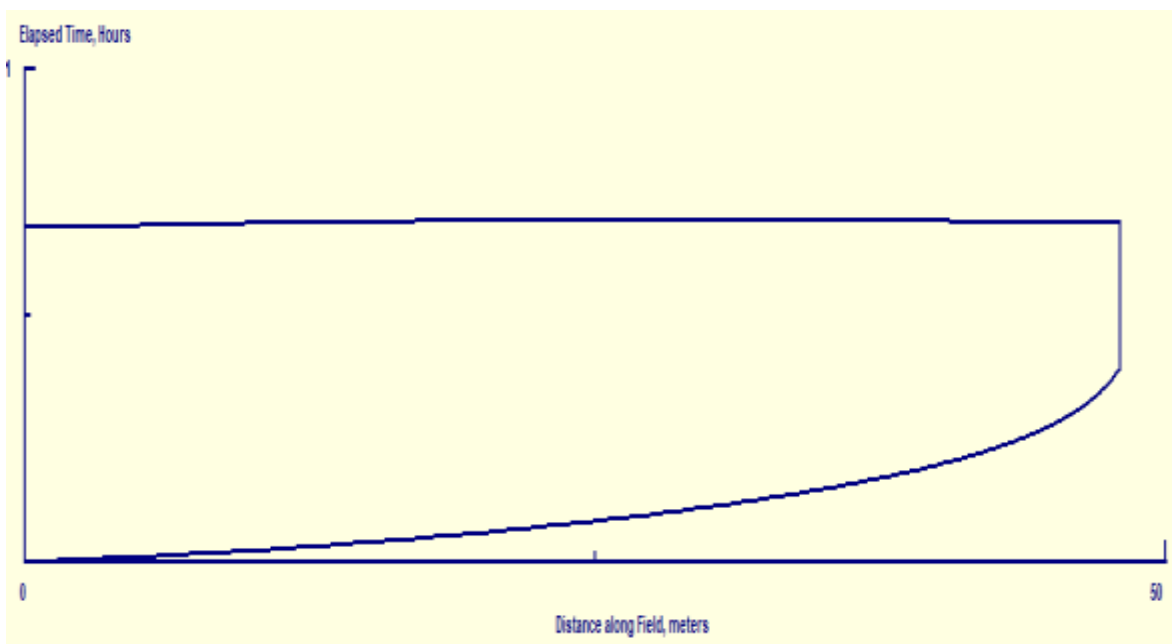


Figure 16: The average advance and recession time graph of Simulation for field 52

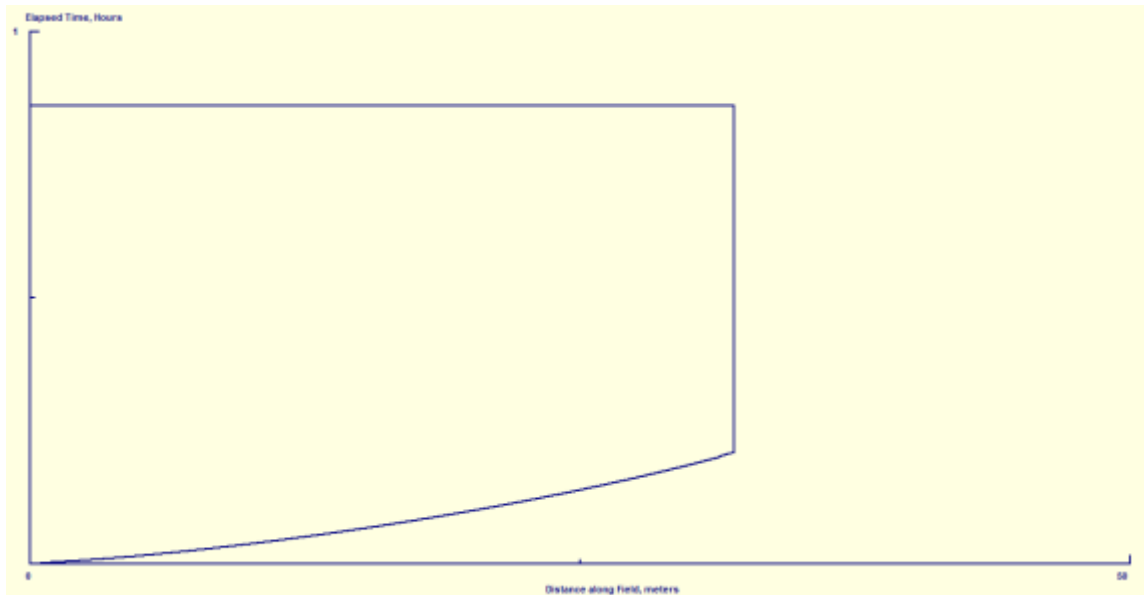


Figure 17: The average advance and recession time graph of Simulation for field 108

4.6. Performance indicators

4.6.1. Application Efficiency

As presented in table 4, the application efficiency obtained under this three selected fields (15, 52 and 108). The average value for estimation and simulation was 74.42%, 41.19% and 64.12% and 74.32%, 50.20% and 75.18% respectively. These result show that the field 15 and 108 has high application efficiency except the field 52 with furrow length 48 m had low application efficiency because at the time of irrigation the soil moisture deficit was very low relative to other field and the applied water lost by deep percolation. These results were similar with Tadesse, (2017) who reported that the furrow application efficiency varies between 40.28% and 76.91%. According to Magwenzi, (2000) the application efficiencies of inter-row furrow irrigation (i.e. water flowing between cane) range from 70% to 75% with SIRMOD simulation of evaluation inter-row irrigation confirmed that 70% level of efficiency. But the application efficiency of this study both estimated and simulated using hydrodynamic model in the SIRMOD for field 52 was showed alight deviation with the above report. The application efficiency found in this field can be considered as low in furrow irrigation. According to Biru, (2018) the range of application efficiency range was between 60% and 80%. The reason for this low application efficiency could be high deep percolation (Table 4). As reported in Horst *et al*, (2005) if there is excess irrigation and small soil moisture deficit at the time of irrigation, a

large amount of water percolate below the root zone and the application efficiency may be less than 50%. In addition as indicated in Simonne *et al*, (2011) the application efficiency of surface irrigation system varies between 20 to 70 (%) and the application efficiency value greater than 50% was unexpected unless it is blocked-end furrow at downstream condition or tail water reuse.

4.6.2. Distribution uniformity

From the evaluation of the three selected fields (15, 52 and 108) using equation 39 the distribution uniformity of furrow irrigation estimated were 91.86%, 90.78% and 89.86% and the simulated value were 92.44%, 91.38% and 93.26% respectively (Table 4). And our result was in line with Magwenzi, (2000) who reported that by evaluation of seven furrow the distribution uniformity obtained ranges from 67 to 97%. The result showed that the applied water for the selected filed were uniformly distributed. This statement was in line with Adisu, (2018) and Irmak *et al*, (2011) they reported that the value of distributions uniformity < 60% show that unevenly water distribution over the entire field and > 80% of distribution uniformity indicate that the applied water relatively uniform to the entire field.

4.6.3. Storages Efficiency

From the results under current water application practice, the storage efficiency of the three selected fields (15, 52 and 108) of furrow irrigation of estimated value was 100%. The simulation result values of the selected fields (15, 52, and 108) were 99.11%, 99.67% and 99.65% respectively (Table 4). These results would be due to the depth of applied water greater than the required water. To achieve high storage efficiency the maximum amount of water should be applied (Irmak *et al*, 2011) and because of the soil textural class which is clay soil. These results could be also due to the presence of ratoon crops in the irrigated fields. These results were in line with Magwenzi, (2000) who reported that storage efficiency of furrow irrigation of ratoon sugar cane is 100%. And the potential attainable value of water storage efficiency for furrow irrigation is 85-100% (Yewendwosen and Zinabu, 2015).

4.6.4. Deep Percolation Ratio

The average deep percolation observed for the estimated and simulation by full hydrodynamic model in SIRMOD software for three selected field (15, 52 and 108) were found to be 25.58%, 58.81% and 35.88% and 25.35%, 49.48% and 24.5% respectively (Table 4). There was high deep percolation loss in field 52 relative to the remains field 15 and 108. This would be due to the soil moisture deficit of very low during irrigation time of field 52. Generally the result indicate that in the study area there was the problem of deep percolation below effective root zone because of the furrow irrigation practice was a blocked-end downstream condition with high discharge rate not concede with their furrow length. The blocking furrow ends often results in excessive deep percolation (Mohammed *et al*, 2006).

Table 4: Performance indicators obtained from the average values of the two furrow irrigation events

FN	Fn	Ea%		DU%		Es%		DPR%	
		Estimated	Simulated	Estimated	Simulated	Estimated	Simulated	Estimated	Simulated
15	F1	72.58	71.61	91.95	91.81	100	98.94	27.42	28.15
	F2	77.65	77.25	90.21	93.19	100	98.91	22.35	22.49
	F3	73.03	74.32	93.43	92.32	100	99.49	26.97	25.42
	Aver	74.42	74.39	91.86	92.44	100	99.11	25.58	25.35
52	F1	41.15	48.46	92.66	89.63	100	99.67	58.85	51.29
	F2	40.64	48.49	92.66	91.75	100	99.67	59.36	51.23
	F3	41.77	53.65	87.01	92.77	100	99.67	58.23	45.93
	Aver	41.19	50.20	90.78	91.38	100	99.67	58.81	49.48
108	F1	67.09	73.99	85.44	93.14	100	99.67	32.91	25.68
	F2	61.25	75.97	88.73	92.20	100	99.61	38.75	23.70
	F3	64.03	75.58	95.40	94.44	100	99.67	35.97	24.12
	Aver	64.12	75.18	89.86	93.26	100	99.65	35.88	24.50

Where: - estimated=represent the calculated values of the measured data, $FN=field\ number$, $fn = furrow\ number$, F1=furrow one, F2= furrow two, F3= furrow three, $Ea=application\ efficiency$, $DU=distribution\ uniformity$, $Es=storage\ efficiency$ and $DPR= deep\ percolation\ ratio$

4.7. Comparison of Three Field Performance Indicators

As indicated in table 4, the three selected fields (15, 52 and 108) had furrow length of 64, 48 and 32 m respectively. The performance indicators (Ea , Es , DU and DPR) of the three selected field were 74.42, 100, 91.86 and 25.58(%) respectively for field 15 with furrow length 64 m, 41.19, 100, 90.78 and 58.81(%) for field 52 with furrow length 48 m and 64.12, 100, 89.86 and 35.88(%) for field 108 with furrow length 32 m. These results showed that higher application efficiency and relatively low deep percolation loss has been recorded for field 15 which had 64 m furrow length and next to field 15 field 108 with furrow length 32 m had better application efficiency and relatively low deep percolation ratio than field 52. The highest deep percolation loss of 58.81 % and low application efficiency (41.19%) for field 52 with furrow length 48 m, were the result might be due to ponding of water for long period and initial soil moisture condition of the field, in addition it might be the highest flow rate. For three selected fields the storage efficiency was 100% because of the depth of applied greater than depth of required.

4.8. Model Performance

The SIRMOD output was compared by coefficient of determination (R^2), root mean square error (RMSE) and mean absolute error (MAE) to analyze the degree of the goodness between estimated and simulated values fit in terms of application efficiency, storage efficiency, distribution uniformity and deep percolation ratio. From the four performance indicator which were determine as indicated in table 4, the storage efficiency was not included in the analysis of R^2 because the estimated storage efficiency of the three selected field 100%. From the values of the performance indices analysis the model result provides good fitting to the field estimated data (Table 5).The value of R^2 obtained as indicated in table 5 were closer to 1 indicates a good fit. This was due to that the R^2 value greater than 0.5 was accepted (Alejo and Espino, 2020). And the model was more fitted for field 108 than the other two fields in terms of R^2 . This statement was in lined with MBE, (2013) which stated that the higher R^2 value model fits to the observed data. The RMSE

and MAE value of field 108 was grater both in Ea and DPR than the other two remaining fields (Table 5).

Table 5: Comparison of the evaluation of the simulated model performances

FN	Comparison parameters	Ea	DU	Es	DPR
		SIRMOD	SIRMOD	SIRMOD	SIRMOD
15	R2	0.75	0.65		0.78
	RMSE	1.07	1.84	0.93	1.07
	MAE	1.07	1.84	0.93	1.07
52	R2	0.79	0.63		0.77
	RMSE	9.24	3.79	0.33	9.57
	MAE	9.24	3.79	0.33	9.57
108	R2	0.91	0.83		0.92
	RMSE	11.51	4.91	0.35	11.82
	MAE	11.51	4.91	0.35	11.82

The comparison analyses were implemented from the average values of the two irrigation event. R^2 = Coefficient of determination, FN = Field number, Ea =Application efficiency, DU = distribution uniformity, DPR = Deep percolation ration, RMSE = root mean square error and MAE= mean absolute error

4.9. Sensitivity Analysis

4.9.1. Discharge rate (Q_0)

The sensitivity analysis was done by making the parameters (L , t_{co} and S_0) constant as default value and by changing the discharge value increasing and decreasing from default values (3 l/s, 2.7 l/s and 2.2 l/s) for selected field (15,52 and 108) respectively.

The application efficiency was increased as the discharge decreased and similarly the application efficiency was decreased as the discharge increased for three selected field (15, 48 and 108) (Table 6).The application efficiency was increased by 24% during 2 l/s discharge rate from the existing value (3 l/s), 8% during 2 l/s discharge rate from existing value 2.7 l/s and 17% during 1.8 l/s discharge rate from existing 2.2 l/s for field 15, 52

and 108 respectively (Table 6). The results were similar with Alejo and Espino, (2020); Lima *et al* , (2014) and Holzapfel *et al*, (2010) they reported that when discharge increased the application efficiency decreased. Application efficiency had inversely proportional with discharge rate and the most sensitive on discharge change and discharge was the main factors affecting application efficiency (Assefa *et al*, 2017). Decreasing the application efficiency when discharge rate increased due to the high value of deep percolation ratio this was because of blocked-end furrow irrigation was practiced.

The distribution efficiency was decreased as discharge rate decreased for field number 15 and 108. The distribution efficiency decreased by 4 % at 2 l/s from the existing discharge 3 l/s and 2% during 1.8 l/s from existing value 2.2 l/s for field 15 and 108 respectively. The result was in line with Gudeta, (2020) and Assefa *et al* ,(2017) they reported that distribution efficiency decreased as discharge rate decreased.

The storage efficiency was decreased as the discharge decreased and when the discharge rate increased the storage efficiency became constant for all selected field (15, 48 and 108) (Table 6). The storage efficiency was decreased by 13 % at 2 l/s from existing value of discharge rate 3 l/s, 14% during 2 l/s from existing value of discharge rate 2.7 l/s and 4% during 1.8 l/s from existing value of discharge rate 2.2 l/s for three selected fields respectively (Table 6). The results were in line with Alejo and Espino, (2020) who reported that as the discharge rate decreased the storage efficiency decreased and as the discharge rate increased the storage efficiency was constant. When increasing the discharge rate, storage efficiency was constant these were due to that as furrow downstream condition was blocked-end. So when discharge increased beyond soil water holding capacity, storage efficiency became constant.

Deep percolation ratio was decreased as the discharge decreased for three selected field (15, 52 and 108). Deep percolation ratio was declined by 24 % at 2 l/s from existing discharge value 3 l/s, 8% at 2l/s from existing discharge value 2.7 l/s and 16.3% at 1.8 l/s from existing discharge value 2.2 l/s for the three selected field respectively (Table 6).Blocked-end furrow irrigation practices were used in the study areas which were exposed to excessive deep percolation loss. The results were found in line with Alejo and Espino,(2020); who reported that as discharge rate increased application efficiency

decreased due to high deep percolation ratio. The flow rate showed greater effect on deep percolation losses due to blocked-end furrow irrigation (Lima *et al* , 2014).

Table 6: Sensitivity of discharge

Ip	field 15					field 52					field 108					
	Ea	Es	DU	DPR	Ip	Ea	Es	DU	DPR	WTR	Ip	Ea	Es	DU	DPR	
Q _o	4	57	100	96	42	3.5	45	100	90	48	6.2	3	58	100	91	42
	3.5	65	100	97	35	3	46	100	90	51	3.1	2.5	69	100	97	30
	3	76	100	97	24	2.7	48	100	93	51	0.7	2.2	78	100	92	21
	2.5	91	99	94	8.6	2.5	51	96	100	49	0.1	2	86	99	91	13
	2	100	87	93	0	2	56	86	100	43	0.1	1.8	95	96	90	4.7

Where:-DPR= deep percolation ratio, IP= input parameter, DU= distribution uniformity, Es= storage efficiency, Ea=application efficiency, WTR = tail water ratio and Q_o= Discharge at the inlet

4.9.2. Furrow Length (L)

The sensitivity analysis was done by making the parameters (Q_o, t_{co} and s_o) were remaining constant as the existing value by changing the furrow length value increasing and decreasing from existing value 64 m, 48 m and 32 m for the three selected field (15,52 and 108 respectively (Table 7).

Application efficiency of all the three selected fields were increased as the furrow length increased and similarly the application efficiency were decreased as furrow length decreased for field 15, 52 and 108 respectively. The application efficiency increased by 21% for furrow length 100 m from existing furrow length 64 m and 16 % during furrow length 48 m from existing furrow length 32 m for field 15 and 108 respectively (Table 7). These results were in line with the result of Alejo and Espino, (2020) they reported that if the furrow inflow rates is large the furrow length increased to obtain high application efficiency, and also this result is in line with the result of Tesfaye *et al*, (2016) who reported that the maximum appliation efficiency obtained by increasing furrow length. In addition, Horst *et al*, (2005) who indicated that high inflow rate are not appropriate for the short furrow irrigation. So that the application efficiency had directly proportional to

furrow length for simulation value in this study and the application efficiency was highly sensitive to furrow length or the length of furrows was the main parameter affecting application efficiency (Table 7).

The distribution efficiency was decreased as furrow length increased, declined by 20% at 75 m furrow length from existing length 64m and 5% at furrow length 48 m from existing furrow length 32 m for field 15 and 108 respectively (Table 7). These results were in line with the result of Gudeta, (2020); Assefa *et al*, (2017), Tesfaye *et al*, (2016) and Guirguis and Zayton, (2015) they stated that when the furrow length increased, the distribution efficiency decreased. This indicated that to obtain high application efficiency the distribution efficiency may be reduced with limited length.

Storage efficiency was decreased as furrow length increased and as furrow length decreased the storage efficiency was constant for the three selected field (15, 52 and 108). The storage efficiency was declined by 19% for furrow length 100 m from existing length 64 m; 24% for furrow length 64 m from existing furrow length 48 m and 40% for furrow length 64 m from existing value 32 m respectively for selected field (table 7). The findings were in lined with Alejo and Espino, (2020) , Guirguis and Zayton, (2015) and Holzapfel *et al*, (2010) they reported as the length of furrow increased the storage efficiency decreased.

Deep percolation ratio was increased as the furrow length decreased similarly decreased as the increased furrow length for field 15 and 108. Deep percolation ratio was declined by 21.1 % at 100 m furrow length from existing length 64 m and 15.2% during 48 m from existing furrow length 32 m, for the selected field (15 and 108) respectively (Table 7). The maximum contribution of furrow length on the deep percolation ratio had inversely proportion to furrow length. The results were found in line with Guirguis and Zayton, (2015) they reported that as the furrow length increased deep percolation ration decreased.

Table 7:Sensitivity of length

Ip	field 15					field 52					WTR	field 108				
	Ea	Es	DU	DPR	Ip	Ea	Es	DU	DPR	Ip		Ea	Es	DU	DPR	
L	100	97	81	82	2.9	64	49	76	100	51	0.1	64	94	60	87	5.8
	75	86	96	75	14	56	49	86	100	51	0.1	56	94	69	87	5.8
	64	76	100	95	24	48	48	100	93	51	0.1	48	94	80	87	5.8
	48	57	100	83	43	40	48	100	92	52	8.4	32	78	100	92	21
	32	38	100	68	62	32	47	100	94	35	18.1	24	59	100	97	41

Where:-DPR= deep percolation ratio, IP= input parameter, DU= distribution uniformity, Es= storage efficiency, Ea=application efficiency,and Q_o = Discharge at the inlet of field

4.9.3. Cutoff time (t_{co})

The sensitivity analysis was done by making the parameters (Q_o , L and S_o) were remaining constant as the existing value by changing the cutoff time value by increasing and decreasing from existing value of cutoff time and the existing value of three fields (15,52 and 108) was 52 min, 35 min and 24 min (Table 8).

The application efficiency was increased as the cutoff time decreased and similarly application efficiency decreased when the cutoff time was increased for the three selected fields (15, 52 and 108). The application efficiency was increased by 24 % at 35 min from the existing cutoff time 52 min, 17% at 25 min from existing cutoff time 35 min and 22% during 15 min from existing cutoff time 24 min for selected field respectively (Table 8). These results were in line with Alejo and Espino, (2020) and Holzapfel *et al*, (2010) who estate that as the cutoff time increased the application efficiency decreased. Application efficiency was highly sensitive to the cutoff time in the blocked-end furrow irrigation.

The distribution efficiency was decreased as the cutoff time decreased and constant when the cutoff time increased for the three selected fields (15, 52 and 108). The distribution efficiency decreased by 4% during 35 min from existing value of cutoff time 52 min, 5% during 25 min from existing value of cutoff time 35 min and 6% during 15 min from existing value of cutoff time 24 min for selected field respectively (Table 8). These results were in line with Alejo and Espino, (2020) who estate that the cutoff time

decreased the distribution efficiency was decreased and as the cutoff time increased the distribution efficiency was constant.

The storage efficiency was decreased as the cutoff time decreased and constant when the cutoff time increased for the three selected field (15, 52 and 108). The storage efficiency declined by 12% at the cutoff time 35 min from the existing cutoff time 52 min, 2% during 25 min from existing cutoff of time 35 min and 21% during 15 min from existing value of cutoff time 24 min for selected field respectively (Table 8).The results were inline with Alejo and Espino , (2020) who show that as the cutoff time decreased the storage efficiency was decreased and as the cutoff time increased the storage efficiency was constant.

The deep percolation ratio was increased, as the cutoff time increased and similarly when the cutoff time decreased the deep percolation ratio was decreased for selected three fields (15, 52 and 108). The deep percolation ratio decreased by 24% during 35 min from existing cutoff time 52 min, 16% during 25 min from existing cutoff time 35 min and 21% during 15 min from existing cutoff time 24 min for three selected field respectively (Table 8). Alejo and Espino, (2020) who revealed that,as cutoff time increased application efficiency decreased because of deep percolation ratio increased.

Table 8:Sensentivity of cutoff time

	field 15					field 52					field 108				
Ip	Ea	Es	DU	DP	Ip	Ea	Es	DU	DP	Ip	Ea	Es	DU	DP	
				R					R					R	
t _c	75	53	100	98	46	45	42	100	94	57	35	56	100	96	44
°	65	62	100	98	38	40	42	100	94	57	30	63	100	96	37
	52	76	100	97	24	35	48	100	93	51	24	78	100	92	21
	45	90	100	95	9.8	30	55	100	92	44	20	92	98	91	7.6
	35	100	88	93	0	25	65	98	88	35	15	100	79	86	0

Where:-DPR= deep percolation ratio, IP= input parameter, DU= distribution uniformity, Es= storage efficiency, Ea=application efficiency and Q₀ = Discharge at the inlet

4.9.4. Furrow Slope (s_o)

The sensitivity analysis was done by making the parameters (Q_o , L and t_{co}) remaining constant as the existing value by increasing and decreasing the furrow slope from existing value.

The application efficiency slightly decreased as the slope of furrow decreased. When the slope of furrow decreased to 0.0002 m/m, the application efficiency was decreased by 1.12% from existing furrow slope 0.00172 m/m for field 15. The slope of the furrow had no change on the application efficiency for field 52 and 108. When the slope of the furrow increased, the application efficiency was constant (Table 9). The result was similar with the finding of Assefa *et al*, (2017) who report that the slope had no effect on application efficiency.

The distribution efficiency was decreased as the slope of the furrow was decreased; the distribution efficiency declined by 19.62% for the slope the furrow was 0.0002 m/m from existing furrow slope 0.00172 m/m and also when the slope was increased to 0.0025 m/m, the distribution efficiency decreased by 6.79% at the furrow slope 0.0025 m/m from the existing furrow slope of 0.00172 m/m for field 15. This result was in line with the result of Assefa *et al*, (2017) who estates that distribution efficiency increased as the slope of the furrow increased. For field 52 the slope of furrow increased as the distribution efficiency was constant but the distribution uniformity increased by 2% when the slope decreased by 0.0001 m/m from the existing slope of 0.00172 m/m. and for field 108 the distribution efficiency was constant whether the slope of furrow increased or decreased (Table 9).

The storage efficiency slightly decreased as the slope was decreased; the storage efficiency was decreased by 1.47% for the slope of the furrow is 0.0002 m/m from the existing furrow slope 0.00172 m/m for field 15. For field 52 and 108 when the slope of the furrow varied had no change on storage efficiency (Table 9). These result was in line with the result of Assefa *et al*. (2017) they reported that slope had no significant variation on storage efficiency.

The deep percolation ratio was slightly increased as the slope the furrow is decreased; the deep percolation ratio was decreased by 1.87% for the furrow slope 0.0002 m/m from existing furrow slope 0.00172 m/m for field 15. For field 52 and 108 when the slope of the furrow varied had no change on deep percolation ratio (Table 9). The slope of the furrow had no effect on the deep percolation ratio. The result was in line with the finding of Assefa *et al*, (2017) who estate that the slope had no variation on deep percolation ratio.

Table 9: Sensitivity of slope

Ip	field 15				field 52				field 108						
	Ea	Es	DU	DP R	Ip	Ea	Es	DU	DP R	Ip	Ea	Es	DU	DP R	
s	0.003	76	100	88	24	0.00	48	100	93	51	0.003	78	100	92	21
o					3										
	0.002	76	100	97	24	0.00	48	100	93	51	0.002	78	100	92	21
					2										
	0.001	76	100	97	24	0.00	48	100	93	51	0.001	78	100	92	21
	72				172					82					
	0.000	75	98	77	25	0.00	48	100	94	52	0.000	78	100	91	21
	2				02					2					
	0.000	76	100	94	23	0.00	48	100	95	52	0.000	78	100	92	21
	1				01					1					

Where:-DPR= deep percolation ratio, IP= input parameter, DU= distribution uniformity, Es= storage efficiency, Ea=application efficiency and Q_o = Discharge at the inlet

5.SUMMARY AND CONCLUSIONS

5.1. Summary

Evaluation of field water application at farm level plays a fundamental role in improving furrow irrigation and in providing information used to advice how to improve their system operation.

The study was done by using three selected fields (15, 54 and 108). All necessary data of soil laboratories, field measurement (furrow geometry, discharge rate, advance, recession time and cutoff time) were measured. The measurements were made during two irrigation event in order to know the continuity of irrigators practice on performance.

A volume balance equation, two point method was used to evaluate the performance of furrow irrigation system in the study area. The four important performance indicators used to evaluate the furrow irrigation system in the selected field of study area were application efficiency, storage efficiency, distribution uniformity and deep-percolation ratio. The sensitivity analysis was done for all decision variables by varying one and keeping the other constant. Sensitivity analysis was simulated to identify the decision variable that had large impact on performance indicators.

Total available water of the selected field of 15, 52 and 108 were found 147.7 mm, 187 mm and 200.7 mm respectively, from which 98.8, 37.8 and 51 mm respectively for first irrigation and 54.3 mm, 28.6 mm and 57 mm respectively for second irrigation were soil moisture deficit. The result of performance evaluation indicated that the average application efficiency of the selected field 15, 52 and 108 were 74.42%, 41.19% and 64.12% respectively for estimation and 74.32%, 50.20% and 75.18 % respectively for model simulation. The average distribution efficiency 91.86%, 90.78% and 89.86% respectively were for estimated value and 92.44%, 91.38% and 93.26% were for model simulation, the average deep percolation ratio 25.58%, 58.81% and 35.88 for estimated value and 25.35%, 49.48% and 24.5% for the model and the storage efficiency of the three selected field was 100% for estimated value and 99.11%, 99.67% and 99.65% respectively for three field.

The irrigation performances indicator obtained from the observed and simulated through model were compared by computing by coefficient of determination (R^2), root mean square errors (RMSE) and mean absolute errors (MAE). The result of sensitivity analysis of decision variables showed that discharge rate, cutoff time and length of furrow were highly sensitive on influencing the application efficiency, deep percolation, distribution uniformity, and storage efficiency. But the slope had low effect on performance indicator in this study area.

5.2. Conclusions

This research was done to evaluate the current irrigation water application at Wonji Shoa Sugar Estate and to identify the management gaps. The study indicates that there were irrigation water management problems in this study area. This may due to that the amount of water applied during the two irrigation event was more than the irrigation requirement which indicates that much amount of water was being wasted due to poor irrigation water management practice especially in field number 52.

Evaluations of performances indicators in the three selected field indicate that the distribution uniformity and storage efficiency was recommended value for all the selected fields. Whereas, the value of application efficiency for field number 15 and 108 was acceptable. But application efficiency of field number 52 was low which had high deep percolation ratio.

Generally in the study area there was the problem of over irrigation and short irrigation schedule. The volume of water applied in selected fields exceeds the irrigation water requirement of the field.

Sensitivity analysis result showed that all irrigation performances indicator were highly affected by change the parameters which were length of furrow, flow rate and cutoff time, but varying the slope of furrow was less sensitive to the performance indicator

Water losses in the study area depend on furrow length, discharge and cutoff. This study indicated that the causes of low application efficiency were excess irrigation, small soil moisture deficit at time of irrigation and short irrigation interval.

Recommendations

Although, it is quite difficult to develop concrete conclusions from one season experiment conducted on single soil type, the following recommendations were given.

1. In-order to solve the problems of performance within a required time evaluation parameter data should be collect periodically from the Estate to refine management practices and identify the changes in the field that occur over the irrigation season
2. Evaluation by direct field measurement for commercial fields expensive and time consuming. Therefore, in future using SIRMOD model can solve such problems and predict the actual performance of furrow irrigation
3. In this study the performance evaluation consider only one type of soil hence, further research work should be done by considering all type of soil type in Wonjii Shoa Sugarcane Estate.
4. The result showed that the depth of water infiltrated in the soil is greater than soil moisture deficit on the irrigation practice, theses indicate problems of over irrigation, so that to minimize the volume of infiltrated ,the amount of water enter in to furrow should optimized by applying irrigation water with optimal cutoff time
5. The sensitivity analysis was undertaken by changing inflow rates, furrow length, cutoff time and furrow slope to obtained better performance. Hence further research work should also be done by incorporating furrow geometry and surface roughness

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7. APPENDIX

Appendix table 1: The kostiakov –Lewis infiltration parameters

Field	field 15			AV	Field 52			AV	Field 108			AV		
	P	IE	F1		F2	F3	F1		F2	F3	F1		F2	F3
a	1		0.1970	0.1970	0.1990	0.1977	0.1950	0.1960	0.1960	0.1957	0.1990	0.2110	0.1650	0.1917
	2		0.1990	0.1930	0.1930	0.1950	0.1930	0.1960	0.1930	0.1940	0.1900	0.1970	0.1950	0.1940
K	1		0.0030	0.0020	0.0040	0.0030	0.0020	0.0010	0.0004	0.0011	0.0007	0.0002	0.0010	0.0006
	2		0.0030	0.0010	0.0010	0.0017	0.0010	0.0003	0.0001	0.0005	0.0060	0.0030	0.0010	0.0033
f_o	1		0.0037	0.0036	0.0034	0.0036	0.0043	0.0041	0.0039	0.0041	0.0045	0.0041	0.0037	0.0041
	2		0.0018	0.0020	0.0023	0.0020	0.0027	0.0029	0.0024	0.0027	0.0041	0.0041	0.0045	0.0042

Where=1= first irrigation event 2= second irrigation event, p=parameter, IE = Irrigation event, a, and k=kostiakov fitting parameters, f_o= basic infiltration rate, F1=furrow one, F2=furrow two, F3= furrow three, and AV=average value

Appendix table 2: The inputs of the full hydrodynamic model to simulate the performance indicators

Furrows cross sectional parameter																
F	F	F	So	n	Ym	TW(	MW(	Base(	σ ₂	σ ₁	γ ₂	γ ₁	ρ ₂	ρ ₁	Cm	Cch
N	N	L			ax(c	cm)	cm)	cm)							h	
15	f1	6	0.00172	0.1	27	99	54	31	1.48	1.12	0.83	3.570	2.57	0.27	0.87	3.11
		4		5					54	34	96	8	97	01	45	09
	f2	6	0.00172	0.1	28	98	52	30	1.50	1.09	0.86	3.590	2.56	0.24	0.91	3.13
		4		5					04	67	46	8	50	74	43	81
	f3	6	0.00172	0.1	26	100	53	27	1.54	1.20	0.88	3.851	2.57	0.31	0.91	3.43
		4		5					23	93	15	9	12	20	59	44
average			0.00172	0.1	27	99	53	29	1.50	1.14	0.86	3.671	2.57	0.27	0.90	3.22
				5					94	31	19	2	20	65	16	78
52	f1	4	0.00172	0.1	26	98	53	27	1.52	1.17	0.86	3.686	2.58	0.30	0.88	3.23
		8		5					98	90	00	2	38	40	68	61
	f2	4	0.00172	0.1	27	100	51	28	1.54	1.16	0.91	3.940	2.54	0.27	0.97	3.56
		8		5					17	87	19	8	47	01	14	77
	f3	4	0.00172	0.1	27	100	52	29	1.52	1.15	0.89	3.837	2.55	0.27	0.94	3.43
		8		5					43	73	08	8	41	09	34	92
average			0.00172	0.1	27	99	52	28	1.53	1.16	0.88	3.821	2.56	0.28	0.93	3.41
				5					20	83	76	6	09	17	39	43
108	f1	3	0.00182	0.1	22	92	46	22	1.59	1.27	0.95	4.461	2.53	0.30	1.00	4.18
		2		5					90	56	20	6	95	65	00	18
	f2	3	0.00182	0.1	24	91	47	24	1.55	1.15	0.90	3.919	2.55	0.26	0.95	3.54
		2		5					76	79	73	3	66	38	32	67
	f3	3	0.00182	0.1	21	86	42	21	1.60	1.21	0.97	4.533	2.52	0.25	1.03	4.31
		2		5					01	83	21	9	33	73	39	81

average	0.00182	0.1	22	90	45	22	1.58	1.21	0.94	4.304	2.53	0.27	0.99	4.01
		5					56	73	38	9	98	59	57	55

Where: FN= field number, F1=furrow one, F2=furrow two, F3= furrow three, So= furrow slope, n= roughness coefficient, Ymax= maximum depth,TW= tope width,MW= middle width, σ_2 , σ_1 , γ_2 , γ_1 , Cmh and, Cch are all fitting parametrs, ρ_2 and ρ_1 =furrow shape parameters

Appendix table 3: Inflow rate and Cutoff time

	Field 15			Field 52			Field 108		
	F1	F2	F3	F1	F2	F3	F1	F2	F3
Inflow rate(l/s)	3.943	3.81	3.67	3.402	3.274	3.15	2.402	2.18	1.96
	1.957	2.18	2.402	2.18	2.291	1.96	2.18	2.18	2.4
Cut-off Time(min)	46	45	49	31	31	29	19	20	22
	64	58	52	38	38	39	30	28	25
	Power coefficient								
P	9.02	8.95	9.14	7.69	7.67	7.68	6.08	5.79	5.68
	7.45	7.51	7.94	6.54	6.58	6.44	5.08	5.00	5.19
R	0.51	0.52	0.50	0.53	0.53	0.54	0.56	0.57	0.56
	0.52	0.53	0.53	0.55	0.55	0.55	0.54	0.56	0.57
	Surface and Subsurface Coefficient								
σ_y	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
σ_z	1.49	1.49	1.50	1.48	1.49	1.49	1.50	1.54	1.40
	0.89	0.89	0.89	0.89	0.88	0.89	0.89	0.88	0.88

Where: F1=furrow one, F2=furrow two, F3= furrow three, P= power coefficient, r= fitting coefficient, σ_y =surface shape factor, σ_z =subsurface shape factor

Appendix table 4: The output comparison of full hydrodynamics model simulation and estimated in terms of infiltration water and performance indicators for two irrigation event

Field NO	Furrow number	Irrigation event	Z(m3)	Estimated /Calculated Value				Z(m3)	SIRMOD Model Simulated Value			
				Ea%	Es%	DU%	DPR%		Ea%	Es%	DU%	DPR%
15	F1	1	13.84	66.38	100.00	89.86	33.62	10.90	82.90	98.20	91.75	16.88

		2	7.48	61.28	100.00	92.38	38.72	7.5	60.31	99.67	91.86	39.42
	F2	1	15.47	57.46	100.00	82.77	42.54	10.3	85	98.15	91.47	14.77
		2	8.06	66.01	100.00	85.50	33.99	7.6	69.49	99.67	94.91	30.2
	F3	1	14.96	59.55	100.00	87.30	40.45	10.8	82	99.31	93.51	17.76
		2	8.57	58.19	100.00	85.50	41.81	7.5	66.64	99.67	91.12	33.08
52	F1	1	7.43	35.94	100.00	93.85	64.06	6.2	42.48	99.67	89.51	57.28
		2	5.82	46.36	100.00	91.47	53.64	5	54.43	99.67	89.74	45.29
	F2	1	6.78	36.46	100.00	91.41	63.54	5.8	45.18	99.67	89.07	54.56
		2	5.99	44.81	100.00	93.92	55.19	5.2	51.79	99.67	94.42	47.9
	F3	1	7.91	34.47	100.00	85.58	65.53	5.4	49.42	99.67	89.73	50.07
		2	5.84	49.07	100.00	88.45	50.93	4.9	57.88	99.67	95.8	41.79
108	F1	1	4.07	65.03	100.00	84.57	34.97	3.3	79.62	99.67	91.33	20.03
		2	3.88	69.14	100.00	86.32	30.86	3.9	68.35	99.67	94.95	31.33
	F2	1	3.66	57.84	100.00	87.82	42.16	2.6	81.22	99.55	89.58	18.41
		2	4.04	64.65	100.00	89.64	35.35	3.7	70.71	99.67	94.81	28.98
	F3	1	3.20	64.87	100.00	95.04	35.13	2.6	80.56	99.67	93.04	19.15
		2	4.01	63.19	100.00	95.75	36.81	3.6	70.59	99.67	95.83	29.09

Where= F1=furrow one, F2=furrow two, F3= furrow three, DPR=deep percolation ratio ,DU= distribution uniformity ,Ea= application efficiency ,Es= storage efficiency,

Appendix table 5: Free flow discharge values for different size of parshal flumes

Head(cm)	Through 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	7.323
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	21.07	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	56.51
24			19.389	39.984	60.312

Source (Malkasa Agricultural Research Center)

Appendix table 6: Reference Evapotranspiration value determined with Cropwat 8

	Tmin	Tmax	Humidity	Wind	Sun	Radation	ET_o
Month	°C	°C	%	Km/Day	hours	MJ/m²/day	mm/Day
January	12.10	26.80	55.00	115.00	8.80	20.60	4.08
February	13.30	28.50	51.00	117.00	9.00	22.20	4.60
March	14.60	29.50	52.00	109.00	8.40	22.30	4.79
April	15.10	29.40	54.00	91.00	8.30	22.30	4.69
May	14.40	30.10	54.00	86.00	8.60	22.20	4.65
June	16.50	29.40	57.00	114.00	8.40	21.30	4.70
July	16.00	26.20	67.00	117.00	6.80	19.20	4.05
August	15.40	25.90	70.00	88.00	7.00	19.90	3.95
September	14.60	26.90	68.00	57.00	7.20	20.30	3.94
October	11.90	27.50	56.00	74.00	8.80	22.10	4.24
Novemeber	10.60	27.00	53.00	102.00	9.40	21.70	4.20

December	11.00	26.50	54.00	108.00	9.00	20.40	3.95
Average	13.00	27.80	58.00	98.00	8.30	21.20	4.32

Where= T_{min} = minimum temperature, T_{max} =maximum temperature, ET_o =reference evapotranspiration



Appendix figure 1: Measuring furrow length of selected fields and furrow geometry measurement



Appendix figure 2: Determination of sampling depth for bulk density and Soil sampling for bulk density



Appendix figure 3: Taking of soil sampling and Inflow measuremet



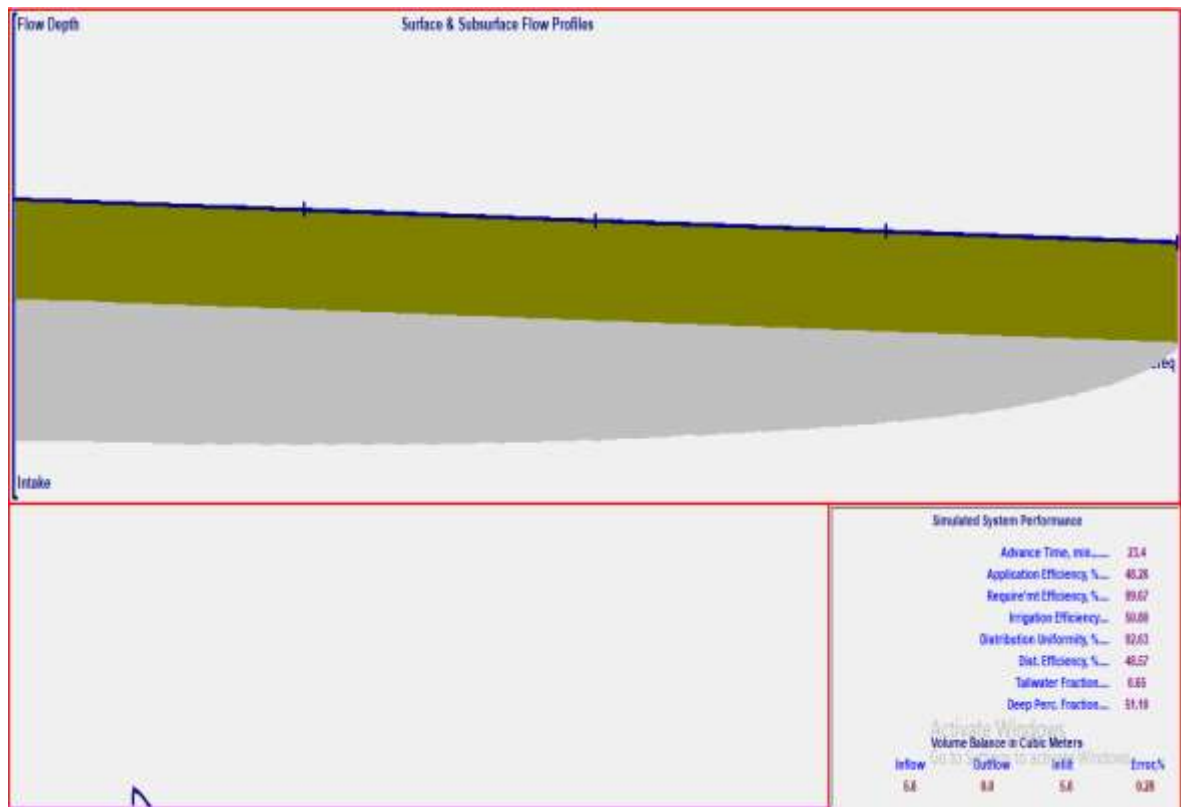
Appendix figure 4: Advance and Recession measurement

Field Topography/Geometry	Inflow Controls	Infiltration Characteristics	Hydrograph Inputs	Design Panel
<div style="display: flex; justify-content: space-between;"> <div style="width: 30%;"> <p>Field Geometry</p> <p>Field Length, m: 64.0</p> <p>Field Width, m: 1.5</p> <p>Furrow Spacing, m: 1.45</p> </div> <div style="width: 30%;"> <p>Manning - n Values</p> <p>First Irrigations: 0.150</p> <p>Later Irrigations: 0.150</p> <p>? Specific Help</p> </div> <div style="width: 30%;"> <p>Flow Cross-Section</p> <p>Top Width (m): 0.990</p> <p>Middle Width (m): 0.530</p> <p>Bottom Width (m): 0.290</p> <p>Maximum Depth (m): 0.270</p> </div> </div>				
<div style="display: flex; justify-content: space-between;"> <div style="width: 30%;"> <p>Field System</p> <p><input type="radio"/> Border/Basin Irrigation</p> <p><input checked="" type="radio"/> Furrow Irrigation</p> </div> <div style="width: 30%;"> <p>Downstream Boundary</p> <p><input type="radio"/> Free Draining</p> <p><input checked="" type="radio"/> Blocked</p> </div> </div>				
<div style="display: flex; justify-content: space-between;"> <div style="width: 30%;"> <p>Slopes</p> <p>First Slope: 0.00172</p> <p>Second Slope: 0.00172</p> <p>Third Slope: 0.00172</p> <p>First Distance, m: 31.0</p> <p>Second Distance, m: 64.0</p> <p>Field CrossSlope: 0.00000</p> <p>? Specific Help</p> </div> <div style="width: 30%;"> <p>Manning Equation Calculator</p> <p>Slope: 0.00800</p> <p>Manning n: 0.0400</p> <p>Flow, lps: 2.0000</p> <p>Depth, m: 0.0000</p> <p>Area, m²: 0.0000</p> <p>Top Width, m: 0.0000</p> <p>Wetted Perimeter, m: 0.0000</p> </div> <div style="width: 30%;"> <p>Hydraulic Section</p> <p>Rho1: 0.1960</p> <p>Rho2: 2.5726</p> <p>Sigma1: 1.1449</p> <p>Sigma2: 1.5128</p> <p>Gamma1: 3.6678</p> <p>Gamma2: 0.8632</p> <p>Cch: 5.2876</p> <p>Cmh: 1.5443</p> </div> </div>				

Appendix figure 5: Field topography input

Field Topography/Geometry	Inflow Controls	Infiltration Characteristics	Hydrograph Inputs	Design Panel
<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p>Simulation Shutoff Control</p> <p><input type="radio"/> By Elapsed Time or No. of Surges</p> <p><input checked="" type="radio"/> By Target Application, zreq</p> </div> <div style="width: 45%;"> <p>Run Parameters</p> <p>Furrow Inflow, lps: 2.994</p> <p>Time of Cutoff, mn: 52.3</p> <p>Dtm, mn: 0.10</p> <p>No of Surges: 0</p> <p>Surge Cycle On-Time, mn: 0.0</p> <p>Cutback Ratio: 0.00</p> <p>CB Length Fraction: 0.0</p> <p>Surge Adj Ratio: 0.00</p> <p>Surge Adj Time, mn: 0.00</p> <p>Leaching Fraction: 0.05</p> </div> </div>				
<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p>Inflow Regime Control</p> <p><input checked="" type="radio"/> Continuous Inflow</p> <p><input type="radio"/> Continuous Inflow w/ Cutback</p> <p><input type="radio"/> Continuous Inflow Hydrograph</p> <p><input type="radio"/> Fixed-Cycle Surge Flow</p> <p><input type="radio"/> Fixed-Cycle Surge Flow w/ Cutback</p> <p><input type="radio"/> Variable-Cycle Surge Flow</p> <p><input type="radio"/> Variable-Cycle Surge Flow w/ Cutback</p> <p><input type="radio"/> Surge Controller</p> </div> <div style="width: 45%;"> <p>Special Numerical Coefficients</p> <p>Phi: 0.60</p> <p>Theta: 0.60</p> <p><input type="checkbox"/> Scalding Protection</p> </div> </div>				
<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p>Type of Simulaton Model</p> <p><input type="radio"/> Kinematic-Wave</p> <p><input type="radio"/> Zero-Inertia</p> <p><input checked="" type="radio"/> Hydrodynamic</p> </div> <div style="width: 45%;"> <p>Simulation Speed & Graphic Slope</p> <p><-Slow-Fast-></p> <p>0 <-Slope-> +</p> </div> </div>				

Appendix figure 6: Inflow Controls Input (for full hydrodynamic model)



Appendix figure 7: Output of full hydrodynamic model

BIOGRAPHICAL SKETCH

Tsige Mohammed Ahmed was born on September 29, 1989 in Dodota Woreda Arsi zone of the Oromia Regional State. She attended her elementary and secondary school from 1996-2003 at Dera town, and high school and preparatory school from 2004-2007 at Dera. After passing the Ethiopian Higher Education Entrance Certificate (EHEEC), she joined Adama Science and Technology University and obtained her B.Sc. degree in Soil and water Conservation and Irrigation Engineering in June 29/2013. After graduation, she was employed by the Ministry of Agriculture in Mizan ATVET College and served as an instructor. In 2018, sponsorship of ministry of agriculture, the author joined the school of graduate studies at Hawassa University to pursue her MSc degree in Irrigation and Drainage Engineering.