PERFORMANCE EVALUATION OF FURROW IRRIGATION IN BELLES SUGAR DEVELOPMENT PROJECT SUGARCANE FARM LEVEL, ETHIOPIA

MASTER OF SCIENCE IN IRRIGATION AND DRAINAGE ENGINEERING THESIS

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LIST OF ACRONYMS AND ABBREVIATIONS

D_U	Distribution Efficiency
DPR	Deep Percolation ratio
E_a	Application Efficiency
E_S	Storage Efficiency
FAO	Agricultural Food Organization
FC	Field Capacity
MAE	Mean Absolute Errors
PWP	Permanent Wilting Point
R^2	Coefficient of determination
RMSE	Root Mean Square Errors
SMD	Soil Moisture Depletion
TAW	Total Available Moisture
Vz	Infiltrated volume
Z_{req}	Required depth to refill the field capacity

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ABSTRACT

Evaluation of farm irrigation system plays a fundamental role in improving surface irrigation and in providing information used to advice irrigators how to improve their system operation. Furrow irrigation is one of the common methods of applying water to sugarcane at Belles sugar development project Sugarcane Plantation. The plantation is facing problems with respect to irrigation water management. This study was initiated with the objectives of evaluating the performance of furrow irrigation system at a farm level.

To evaluate the performance of furrow irrigation system, a soil laboratory and field measurements (field layout, furrow geometry, time of cutoff, discharge) are made. The soil infiltration parameters ‘a’, ‘k’ and ‘f_o’ for each irrigation event are determined based on a two-point approximation to volume balance method that incorporated modified Kostiakove Lewis infiltration function.

Statically comparison of models outcome found the Win SRFR simulated model values provides good fitter than the SIRMOD simulation values to the estimated values. The analyses of the performance of the furrow irrigation in terms of application efficiency (Ea), distribution efficiency (Du), storage efficiency tail water Ratio (TWR), and Deep Percolation (DP) were done and found to be, the average application efficiency 62.1%, 65.3% and 68.5% for SIRMOD, estimated and WinSRFR simulated values; distribution efficiency 90.4%, 92.4% and 95.5% for estimated, SIRMOD and WinSRFR simulated value; storage efficiency 24.1%, 26.4% and 32.8% for SIRMOD, WinSRFR simulated and estimated values; TWR 31.2%, 34.2% and 37.9% for WinSRFR, estimated and SIRMOD simulated values, respectively and deep percolation ratio for all estimation is null. From the sensitivity analysis furrow slopes are higher sensitive than other parameters on influencing the application efficiency. The effects of furrow lengths are highly influencing on TWR. The effect of discharge influence on the storage efficiency also high with compared to others whereas the time of cutoff found affect the distribution efficiency.

Key words: Furrow irrigation, Performance indices, sensitivity analysis

1. INTRODUCTION

1.1. Background

Surface irrigation is the most widely used method of irrigation water application to croplands worldwide. Surface irrigation accounts for over 90% of all irrigated lands in the world (Jurriens *et al*., 2001). In the coming decades, as the competition for water resources accelerates and global population growth continues to escalate, surface irrigation will have to contend with the difficult assignment of producing more food and fiber with less resources. Obviously, if the surface irrigation is to remain a sustainable and positive social and economic force in the 21st century, it needs to evolve into an efficient, cost effective, and environmentally benign technology.

Surface irrigated agriculture faces a number of difficult problems. One of the major concerns is generally poor efficiency with which water resources have been used for irrigation. A large part of low performance may be due to inadequate water management at system and field level. Relatively conservative estimate is that 40% or more of the water diverted for irrigation is wasted at farm level through either deep percolation or surface runoff (Walker, 1989)

Agriculture is a backbone of Ethiopian economy development and a key driving force of its long-term growth and food security (Seleshi *et al*., 2010). Irrigation has contributed significantly to poverty reduction, food security, and improving the quality of life for the population.

Ethiopia faces four key challenges on effectively implementation of irrigation, i.e., technical, socio-economic, institutional, and environmental challenges that must be overcome in order to meet the ambitious target. Of these key challenges, low-performance (under performance) of schemes is the one which is identified and specific recommendations are given by the team of researchers to address these challenges (Seleshi *et al*., 2010). Especially the sustainability of large-scale irrigation largely depends on the technical, socio-economic, institutional and management planning. Monitoring and evaluation of their performance is, therefore the first measure that has to be taken to improve irrigation efficiencies at farm and field levels.

Belles sugar development project is one of the largest scale irrigation schemes in Ethiopia being operation of constructing and managing by the public enterprise planning a total area of 75,000 hectares sugar cane cultivation by furrow and sprinkler irrigation system (USDA, 2015).

Knowing the efficiencies and the effectiveness of water use at farm level and to alleviate the current challenges caused by inefficient operation of irrigation system at Belles sugar development project is found to be important for possible recommendations of improvement of the scheme. Since its inception, on-farm irrigation system evaluation studies had never been conducted on the performance of this irrigation scheme. For long term sustainability of an irrigation system, improvements in the performance of current water application and on-farm water management practices seem to be more necessary than any other practice. An important aspect that has been considered in several studies is to design efficient irrigation systems at the farm-level (Feyen and Zerihun, 1999) and Zerihun *et al*., 2001). So, the performance evaluation of the scheme would help to improve the performance of the irrigation system in terms of efficiencies, farm water management and, to identify causes for poor irrigation management system. The evaluation includes field parameters and decision variables those that an irrigation designer can adapt to find the best irrigation performance for the given or selected field parameters. Efficient application and distribution of water by furrow irrigation is dependent on furrow parameters such as inflow, soil texture, field slope, soil infiltration, plant coverage, roughness coefficient, field shape, irrigation management and etc. It is essential to understand the role and inter-dependence of these factors, which determine the prescribed amount of water to apply and ensure uniform application down the full furrow length. Improved efficiency in irrigation system design can help reduce the amount of irrigation water applied there by reducing water runoff problems while at the same time maintaining crop water needs (Pereira and Trout, 1999).

Application discharge is the main factor affecting application efficiency. In addition, application efficiency depends on the soil water deficit at the time of irrigation (Pereira and Trout, 1999). (Raine and Bakker, 1996) identified a range of methods to improve water application efficiencies in the sugar industry including the use of appropriate furrow lengths, irrigation cut of times and water application rates.

Interactions between the variables determine advance time, recession time, infiltrated depths and corresponding irrigation efficiencies and uniformities (Basem, 2012). Evaluation variables are basically indexes for determining the irrigation performance; these are application efficiency, application uniformity, storage or water requirement efficiency, deep percolation and tail water ratio.

Efforts to achieve high application efficiencies for furrow irrigated system are limited by very large spatial and temporal variation in infiltration characteristics. Thus, while efficiencies of 85 to 90% are periodically reported from studies incorporating careful soil moisture monitoring and automation, efficiencies in the order of 50 to 70% are more common. When furrow irrigation has a good performance it's the water application efficiency is greater than 70% with less than 20% deep percolation and 20% losses, while storage efficiency is greater than 85 to 90% (Walker, 1989).

The SIRMOD and Win SRFR models simulation routine is used the numerical solution of the Saint-Venant equations for conservation of mass and momentum as described by (Walker and Skogerboe, 1987).

1.2. Statement of the problem

The fundamental problem that enforcing this research is, Belles Sugar Development Project is one of the largest irrigation projects in Ethiopia but it lacks performance assessment results for improvement of the overall management of the system in terms of cutoff time, field dimensions, flow rate, advance and recession of water across the field surface; and enhance efficiency such as application efficiency, storage efficiency, uniformity efficiency, distribution efficiency. Therefore this study envisaged to solve the management and operational practice options problem.

According to the pervious researches performance evaluation of furrow irrigation system measuring the infiltration rate at static water condition by cylinder infiltrometers for representing through the furrow length studied in many fields. However, it does not consider the dynamic condition of water movement over the soil through the furrow length and doesn't get precise evaluation value especially for large scale irrigation scheme. In this study applying the volume balance model from two points on the advance curve would solve those problems so that representative distribution of infiltration along the furrow length obtained.

In addition many researchers had done the evaluation of furrow irrigation using only one simulation model. However, comparing of this evaluation through two simulation models to investigate amount of their errors and limitations has not been done. In this study SIRMOD and Win SRFR models were used to evaluate the performance of furrow irrigation and compare their result.

1.3. Objective

1.3.1. General objective

The general objective of this research is evaluate furrow irrigation system performance in the Belles large scale irrigation project

1.3.2. Specific objectives

The specific objective of this research includes:

- To evaluate the current practices of the decision variables such as advance, cut off time, loss of water and intake operation of the furrow irrigation system
- To identify management practices options in-order to optimize the irrigation efficiencies (application efficiency, storage efficiency, deep percolation and distribution uniformity).
- To compare performance efficiencies via SIRMOD III and WinSRFR surface irrigation model output value and develop sensitivity analysis for different management options.

1.4. Scope of the Study

This study focus on Belles Sugar Development Project furrow irrigation system particularly on sugar cane farm level to get representative evaluation values of data /information/ for a particular selection of length, shape, field inflow rate, cut off time, advanced time and irrigation efficiencies by using laboratory test and field evaluation parameters are done.

1.5. Purpose of the Study

The purpose of this field experimental study is to test the theory of performance that influence on the furrow irrigation system relates the field parameters and decision variables to irrigation efficiencies, controlling for irrigation management options for irrigator at Belles large scale irrigation scheme. The performance evaluation of the scheme would help to improve the performance of the irrigation system in terms of efficiencies, farm water management and, to identify causes for poor irrigation management system.

2. LITERATURE REVIEW

2.1. Management of Furrow Irrigation

According to U.S Bureau of Reclamation, (2005), “Irrigation Water Management” means management of irrigation water on the farm. Developing countries need to find ways to grow and to be more productive with the wise use of water consumption. According to Burt and Styles, (1999) the performance of irrigation efficiencies improved on-farm water management, which depends upon improved the reliability of water delivery service to the field. Therefore, the designs of the irrigation system, the degree of land preparation, and the skill and care of the irrigator are the principal management factors influencing the performance of the irrigation efficiency (Michael, 1997). However, most advantage that the system has the potential for quicker advance, reduce total water required, shorter total inflow time thus, the application efficiency and uniformity over the continuous flow, if it is properly managed.

According to Richard et al., (2010) Surface irrigation simulation models are useful tools both at the design and management stages of the surface systems. Therefore, using simulation modeling helps to optimize field parameter and making management decision variables as to the appropriate values of these variables that produce the best performance for modifying future irrigations in order to achieve the desired level of performance.

2.2. Factors Affecting the Performance of Irrigation Schemes

The performance of an irrigation scheme is influenced by socio-economic, agronomic, environmental and technical constraints. Factors are often interlinked, so causes and effects may not be readily distinguishable. Physical defects may be more easily identified, but their removal will not necessarily solve problems of under-performance. According to Mussie, (2016) the main factors that influence the performance of irrigation schemes include: Agricultural and economic factors, Poor system design and operation, Deterioration of system infrastructure, Land degradation, such as surface flooding, shallow groundwater table, land fragmentation, erosion and pollution, current practice parameter variation from design, command area less than design and deterioration of supply water to the field.

2.3. Evaluating Furrow Irrigation System

Various parameters and variables are involved in the furrow irrigation evaluation (Basem, 2012) and they can be field parameters, decision variables, or evaluation variables. Evaluations, as (Pereira and Trout, 1999) described, provide information used to advise irrigators on how to improve their system design and/or operation, as well as information on improving design, model validation and updating, optimization programming, and developing real-time irrigation management decisions. Basic field evaluation includes observation of Inflow and outflow rates and volumes (volume balance), soil water requirements and storage, slope, topography, and geometry of the field; and management procedures used by the irrigator

The principal objective of evaluating furrow irrigation systems is to identify management practices and systems that can be effectively implemented to improve the irrigation efficiency. Evaluations are useful in a number of analyses and operations, particularly those that are essential to improve management and control. Evaluation data can be collected periodically from the system to refine management practices and identify the changes in the field that occur over the irrigation season or from year to year (FAO, 1989).

The performance of any irrigation system is the degree to which it achieves desired objectives. As many furrow irrigation practices do not perform as well as they should, there is a need to identify the areas in which they fall short of their potential (Jorge, 1993). It is therefore important to measure and evaluate their success or failure objectively and identifies specific areas in need of improvement.

2.3.1. Field Parameters

a) Soil infiltration characteristics

The term infiltration describes the phenomenon that water enters into the soil profile and the flux or the rate of water entering is called infiltration rate (ASAE, 1983). Basically, most researchers stated that infiltration characteristics of soils are the dominant field parameters in the design, evaluation and management of surface irrigation, since it has the strongest influence on the movement of water over the soil. These characteristics are the factors which determine the advance and recession times, the depth of infiltration and thus generally, the performance of applied irrigation (Esfandiari and Maheshwari, 1997).

In general, infiltration characteristics are affected by soil-related factors like variation of texture, structure and initial water content in the soil profile, surface and subsurface cracking, soil swelling during wetting and air entrapment (Esfandiari and Maheshwari, 1997). In furrow irrigation, the process of infiltration involves soil water movement in both vertical and lateral directions (ASAE, 1983). Accordingly, this is because of the influence of furrow geometry (size and shape) on the rate of infiltration. Local measurement of infiltration using methods such as ring infilitrometers often fail to provide infiltration characteristics representative for the whole length of furrow spatial variability. Based on the concept of large area methods, solution of the inverse problem has generated most interesting means of determining the infiltration parameter values from the measured furrow irrigation advance (McClymont and Smith, 1996). Models used to solve the inverse problem consist of two parts; an equation describing the process of infiltration and another component representing the distribution of water temporarily stored on the surface of the furrow. The later usually takes the form of either hydrodynamic advance model /consisting of both a continuity equation and a momentum equation/ or a volume balance model (only the continuity equation) (McClymont and Smith, 1996). The volume balance model has been widely used for design and field evaluation procedures and has been validated with field and laboratory data (Elliott and Walker, 1982; Walker and Skogerboe, 1987; Guardo, 1988). They found that the volume balance model provides satisfactory predictions of the advance-infiltration phase, although it is less complex and less mathematically demanding than the zero-inertia model.

According to McClymont and Smith (1996) infiltration equation for furrow irrigation and well suited to most soil types as it takes into consideration the basic infiltration rate. Esfandiari and Maheshwari, (1997) states that the value of ‘a’ depends on the initial soil-water content and the extent of cracking on the surface and in the profile. One of the standard methods developed used to determine the infiltration parameter is the two-point method that was proposed by (Elliott and Walker, 1982). According to Esfandiari and Maheshwari (1997), the two-point method is attractive in field application as it requires minimum data such as inflow rate, flow area at the inlet section of furrow and elapsed time for advancing the water front at two points (at the middle and end of the furrow).

The two-point method requires that the basic infiltration rate must be determined separately by inflow-outflow method after irrigation is completed. The input data in the two-point method are used to generate two nonlinear volume balance equations that are to become linear applying a log-transformation (McClymont and Smith, 1996). Then, two linear algebraic equations with two unknowns are obtained.

b) Flow resistance

Manning's roughness coefficient (n) is a measure of the tackle/persist effect that flow may convergence/encounter as it moves down the furrow. It represents the effect of combined resistant force, which acts opposite to the direction of flow. The combined resisting force includes both shear and drag forces. During the irrigation, the sheer force is boost due to the uneven furrow bottom surface, where as the drag force is developed due to the vegetation growth in the furrow (Gilley and Finkner, 1991). Manning's roughness coefficient depends on various factors such as vegetation in the furrow, mean slope of the furrow bottom, and inflow rate (Trout, 1992). It depends mostly on the channel wall material, condition, and geometry (Yen, 1992). Manning's *n* varied inversely with inflow rates and also varied directly with slope and percentages of vegetation cover in furrows. According to Sepaskhah and Bondar, (2002) suggestion the vegetation cover has the greatest effect on Manning's roughness coefficient than furrow slope. They also stated that the value of Manning's roughness coefficient could be increased three times for 100% of vegetation cover. When vegetation is present in a furrow, turbulence intensity increases, causing additional loss of energy and retardation of flow. Strelkoff et al. (2000) suggest that Manning's (n*)* is acceptable for resistance from the field surface, but not from plant parts that protrude into the flow. Manning's (n) has also been known to decrease over time as the soil surface is smoothed by the flowing water, and as clods melt, the soil spreads out to fill holes (Clemmens et al., 2001). According to them, the initial advancing front's often see much higher flow resistance than that which occurs in the irrigation stream well behind it (in either distance or time).

The value of Manning's roughness coefficient (n) range from about 0.02 for previously irrigated and smooth soil, to about 0.04 for freshly tilled soil, to about 0.15 for conditions where dense growth retarded the water movement (Walker, 1989), whereas newly constructed furrows typically have (n) values of about 0.03-0.05 depending on the soil aggregation (USDA-NRCS, 1997). For the furrows, this roughness (n) is either calculated from a single water depth at the upstream end or set to a constant value (typically n is 0.03 to 0.04). For furrows which have plant, surface roughness is a function of the plant density and plant height. It should increase with plant height however; Robertson et al., (2004) failed to identify any simple correlation indicating the complexity of such relationships. Surfaces become hydraulically rougher as crop density and size increase (USDA-NRCS, 1997) and for this study based on the sugar cane and weeds which resisted the flow of water 0.2 was adapted.

c) Required depth

The maximum required depth can be determined from the total soil-moisture holding capacity, i.e., the total available moisture (TAM) between field capacity and wilting point and the allowable depletion fraction, which is called the readily available moisture content (RAM). Together with an a crop rooting depth, this gives the maximum depth to which the soil can dry out and the depth the irrigation water supply must reach by the end of an irrigation interval.

It is traditionally seen as fixed, determined from the irrigation schedule. However there can be some advantage in considering it as a management variable and under some circumstances it may be less than the Z_{req} (or deficit). It could be viewed as the maximum amount to be applied and that the actual amount applied in the irrigation may be reduced if it results in improved performance. The disadvantage is that the next irrigation would need to occur sooner to compensate for the reduced application. It does not affect the advance and recession curves.

d) Field slope

The longitudinal slope of the furrow impacts both the advance and recession. This is evident through examination of the Manning equation. For a given discharge, increasing the slope increases the rates of advance and recession. As with surface roughness, the influence of slope is a second order effect determined through its effect on the area term in the volume balance equation. For any irrigated field the slope is fixed at the design stage and can only be altered by a substantial land forming (earth works) operation. According to Jurreins et al., (2001), for graded borders and furrows, the field slope (So) should not be too high (to prevent erosion) or too low (to prevent slow advance). According to FAO (1999) standard guidelines for the evaluation of slope gradient, slopes which are less than 2% are very suitable for surface irrigation. But slopes, which are greater than 8%, are not generally recommended. The most suitable slopes for furrows range between 0.05 to 1.5%. Slopes up to 2% can work for small furrows and corrugations. According to Gosnell (2001) the slope of 0.1% is typically used for row crops although flatter grades of up to 0.05% are successfully used on sugarcane. The gradient should be based on a plan of the desired row directions as determined by the topographic lay of the land.

e) Furrow geometry

According to Feyen and Zerihun, (1999) the geometry of a furrow has significant effect on the surface hydraulics as well as infiltration. Furrows could be of different cross-sectional shapes and as miniature channels they generally are characterized by a ratio of depth to width of flow which is higher order of magnitude compared with the other methods (basin and border). Hence the variation in depth not only affects surface flow but also the contact area between soil and water and thus infiltration. It is therefore important to take into account of the channel geometry in modeling furrow irrigation processes. For reasons of simplicity and other practical considerations, such as accounting for irregularities in channel cross-sections, it is customary to assume that a power law relationship holds well between the following important channel geometry elements of a furrow (Walker, 2003); Cross sectional area of flow (A) is required to estimate surface storage and flow velocity, Wetted perimeter (P) affects infiltration and Hydraulic radius (R) is needed to calculate the flow resistance.

If furrows are constructed by hand, there can be appreciable longitudinal variation in cross-section as well as in bottom slope. But even with machine-made furrows, if the irrigated soils are erodible and stream velocities are high, there can be temporal and spatial variation in cross-section as the result of erosion and deposition (Trout, 1992).

2.3.2. Decision Variables

a) Field dimensions

For furrows, there is one field dimension which is the furrow length. Field length can influence the distribution uniformity because the advance rate becomes slower as the irrigation water has to travel further down the furrow (Jurriens et al., 2001). This means it generally becomes more difficult to achieve high performance as field length increases.

Modifying existing furrow lengths may be an appropriate strategy for some situations in the design phase, but it is important to evaluate performance first as satisfactory results may be achievable through simple changes rather than costly redevelopment.

The length of field does influence the irrigation performance markedly. The longer the field the higher the flow rate needs to be to maintain a sufficiently fast advance rate. Inevitably the advance rate will slow toward the downstream end of the field making it harder to maintain equal opportunity times over the whole length of the field. The modern trend is for longer runs, often in excess of 1000 m, in contrast to the shorter lengths required for maximum efficiency of applications (Khatri 2007). The most important factors which need due consideration in determining the furrow length are soil type, stream size, irrigation depth, field slope, field size and farming practices. Usually long furrow length is preferred by the user because of short furrows need more time and labor, but long furrow need high inflow rate. When irrigating clay soil, water infiltrates slowly. This means that the furrow has to be long enough to allow infiltrating to obtain the required irrigation depth. If the furrows are not long enough for the stream size, excessive run-off can occur.

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

b) Flow rate

Inflow rate is explicit in the volume balance equation and is a most important variable in the surface irrigation process, second only to infiltration. Inflow rate, which is affected by the slope, the length of the furrow and the intake rate can be adjusted by the designer to achieve good uniformity and to irrigate to the required depth in reasonable time. According to Panoras et al. (1996), who have dealt with furrow irrigation, the changeable parameters in furrow irrigation variables are the inflow rate and the length of the furrow. It is one of the key variables in influencing the outcomes of an irrigation event; it affects the rate of advance to a significant degree and recession in an indirect way. It affects recession only when the infiltration perimeter and volume stored at the surface depends on inflow. It has a significant effect on uniformity, efficiency and adequacy of irrigation. Like furrow length, L, flow rate is a variable whose value can be fixed by the designer at the design phase or prior to or following the initial of every irrigation such that system performance is maximized. It should not be too high as to cause scouring and should not be too small as otherwise the water will not advance to the downstream end.

c) The advance and recession of water across the field surface

Advance times recession of water across the field surface variation from furrow to furrow was improved by precision land leveling and affect on both uniformity and efficiency (USDA-NRCS, 1997). The variation of advance and recession of water across the field leads to variation in the amount of water infiltrated into the soil along the furrow length if other constraints are the same.

d) Cutoff time

Cutoff time (t_{co}) is the time at which the supply is, a time that elapses since irrigation starts until it is turned off. It is one of the three variables, the other two being L and Q_0, over which the engineer and irrigator has a degree of control. Cutoff time has no impact on advance as long as the latter is taken equal or greater than the advance time. Cutoff time, however, has an influence on recession. The most important effect of cutoff time is reflected on the amount of losses, deep percolation and surface runoff, and hence efficiency as well as adequacy of irrigation. In general for any given factor level combination the selection of an appropriate value of t_{co} is made on the basis of the target application depth and acceptable level of deficit. Jurriens *et al*. (2001) suggested that cutoff time for furrow irrigation method occurs usually some time after the end of the advance time so as to obtain infiltration to the required depth at the downstream end of the field. Cutting the inflow too soon will result in an insufficient depth of application, poor uniformity and the real possibility of the advance not reaching the bottom end of the field. If the cut-off is too late, the depth of application may be excessive with large losses of water in the form of deep percolation below the root zone and runoff from the end of the field. The application efficiency will be lowered. So, clearly, there are limits to the value that you can choose for the cutoff time, to achieve good irrigation performance.

According to Walker (2003), of the field parameters and decision variables discussed above:

Two are essentially beyond the control of the irrigator (infiltration and surface roughness); Two are fixed at the design stage (length and slope); and the remainder three (flow rate, cutoff time and desired depth of application) are management variables that able to be varied or same during individual irrigations.

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

2.3.3. Performances measurement

The performance of an irrigation method can be evaluated by determining how well the irrigation meets the water requirements and how well the applied water is distributed throughout the field (Holzapfel *et al*., 1985). Water applied for irrigation should: meet the plant water requirements at the time of irrigation and not exceed the available water-storage capacity of the soil profile. Improvement of irrigation method requires the considerations of the factors influencing the hydraulic process, the water infiltration and uniformity of water application to the entire field (Hlavek 1995). The consideration of different factors renders irrigation management a complex decision-making and field practice process (Periera and Trout 1999). The common parameters used to estimate irrigation performance for on-farm irrigation system include application efficiency, uniformity and storage efficiency. Recently complementary terms such as runoff ratio, deep percolation ratio, are being applied (Jurreins *et al*. 2001).

a) Application Efficiency (E_a)

When water is diverted into any water application system such as furrows, part of the water infiltrate into the soil for consumptive use by the crop, while the rest is lost as deep percolation and runoff. The efficiency terms determine these components and compare them with the volume of water actually applied to the field. The term is an indication of the effectiveness of the system in reducing losses during an irrigation event.

Application efficiency refers to the amount of water needed for crop production compared with the amount applied to the field and depends on system uniformity and management. It is the ratio of the amount of irrigation water beneficially used to the amount of applied water.

The major losses which affect the irrigation efficiency are drainage below the root zone and surface runoff. It can be defined as the ratio of the volumes (depth) of water stored in the root zone for use by the plant to the volume (depth) of water applied to the field (Zerihun et al., 1997).

According to Eldeiry et al. (2005) found in a study of design of furrow irrigation in silt loam soil that the furrow length and application discharge are the main factors affecting application efficiency. In addition, application efficiency depends on the soil water deficit at time of irrigation (Pereira and Luis, 1999: Pereira and Trout, 1999). Holzapfel et al. (2009) indicate that application efficiency correlated well with the design variables but not with yield. However, it is the most important parameter to use when evaluating deep percolation.

Raine and Bakker (1996) identified a range of methods to improve water application efficiencies in the sugar industry including the use of appropriate furrow lengths, irrigation cutoff times and water application rates. In their study, they were able to demonstrate that differences in efficiency related directly to soil type, specific management practices and farm design. They demonstrated on alluvial and cracking clay soils that increasing the furrow length reduced Ea due to increased deep drainage losses. This effect was larger on the high infiltration alluvial soils where increasing the furrow length from 300 to 700 m decreased efficiency from 73 to 42%. The majority of the excess irrigation water was lost as deep drainage with little surface runoff.

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

Kenneth (1988) indicated that attainable water application efficiencies vary greatly with irrigation system, type and management, and suggested that the attainable application efficiency for surface irrigation are 80-90%, 70-85% and 60-75% under basin, border and furrow type of system respectively. While FAO (1989) suggested 60 % attainable water application efficiencies for surface irrigation method. Also (Norman, 1999), said that a minimum value of the ratio of crop water demand to the actual amount of water supplied to the field of 0.6 (or irrigation efficiency of 60%) is included in the design of most surface irrigation systems to accommodate crop water needs and anticipated losses. Value below this limit would normally be considered unacceptable.

According to Magwenzi (2000) the difference in application efficiencies between inter-row (water flowing between cane rows) and in-row (water flowing in the cane row) furrow irrigation. The value ranged from 70% to 75% for the inter-row furrow irrigation events, application efficiencies and 48% and 57% for the in-row furrow irrigation events. The in-row irrigation result shows that this type of furrow irrigation is inefficient. This is mainly attributable to increased resistance to water flow by the crop plants.

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

b) Storage Efficiency (E_s)

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

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

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

According to Holzapfel *et al.*, (2009), storage efficiency was well correlated with the design variables through the exponential relation. It increases its value with an increase in both inflow and cutoff time and a decrease in furrow length. Throughout the study, it was observed that a variation in the cutoff time affects more significantly the requirement efficiency than does the inflow or furrow length. According to Habib, (2004); who found E_s in the ranges of 97.4–100% with more than 50% of tested furrows having a value of 100%. It is also concurrent with the finding of (Teshome, 2006) who reported 100% E_s for all furrows had been meeting the irrigation water requirement of the system.

c) Application Uniformity (DU)

Uniformity refers to the evenness of the infiltrated water throughout a field and depends on system design and maintenance (Jurreins *et al.*, 2001). A uniformity of 100% means the same amount of water infiltrates everywhere in a field. No irrigation system, however, can apply water at 100% uniformity. Regardless of the irrigation method, some parts of a field infiltrate more water than other areas. This means the larger the non uniformity, the larger the differences in infiltrated water throughout the field and the more the drainage below the root zone. To fully express the efficiency of an irrigation system, the uniformity of water applied need to be evaluated.

d) Deep Percolation (DP)

Water losses from the field occur as deep percolation (depths greater than Z_{req}) and as field tail water or runoff. To compute E_a, it is necessary to identify at least one of these losses as well as the amount of water stored in the root zone. This implies that the difference between the total amount of root zone storage capacity available at the time of irrigation and the actual water stored due to irrigation be separated, i.e. the amount of under-irrigation in the soil profile must be determined as well as the losses. Elderiry *et al.*, (2005) reported that the main constraint on furrow irrigation efficiency is that a significant amount of water is lost to runoff and deep percolation. These looses depend on the furrow length, discharge and cut off time.

The SIRMOD and Win SRFR models simulation routine is used the numerical solution of the Saint-Venant equations for conservation of mass and momentum as described by (Walker and Skogerboe, 1987). According to McClymont and Smith (1996) description the input parameters for both models; are furrow geometry, required depth, slope, time of cutoff, furrow length, inflow rate and the manning’s n coefficient.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

Belles sugar development project is found in Amhara Regional State Awi zone Jawi wereda at 576 kilo meter distance from North of Addis Ababa where as three sugar factories are under construction and some parts of its plantation found at Benishangul Gumuz Regional State. It is a project with a total area of 75,000 hectares for cultivation and its water supply is from Beles River. When the factories reach at their full capacity, each of them will be capable of producing 242,000 tons of sugar and 20,827 meter cube ethanol per year (USDA, 2015). It is located between 11˚06'40" to 12˚30'41"N and 35˚59'9" to 36˚46'18"E grids and at an altitude of 1000 - 1300 meter.(ethio dem). Jawi wereda has an average rainfall 1447 mm/y and average temperature 24.5℃**;** minimum temperature 16.4^{0}C and maximum temperature is 32.5$^{\mathbf{0}}$C.

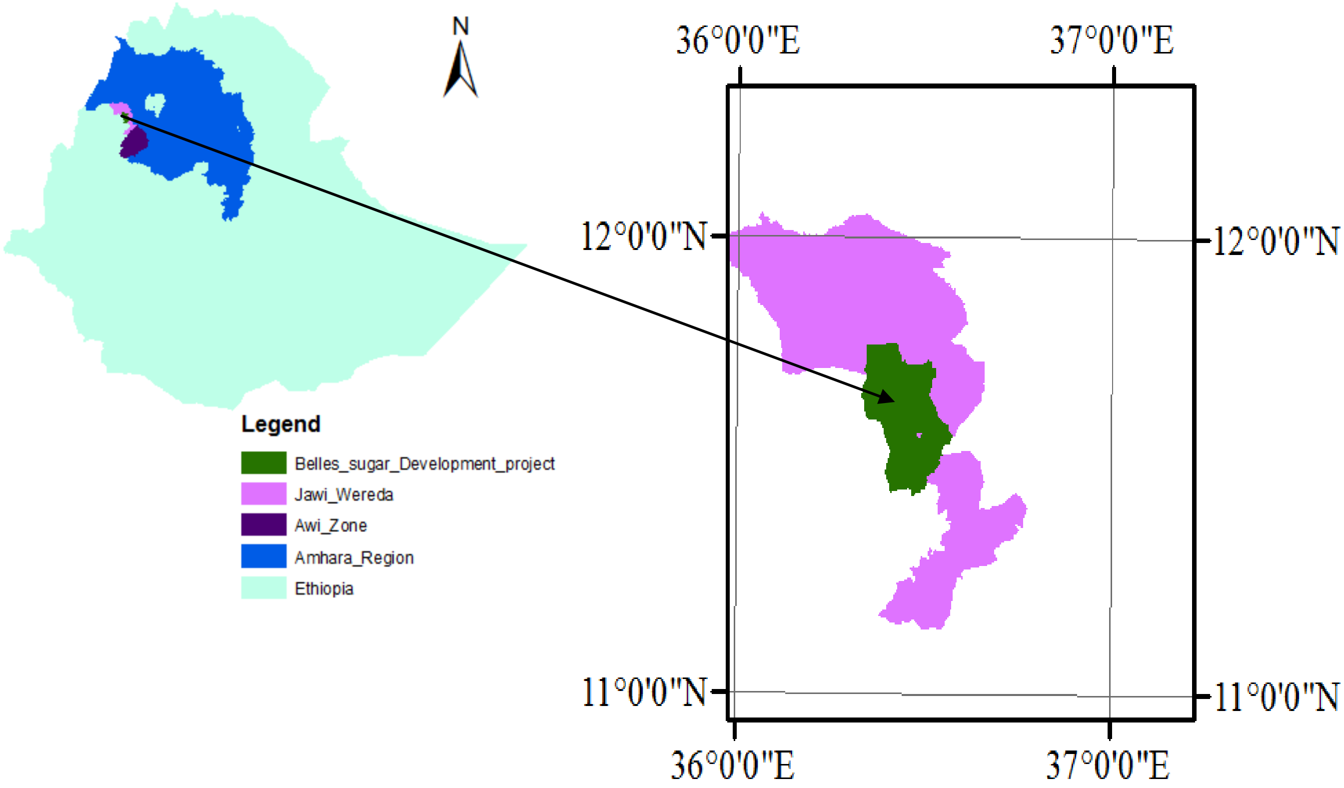


Figure 3:1. Location of Belles Irrigation project

3.2. Field Layout and Experimental Setup

With the help of the project foreman from 1310 ha of furrow irrigation based on the soil type in the area, time and budget I had. The experimental fields which had a size of 100 m X 100 m and slope between 1.8% (measured by water-level) were selected. The field has 67 furrows and from one fifth of it taken as the measuring test furrows which has 110 cm – 130 cm of furrow spacing. The general field layout and experimental set up common for a furrow set is presented in Figure 3.2, it is the same for all furrows. Two left and right to the measured test furrows is buffer furrows were used to hinder unexpected laterals moisture movement beyond the monitored furrows.

A 3 inch standard Parshal flume, manufactured in the laboratory based on standard design was installed near the down-stream end of the individual furrows in a furrow set except the buffer furrows, to monitor the rate of out flowing irrigation water. The water was supplied to each furrow using a hydro flume/gated pipe which is made of polyethylene plastic. The flumes were positioned carefully at the down-stream bottom end of the ditch so as to attain a smooth flow near the entrance and to avoid submergence near the throat of the flumes. The gap between the ditch bottom and flumes were covered by plastic sheet for the sake of that furrow section not to be disturbed by erosion due to the jetting of water from the siphons. ‘Timing points’ or advance-recession stations were established along the furrows at 25 m interval using pegs and string. Known volume plastic buckets were also buried at the furrow down-stream end (at 100 m) to collect the tail water or run-off for a fixed time (four second) interval.

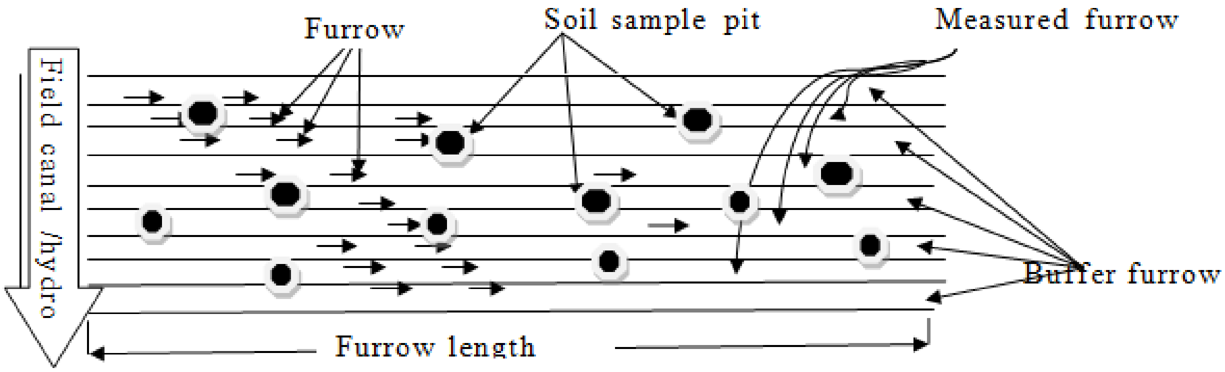


Figure 3:2. Field Layout and Experimental Set up

3.3. Soil Characteristics

Composite soil samples at five interval soil depths considering the effective rooting depth of sugarcane which is actively extract water vary from 0.9-1.2 m for under rain-fed conditions extend to 1.8 m for arid condition (Holden J R and P J McGuire, 2010 and USDA-NRCS, 1997), 0-30, 30-60, 60-90, 90-120 and 120-150 cm were taken from 24 pit W- shape fashion from the field (USDA-NRCS, 1997).

The composite samples were analyzed for soil texture, field capacity (FC) and permanent wilting point (PWP) using auger whereas for bulk density undisturbed soil samples at the same depth were taken using core samplers.

The percentage of sand, silt and clay of the composite soil sample were determined by sieve analysis method. After the percentage of sand, silt, and clay was measured, the soil had assigned a textural class using the USDA textural triangle, (Kamara and Haque, 1991; and Sahlemedhin and Taye, 2000).

Soil bulk density in (g/cm^3) was determined using gravimetric method described in (Walker, 1989; Kamara and Haque, 1991; and Sahlemedhin and Taye, 2000). Undisturbed soil samples were taken using core samplers of known volume and the samples were weighed and placed in an oven at 105 ^{0}C for 24 hrs. After 24 hrs, the oven dried soil was weighed, and then bulk density was calculated using equation 3.1.

$$\mathbf{Soil\ bulk\ density\ (Db)}\left(\mathbf{{}^{g}/_{cm^3}}\right) = \frac{\mathbf{oven\ dry\ weight\ of\ soil}}{\mathbf{volume\ of\ soil}} - - - - - - - - - - - - - - \mathbf{3.1}$$

Moisture contents at FC and PWP determination were by using a pressure plate and applying a suction of –1/3 atmosphere to a saturated soil sample. When water is no longer leaving the soil sample, the soil moisture into the sample is equated to field capacity where as the moisture content at a pressure of –15 atmospheres from a pressure plate test is PWP (Kirkham, 2005).

The available water capacity of a soil is the maximum quantity of water that can be extracted from the soil profile by plants (FAO, 1999). The total available water, TAW is the difference between field capacity and permanent wilting point moisture contents multiplied by the depth of the root zone (R_d) calculated using Equation 3.2 (USDA-NRCS 1997):

$$\mathbf{TAW = R_d * \left(\theta_{fc} - \theta_{wp}\right) ----------------------------- 3.2}$$

Where;

TAW = Total available soil moisture at 1 m depth of soil (mm/m)

θ_{Fc} = volumetric soil moisture at field capacity (%)

θ_{WP} = volumetric soil moisture at the permanent wilting point (%)

Water Content Expressed as a Depth:

$$\mathbf{Depth\ of\ Water = \theta * Depth\ of\ Soil ---------------------------3.3}$$

Soil Moisture Depletion (SMD) at the Time of Sampling (USDA-NRCS, 1997):

$$\mathbf{SMD = 10 * (\theta_{fc} - \theta_i) * R_d ------------------------------3.4}$$

3.4. Determination of Field Evaluation Parameters

The method used for evaluation of furrow irrigation performance follows (Merriam and Keller, 1978) as adapted by (Calejo *et al.*, 1998). Measurements included furrow discharge, furrow cross-sections, advance and recession, hydraulics roughness and infiltration. 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.

3.4.1. Furrow Geometry Parameters

Furrow cross-sections at the inlet of the furrow were measured using a profilometer. The profilometer which consists mainly of t-pins, a frame, a level, measuring pins (vertical moveable rods) and a level adjustment mechanism was constructed at Belles sugar Factory workshop. The measuring pins were made to be 40 cm long in order to provide sufficient height above the frame for measurements. The pins were spaced at regular (2 cm) interval in order to obtain profiles of satisfactory accuracy.

The data obtained from profilometer measurement parameters, top width, middle width, base, and maximum depth used to derive the relationship between the depth of water in the furrow and the corresponding top width.

The flow cross-section is computed with fitting parameter of furrow shape Rho$_{1,\,2}$ ($\rho_{1,2}$), Sigma$_{1,2}$ ($\sigma_{1,2}$), Gamma$_{1,\,2}$ ($\gamma_{1,\,2}$), are automatically computed (Walker and Skokerboe, 1987).

$$\mathbf{A} = \boldsymbol{\sigma_1} y^{\sigma_2} -3.5$$

$$\boldsymbol{\sigma_1} = \frac{\frac{\mathbf{y_{max}}}{\mathbf{2}}(\frac{\mathbf{Base}}{\mathbf{2}} + \mathbf{T_{mid}} + \frac{\mathbf{T_{mid}}}{\mathbf{2}}}{\mathbf{y_{max}^{\sigma_2}}} - 3.6$$

$$\boldsymbol{\sigma_2} = \frac{\mathbf{log}[\frac{\frac{\mathbf{y_{max}}}{\mathbf{2}}\left(\frac{\mathbf{Base}}{\mathbf{2}} + \mathbf{T_{mid}} + \frac{\mathbf{T_{max}}}{\mathbf{2}}\right)}{\frac{\mathbf{y_{max}}}{\mathbf{2}}(\frac{\mathbf{Base}}{\mathbf{2}} + \frac{\mathbf{T_{mid}}}{\mathbf{2}}}]}{\mathbf{log2}} -3.7$$

Where (σ_1, σ_2) fitting parameter of furrow shape

The wetted perimeter (wp) fitting parameters γ_1 and γ_2 were obtained using equation 3.9 And 3.10, respectily (Walker and Skokerboe, 1987) which relates the wetted perimeter with flow depth.

$$\mathbf{wp} = \gamma_1 \mathbf{y}^{\gamma_2} ------------------------------- \mathbf{3.8}$$

$$\gamma_1 = \frac{[\mathbf{Base} + \sqrt{\mathbf{y}_{\mathbf{max}}^2 + (\mathbf{T}_{\mathbf{mid}} - \mathbf{Base})^2} + \sqrt{\mathbf{y}_{\mathbf{max}}^2 + (\mathbf{T}_{\mathbf{max}} - \mathbf{T}_{\mathbf{mid}})^2}]}{y_{max}^{\gamma_2}} --------- --\mathbf{3.9}$$

$$\gamma_2 = \frac{\log\{\frac{\left[\mathbf{Base} + \sqrt{\mathbf{y}_{\mathbf{max}}^2 + (\mathbf{T}_{\mathbf{mid}} - \mathbf{Base})^2} + \sqrt{\mathbf{y}_{\mathbf{max}}^2 + (\mathbf{T}_{\mathbf{max}} - \mathbf{T}_{\mathbf{mid}})^2}\right]}{\left[\mathbf{Base} + \sqrt{\mathbf{y}_{\mathbf{max}}^2 + (\mathbf{T}_{\mathbf{mid}} - \mathbf{Base})^2}\right]}\}}{\log 2} ------\mathbf{3.10}$$

Moreover, the average area of the surface stream is constant from the beginning of irrigation from at the advance halts to the end of the field. The water depth at the inlet of the system is usually assumed to be the normal depth, which can be computed using Manning's equation as follows (Walker, 1989):

$$\mathbf{A}_{\mathbf{o}} = [\frac{\frac{\mathbf{Q}_{\mathbf{o}}^2 \mathbf{n}^2}{\mathbf{3600}}}{\mathbf{S}_{\mathbf{o}} \rho_1}]^{\frac{1}{\rho_2}} ---------------------------- - \mathbf{3.11}$$

$$\mathbf{A}^2 \mathbf{R}^{4/3} = \rho_1 \mathbf{A}^{\rho_2} ---------------------------- - \mathbf{3.12}$$

$$\rho_2 = \frac{10}{3} - \frac{4\gamma_2}{3\sigma_2} ---------------------------- \mathbf{3.13}$$

$$\rho_1 = \frac{\sigma_1^{\frac{10}{3} - \rho_2}}{\gamma_1^{\frac{4}{3}}} -----------------------------\mathbf{3.14}$$

Where n = manning roughness coefficient; S_0 = field slope (m /m); ρ_1 and ρ_2 = parameters depending on the furrow geometry.

For this study based on the density of sugar cane plant and the field length the Manning's roughness coefficient of 0.2 was used during irrigation events (Eduardo *et al.* 2012; Walker 1989; and Zeleke, 2007) used 0.1.

3.4.2. Infiltration

The infiltration function is empirically determined to yield the relationship between the infiltrated water and the opportunity time (the time during which the water contact the soil). The power type- Kostiakov function is the most widely accepted to describe the infiltration characteristics:

The simplest and most commonly used approximations for infiltration are the modified Kostiakov equation which can be written in general terms for furrow irrigation as;

$Z = kt_0^a + f_o t_0$ -- 3.15

Where Z = cumulative infiltration per unit length of furrow (m^3/m), t_0 = infiltration opportunity time (min.), k = fitting parameter (m^3/mina/m), a = fitting parameter, $0<a<1$, (dimensionless), and f_o = steady or basic infiltration for the soil (m^3/min/m)

The volume balance method was used to determine the infiltration fitting parameters 'a' and 'k', based on the volume of water entering the field (Q.t) being equal to the volume of surface water (V_{sur}) plus the volume of infiltrated water (V_{inf}) (Raine and Smith, 2007).

$Q.t = V_{sur} + V_{inf}$ ---3.16

Q: is the flow, m^3/min/furrow or unit width, t: is the moments when the water reaches the points where water height is measured (min), V_{sur}, V_{inf} are the volume of surface and infiltration water (m^3).

The two-point method is based on the volume balance in which the measurement of advance times at two points, preferably one in the middle and the other at the end of a furrow, is used to calculate values of the infiltration parameters (Elliott and Walker, 1982). Equation 3.17 written as:

$$\mathbf{Q_o t_L = \sigma_y A_o L + \sigma_z k t_L^a L + \frac{f_o t_L L}{(1+r)}} - \mathbf{- 3.17}$$

The basic infiltration rate, f_o, needs to be determined independently. When the field evaluation includes measurements of inflow and outflow, f_o was determined as:

$$\mathbf{f_o = \frac{Q_o - Q_{tw}}{L}} - \mathbf{- 3.18}$$

$$\boldsymbol{a} = \frac{\mathbf{log}\left(\frac{\boldsymbol{V_L}}{\boldsymbol{V_{.5L}}}\right)}{\mathbf{log}\left(\frac{\boldsymbol{t_L}}{\boldsymbol{t_{.5l}}}\right)} - \mathbf{- -3.19}$$

$$\mathbf{k = \frac{V_L}{\sigma_z t_L^a}} - \mathbf{- -3.20}$$

Where

$$\mathbf{V_L = \frac{Q_o t_L}{L} - \sigma_y A_o - \frac{f_o t_L}{(1+r)}} - \mathbf{3.21}$$

$$\mathbf{V_{.5L} = \frac{2Q_o t_{.5L}}{L} - \sigma_y A_o + \frac{f_o t_{.5L}}{(1+r)}} - \mathbf{- -3.22}$$

The value of σ_y is the surface flow shape factor from many authors have used assumed to be constant during the advance and is in the range of 0.7– 0.9 (Strelkoff and Katopodes, 1977). Walker and Skogerboe (1987) have proposed that $\sigma_y = 0.77$. In this study it was determined by equation 3.23 (USDA –NRCS, 1997).

$$\boldsymbol{\sigma}_{\mathbf{y}} = \frac{\mathbf{0.778}}{\mathbf{1 + 0.363e^{-12.07\frac{rpt_l^{1-r}}{Q_o}A_o}}} - 3.23$$

σ_z is the “subsurface shape factor “described by:

$$\boldsymbol{\sigma_z} = \frac{\mathbf{a + r(1 - a) + 1}}{\mathbf{(1 + r)(1 + a)}} - 3.24$$

Where Q_0 = inflow rate (m3/min), Q_{tw} = tail water outflow per furrow (m^3/min, $\sigma_y A_0$ = surface storage at the point of interest (m^2), A_0 = the average cross-sectional area of flow at the inlet (m^2), L = length of the field or to the desired distance (m), a = kostiakov lewis coefficient, **r** is the exponent in the power advance equation 3.25,

$$\boldsymbol{r} = \frac{\log\left(\frac{L}{.5L}\right)}{\log\left(\frac{t_L}{t_{.5L}}\right)} - 3.25$$

To integrate the subsurface flow profile the trapezoidal rule was improved (Valéria *et al*. 2014), thus the total infiltrated volume was determined by equation 3.26:

$$\mathbf{V_z} = \frac{\mathbf{L}}{\mathbf{2n}}[\mathbf{Z_o} + (\mathbf{2Z_1} + \mathbf{2Z_2} + \cdots + \mathbf{2Z_{n-1}}) + \mathbf{2Z_n}] - - - - - - - - - - - - - - - - - - 3.26$$

Where V_z = infiltrated volume (m^3), L = furrow length (m), Z_i = accumulated infiltration for point i (m^3m^{-1}), n = number of segments in which the furrow length is subdivided.

3.4.3. Advance and Recession Times

Advance and recession times were measured for each furrow lengths. Stakes were driven into the soil along the furrows at fixed interval of 25 m before irrigation event. Station 0+00 was the inlet end of the furrow. Advance times were recorded at the time when water reach at each stakes from the start of water entry to the furrows. Recession times (t_{rec}) were recorded at the times when water fully infiltrated the soil at the observation sections.

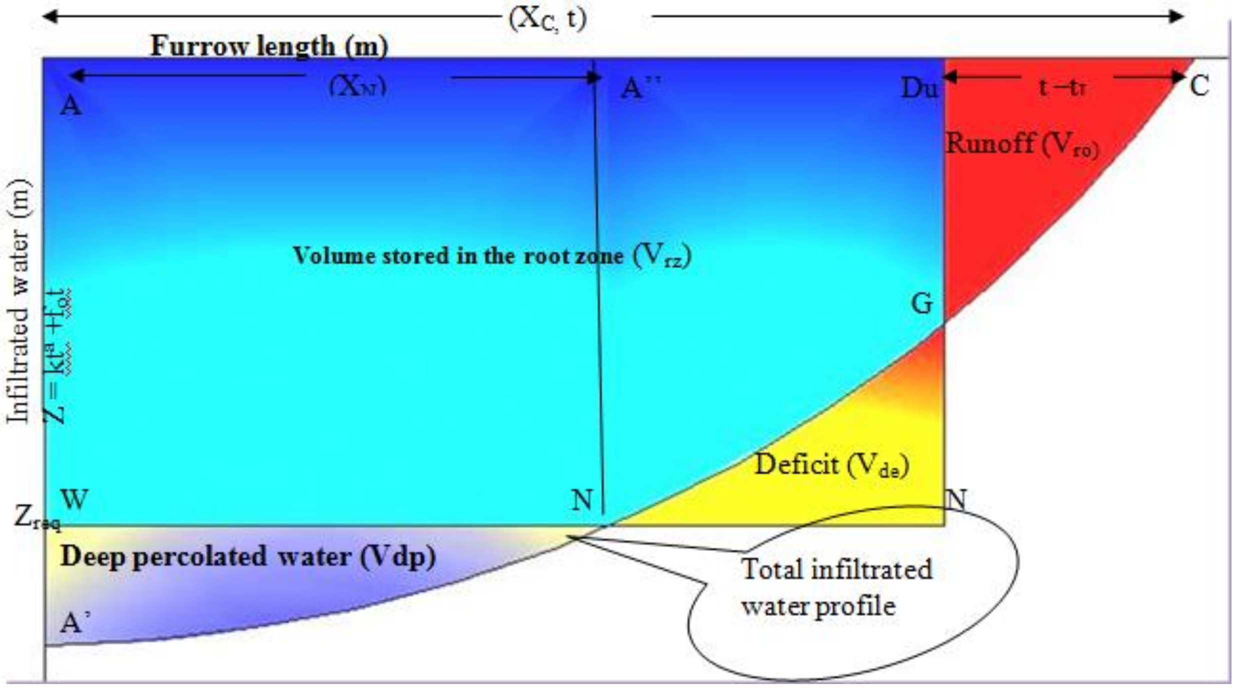


Figure 3:3. Components of the Infiltrated Water Profile in Furrow Irrigation

Where;- V_z - ADuGNA’WA - Total infiltrated volume, m^3; V_{za} - AA”NA’WA - Infiltrated volume in the area adequately irrigated, m^3; X_N -Furrow length adequately irrigated, m; V_{zi} - A”DuGNA” - Infiltrated volume in the area inadequately irrigated, m^3; V_{rz} - ADuGNWA - Volume stored in the root zone, m^3; V_{dp} - WNA’W - Deep percolated volume, m^3; V_{de} – NGBN- Irrigation deficit volume, m^3; V_{ro} – DuCGDu – Runoff volume, m^3; t- opportunity time; t_L- time required for the water front to reach the lower end of the furrow (advance time).

Following the field evaluation, the next step is to determine the infiltration function and then, in conjunction with the recorded intake opportunity time, the distribution of water applied to the root zone. The length should be subdivided into by 2 m increments and the cumulative intake computed for each increment by:

$Z_i = k\,[(t_r-t_x)_i^{\,a}] + f_o\,[t_r-(t_x)_i]$ ---3.27

Where t_x and t_x are the recession and time cutoff time, respectively in minutes.

The infiltration curve (plot) integrates numerically to determine the depth added to the root zone; finally the application efficiency (Ea) was calculated using (equation 3.28) and other performance indices (USDA-NRCS, 1997) also was determined and analyzed as shown bellow based on the Figure 3.2 and the Equations from 3.29-3.32.

$$\mathbf{Ea} = \frac{\textbf{Volume of water added to the root zone (Vrz)}}{\textbf{Volume of water applied to the field (Vap)}} - - - - - - - - - - - - - - - - - \mathbf{3.28}$$

$$\mathbf{Es} = \frac{\textbf{Volume of water added to the root storage (Vrz)}}{\textbf{Potential soil moisture storage volume }(\mathbf{Zreq} * \mathbf{L})} - - - - - - - - - - - - - - - - \mathbf{3.29}$$

$$\mathbf{DPR} = \frac{\textbf{Volume of deep percolation}}{\textbf{Volume of water applied to the field}} - \mathbf{3.30}$$

$$\mathbf{TWR} = \frac{\textbf{Volum of runoff (Vro)}}{\textbf{Volume of water applied to the field (Vap)}} - - - - - - - - - - - - - - - - - \mathbf{3.31}$$

The distribution uniformity of irrigation water, the minimum depth infiltrated and the average depth was determined from the infiltration depth curve and distribution uniformity was calculated using (equation 3.32)

$$\boldsymbol{Du} = \frac{\mathbf{Iav}\ (\mathbf{0.75L} - \mathbf{L})}{\mathbf{Iav}\ (\mathbf{L})} - \mathbf{3.32}$$

Where Du = distribution uniformity, TWR = tail water ratio, Ea = application efficiency %, Es = storage efficiency %, DPR = deep percolation ratio, $I_{av\ (0.75L-L)}$ = average infiltration depth of the lower quarter of the furrow length (cm), Iav $_{(L)}$ = average infiltrated depth for the whole field length (cm).

In order to know the continuity of irrigators practice during irrigation time on performance, these performance indices were measured during two irrigation events for 12 furrows inflow and time of cutoff are shown in Appendix table 7:2.

Comparison and evaluation of furrow irrigation system performance via SIRMODIII (Wynn R**,** 2003) and WinSRFR 4.1.3 (Eduardo *et al.*, 2012) surface irrigation models output value and develop a sensitivity analysis for different management options were done.

The input parameters for SIRMOD and Win SRFR are cross-sectional geometry parameters, manning roughness coefficient, field length, furrow spacing, slope, inflow rate Qo, cutoff times, irrigation required depth basic infiltration rate (f_o). The Kostiakov infiltration parameters, ‘k’ and ‘a’ for the models are simulated from the event tool for WinSRFR and Two Point tool for SIRMOD models and the performance indices are the output of the two models (See Table 4:2).

Mathematical and graphical expressions are adapted that provided an insight for compressive analysis and evaluations. Comparing criteria for the evaluation of the simulated models’ performances indices the following statistical parameters; such as coefficient of determination (R^2), root mean square errors (RMSE) and mean absolute errors (MAE) are used.

The statistical performance evaluation comparison criteria that were used to reflect the goodness of simulation expressed as (Legates and McCabe, 1999):

$$\mathbf{R^2 = \frac{\left(\sum_{i=1}^{n}(O_i - \bar{O})(S_i - \bar{S})\right)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2 * \sum_{i=1}^{n}(S_i - \bar{S})^2}} ------------------------ \mathbf{3.33}$$

$$\mathbf{RMSE = \sqrt{\frac{\sum_{i=1}^{n}(O_i - S_i)^2}{n}}} ---------------------------- \mathbf{3.34}$$

$$\mathbf{MAE = \frac{\sum_{i=1}^{n}|O_i - S_i|}{n}} ------------------------------ \mathbf{3.35}$$

Where O_i = corresponding values of estimated from observation/measured; S_i = corresponding value simulated by models; n = number of observations/measured; $\mathbf{\bar{O}}$ = average of the estimated values; and $\mathbf{\bar{S}}$ = average of the simulated values. O_{max} = the maximum experimental value. O_{min} =

the minimum experimental value; R^2 = coefficient of determination, RMSE = root mean square errors, MAE = mean absolute errors

The coefficient of determination (R^2) measures the degree of correlation between the estimated and calculated values, where values approaching 1.0 indicate a good correlation. The root mean square error (RMSE) expresses the error in the same units that describe the variable (Legates and McCabe, 1999). The lower the RMSE value the better fitting with the measured value. The mean absolute error (MAE) is the average value of the absolute differences between the estimated and calculated values. A low MAE implies good model performance.

For the analysis of sensitivity the average value of the input parameters (discharge, furrow length, cutoff time and furrow slope) and the estimated and simulated values of this parameter were taken as actual condition. The actual value is taken from the average values of the measured parameter which had 4.65 l/s, 100 m, 23.4 min and 0.018% for flow rates per furrow, furrow lengths, time of cutoff and slopes, respectively and the changed input parameter for discharge (4, 3.5 and 3 l/s), furrow length (90, 70 and 50 m), time of cutoff (25, 30 and 35 min) and furrow slope (0.0162, 0.01 and 0.007%) taken.

The contribution of each parameter on each performance indices is calculated by; changed value mines the actual value then divided by the actual value multiply by 100%.

4. RESULTS AND DISCUSSIONS

4.1. Soil Laboratory Analysis

Soil physical property analysis of the experimental plot is presented in Table 4.1. The data revealed that, it had a silt loam texture with percentage of sand, silt and clay as 21.5, 54.92 and 23.58%, respectively. The soil had an average moisture content of 22.6% at field capacity (FC) and 12.6% at permanent wilting point (PWP) on weight bases. The average bulk density of the soil is found to be 1.4 g/cm^3 at a depth of 0 – 150 cm. The value of bulk density is in agreement with the work by (Booker, 2006) which ranged from 1.29-1.5 g/cm^3 for silt loam soils and the average value of 1.4 g/cm^3. It is also in agreement with (Sundra, 2000) the bulk density of soils for sugarcane should be with a range of 1.1-1.4 g/cm^3.

Table 4:1. Soil physical properties and soil laboratory analysis of experimental Site

Soil depth (cm)	0-30	30-60	60-90	90-120	120-150	Average
Sand (%)	21.7	20.9	20.8	21.3	22.8	21.5
Silt (%)	52.4	53.8	55.7	54.2	58.5	54.9
Clay (%)	25.9	25.3	23.5	24.5	18.7	23.6
Textural class	silt loam	silt loam	silt loam	silt loam	silt loam	silt loam
Db, (gm/cm3)	1.35	1.4	1.43	1.48	1.5	1.4
θ_i (%)	16.2	16.3	16.5	16.8	17.0	16.6
θ_{fc} (%)	21.7	22.2	22.6	23.1	23.5	22.6
θ_{wp}(%)	12.1	12.4	12.6	12.9	13.1	12.6
TAW (mm/m)	130.1	137.6	143.3	151.3	156.4	143.6
TAW (mm)	39.0	41.3	43.0	45.4	46.9	215.4
SMD (mm)	22.5	24.5	26.3	27.7	29.4	130.2

Total available water holding capacity of the soil is found 215.4 mm from which 130.2 mm (60.44%) is soil moisture deficit or to be required irrigation water for sugarcane. The observed soil moisture deficits, SMD (mm), is assumed as the best estimates of Z_{req} which represents the depth of water the irrigation system should be supply and this is referred to as Z_{req} Basem (2012). It is estimated from field measurements of soil water contents before irrigation. For all irrigation events, the root zone depths water extraction potential for sugarcane were assumed to equal 0.9 –

1.8 m based on phenological of sugarcane root mass (Holden J R and P J McGuire, 2010; and USDA-NRCS, 1997) and Z_{req} is found 130.2 mm through 150 cm soil depth.

4.2. Furrow Characteristics

The average measured slopes of furrows are 1.8%. It is agree with (FAO, 1999) the slope of all furrows was even surface standard guidelines for the evaluation of slope gradient; slopes are less than 2%.

The result of the profilometer measurement gave typical furrow cross section before irrigation which is like a parabolic in shape (See figure 4:1). The furrows have a dimension of 110-123 cm with 117 cm average top width and 35-45 cm bottom width with average of 38 cm and 12 cm furrow depth.

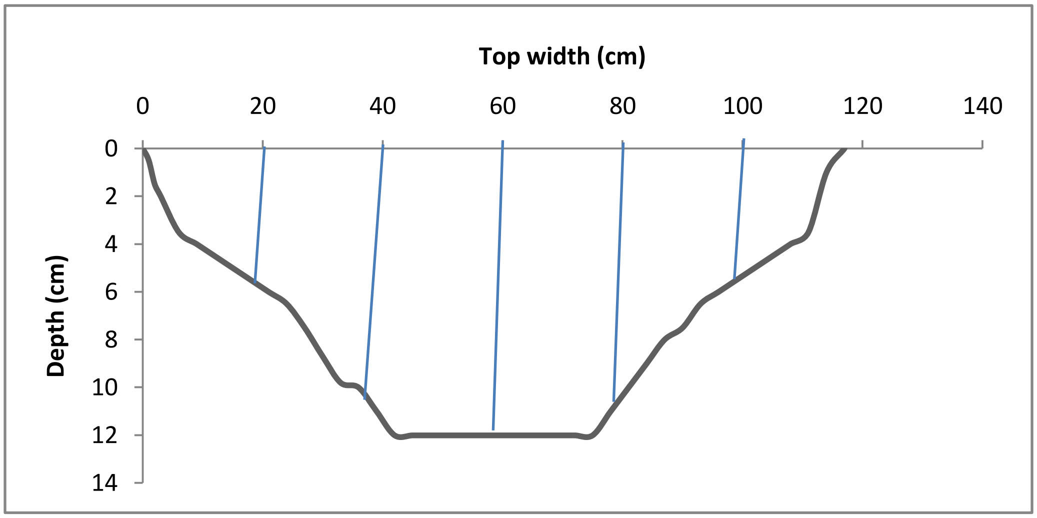


Figure 4:1. Average cross section for 12 furrows

Top width, bottom width and middle width for 12 furrows with furrow shape parameters were determined for the models input and summarized in Appendix Table 7:2.

4.3. Infiltration Parameters

The result of infiltration parameters indicate that an average basic infiltration rates is found 0.00072 m^3/m/min obtained for all furrows. Moreover, the average Kostiakov-Lewis parameter 'k' is estimated to be 0.023, 0.033 and 42.821 based on the measured value, SIRMOD and

WinSRFR models respectively. Similarly, the ‘a’ parameter is estimated to be 0.103, 0.188 and 0.308 based on the measured, SIRMOD and WinSRFR models respectively (See Table 4:2). A typical infiltration characteristic for the infiltration volume balance method is presented in (Figure 4:2).

Table 4:2. The Kostiakov-Lewis parameters

Parameters	Irr. Event	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	Average
k	1	0.030	0.025	0.017	0.031	0.014	0.031	0.027	0.020	0.022	0.030	0.024	0.030	0.025^{m}
		0.021	0.005	0.012	0.023	0.005	0.004	0.016	0.007	0.010	0.015	0.009	0.015	0.012^{s}
		40.916	53.830	45.501	49.360	62.232	38.403	38.252	45.762	36.235	38.177	36.292	45.912	44.239^{w}
	2	0.025	0.014	0.021	0.032	0.012	0.027	0.026	0.016	0.020	0.025	0.019	0.016	0.021^{m}
		0.015	0.007	0.007	0.022	0.005	0.017	0.129	0.209	0.196	0.020	0.014	0.007	0.054^{s}
		38.365	46.592	46.712	41.092	36.337	38.929	46.363	44.155	44.520	38.682	36.325	38.767	41.403^{w}
a (–)	1	0.017	0.055	0.197	0.025	0.159	0.012	0.090	0.133	0.128	0.012	0.041	0.012	0.073^{m}
		0.024	0.484	0.207	0.090	0.574	0.360	0.077	0.348	0.156	0.079	0.169	0.085	0.221^{s}
		0.225	0.502	0.329	0.238	0.533	0.238	0.240	0.416	0.304	0.241	0.303	0.403	0.331^{w}
	2	0.055	0.279	0.135	0.067	0.346	0.047	0.050	0.198	0.089	0.051	0.093	0.195	0.134^{m}
		0.085	0.345	0.333	0.036	0.574	0.021	0.017	0.011	0.012	0.018	0.066	0.342	0.155^{s}
		0.249	0.413	0.403	0.201	0.390	0.196	0.274	0.338	0.328	0.199	0.242	0.198	0.286^{w}

Note; $^{m,\ s,\ w}$ *represents measured, SIRMOD, Win SRFR value rows. K values unit for measured and SIRMOD are (m*^{3}*/min/m) whereas Win SRFR are mm/hr*^{a}*.*

Based on these data, the cumulative infiltration equation is derived as;

$$Z = 0.023t_o^{0.103} + 0.00072t_o \text{ based on measured estimation}$$

$$Z = 0.033t_o^{0.188} + 0.00072t_o \text{ based on SIRMOD simulation}$$

$$Z = 42.821t_o^{0.308} + 0.0432t_o \text{ based on Win SRFR simulation}$$

Where,

Z = depth of water infiltrated (mm/m) and t_o = infiltration opportunity time (min); for Win SRFR in (hr).

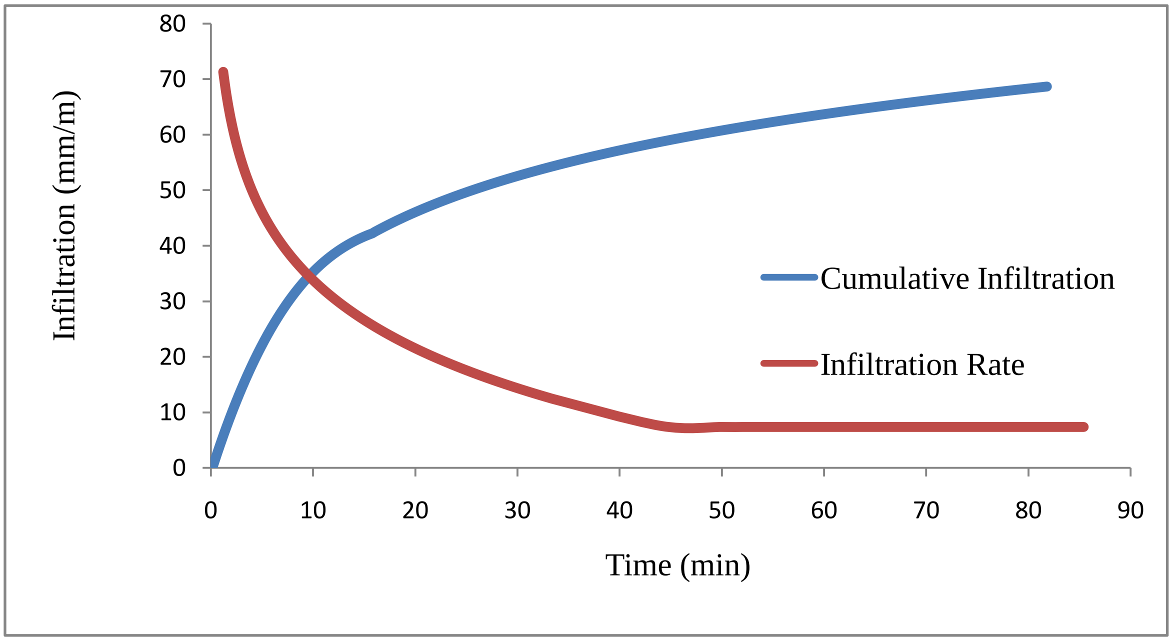


Figure 4:2. Cumulative infiltration and infiltration rate

4.4. Advance and Recession Times

The typical advance and recession curves for the average of 12 furrows in irrigation event one and two are presented in Figures 4:3.The result showed that long advance times and the recession curve is about linear, with relatively small difference between the upstream and the downstream sections. The vertical difference between advance and recession curves at any particular point gives the infiltration opportunity time. The opportunity times are used for determining the average infiltration rates of furrows. Since furrows are free draining and the inflow is constant, infiltration opportunity time decreased from the head end to tail end of furrows. This leads to variation in the amount of water infiltrated into the soil along the furrow length.

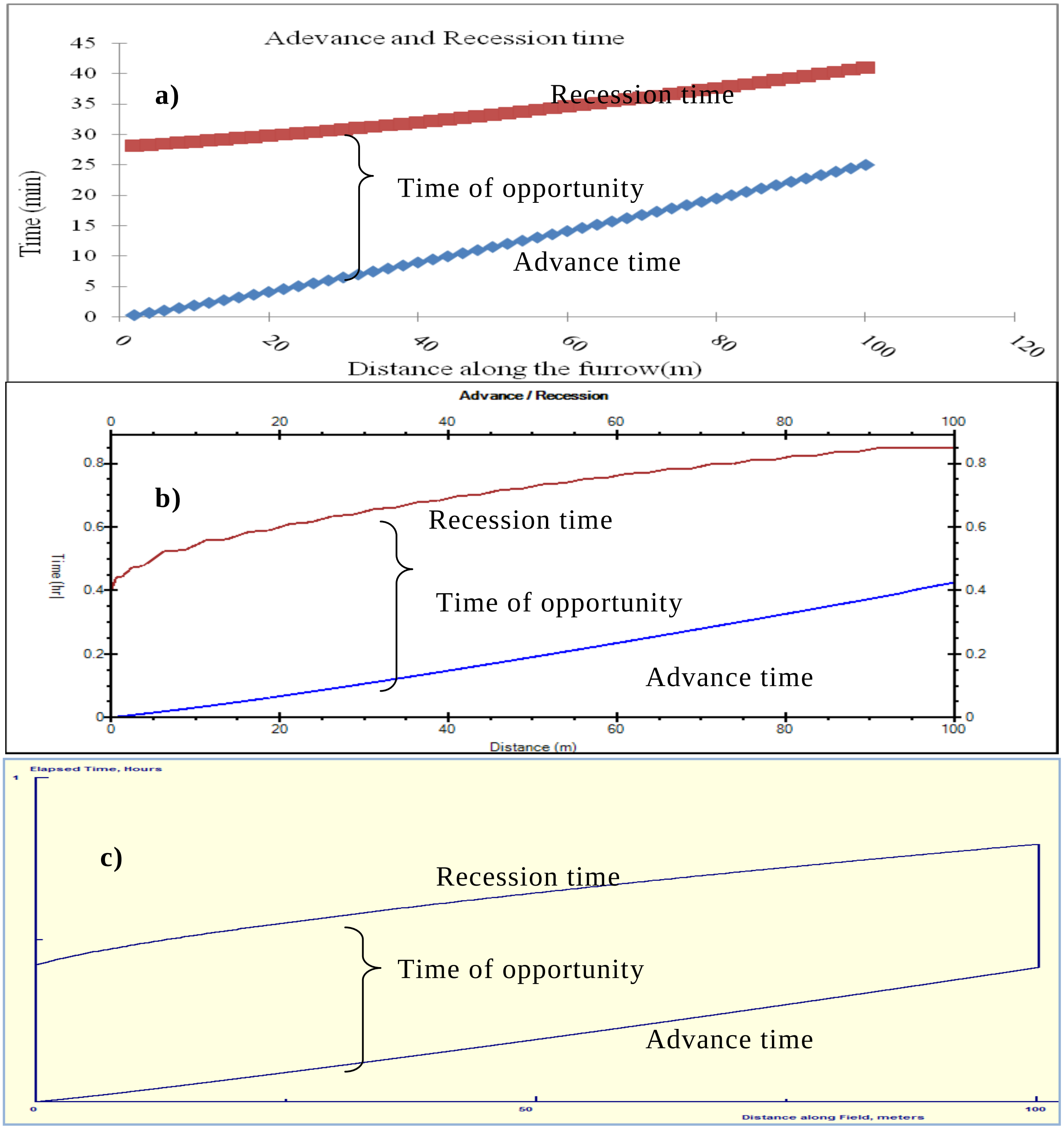


Figure 4:3. The average advance and recession time graph *for estimated (a), WinSRFR (b) and SIRMOD (c) simulated*

4.5. Irrigation Performances

4.5.1. Application Efficiency

As shown in Table 4:5, the application efficiency obtained under this experiment the average value for estimation, SIRMOD and WinSRFR simulation 65.3%, 62.1% and 68.5% respectively for 100 m furrows length is found and 1.8% furrow slope interaction. This result is in agreement with the result of (Kassa, 2001; Magwenzi, 2000; and Teshome, 2006). They had estimated the application efficiency in the order of 30-60%, inter-row (70-75%) and in row (48-57%) irrigation and 30-65%, respectively.

4.5.2. Distribution Efficiency

Distribution efficiency (Du) concerns the distribution of water over the actual field and is the ratio of the average low-quarter depth of irrigation water infiltrated to the average depth of irrigation water infiltrated, expressed as a percent (Merriam *et al.,* 1983). Distribution efficiency 90.4%, 92.4% and 95.5% for estimated, WinSRFR and SIRMOD simulated values, respectively implies that through the length of furrow the elemental areas receive water by this percentage amount. From to the study conducted by (Eisenhauer, 1997), distribution efficiency, D_u less than 60% indicates that the irrigation water is unevenly distributed, while D_u greater than 60% indicates that the application is relatively uniform over the entire field. According to Ismail *et al.,* (2004) the distribution uniformity of furrow irrigation greater than 80% are homogenous, greater than 70% slightly homogenous and less than 70% non homogenous so that all irrigation events of the study are within acceptable limit. Therefore, according to this study the result of distribution efficiency obtained indicates that the application is homogenously uniform in the entire field.

4.5.3. Storage efficiency

Water storage efficiency becomes important when water supplies are limited or when excessive time is required to secure adequate penetration of water into the soil. Mean water storage efficiency (Es) analyzed indicates that the irrigated crops did not received the required amount of water during irrigation events. Storage efficiency of the field furrows varies between

25.4 - 41.3% for estimated, 17.8 – 31% for SIRMOD simulation and 20 -33% for WinSRFR with mean value of 32.8%, 24.2% and 26.4% respectively; (See Appendix Table 7:3). This result is not agree with Habib (2004); who found E_s in the ranges of 97.4–100% with more than 50% of tested furrows having a value of 100%. It is also concurrent with the finding of (Teshome, 2006) who reported 100% E_s for all furrows. This result showed that the depth of water infiltrated in the soil is not satisfied the soil moisture deficit on the irrigation practice and need's long time of applied water to refill the root zone.

4.5.4. Deep Percolation Ratio

Since storage efficiency of the field was less than 100% no deep percolation loss occurred during application.

4.5.5. Tail Water Ratio (TWR)

Average runoff ratio for the estimated, SIRMOD and the Win SRFR simulated are found 34.1%, 37.9% and 31.2%, respectively showing that there were runoff losses from fields during irrigation event (the detail analysis see Appendix Tables 7:3). Higher value in runoff ratio is due to fields' topography and methods of irrigation application. These runoff losses escaped from irrigated fields flow to downstream fields to be reused beneficially or considered as waste water which causes water logging and land unproductive. As shown in Table 4:3 the result found on this study is greater than (Walker, 1989) Relatively conservative estimation values which is 20%.

Table 4:3. Performance indices carried out from the average values of the two furrow irrigation events

Furrow No.	Ea			Du			Es			TWR		
	Estimated	SIRMOD	WinSRFR	Estimated	SIRMOD	WinSRFR	Estimated	SIRMOD	WinSRFR	Estimated	SIRMOD	WinSRFR
F_1	64.1	60.5	66.5	94.8	96.3	93.0	30.6	25.2	26.5	35.9	39.6	33.0
F_2	67.5	66.2	72.0	88.1	95.1	90.5	32.9	24.8	26.9	32.5	33.8	27.5
F_3	66.5	63.4	70.5	89.4	94.8	92.5	33.1	24.3	26.9	33.5	36.6	29.5
F_4	68.5	64.7	70.0	91.6	95.3	94.5	39.3	28.6	30.7	31.5	35.3	30.0
F_5	66.7	64.3	70.5	87.0	94.8	87.0	31.2	23.3	25.3	33.3	35.7	29.0
F_6	66.2	59.7	66.7	91.5	95.5	94.0	33.7	23.4	26.1	33.8	40.4	33.3
F_7	66.8	62.6	69.0	90.7	95.2	93.5	34.7	25.1	27.6	33.2	37.5	30.5
F_8	66.3	63.6	70.0	89.2	95.5	92.5	32.4	23.9	26.1	33.7	36.4	29.5
F_9	64.2	61.0	67.5	89.5	95.7	92.0	30.7	22.5	24.6	35.8	39.0	32.5
F_{10}	64.9	59.8	66.0	91.8	96.0	93.5	33.1	23.5	26.1	35.1	40.2	33.5
F_{11}	61.6	57.4	64.5	90.0	96.6	92.5	28.8	20.6	23.0	38.4	42.6	35.0
F_{12}	65.9	61.9	68.5	90.8	95.7	93.0	32.9	23.7	26.4	34.1	38.1	31.0
Aver	65.3	62.1	68.5	90.4	95.5	92.4	32.8	24.1	26.4	34.2	37.9	31.2

Note; *estimated is represent the calculated values determined by using the measured parameter data*

4.6. Models Output Comparison

The Irrigation Performances indices obtained from the observed and simulated through SIRMOD and Win SRFR models are compared by computing standard statistical performance comparison criteria. From the values of the performance indices analysis the Win SRFR simulated model provides good fitter than the SIRMOD simulation to the measured data (See Table 4:4).

Table 4:4. Comparison of the evaluation of the simulated models' performances indices

Comparison Parameters	Ea		Du		Es		TWR	
	SIRMOD	Win SRFR	SIRMOD	Win SRFR	SIRMOD	Win SRFR	SIRMOD	Win SRFR
R^2	0.70	0.74	0.34	0.66	0.35	0.88	0.66	0.74
RMSE	3.91	2.87	5.47	2.4	8.79	6.51	3.91	3.29
MAE	3.70	2.70	5.28	2.19	8.69	6.42	3.70	3.04

The comparison analysis of performance indices are carried out from the average values of the two irrigation events (See Table 4:3) to represent the performance of the system throughout the whole period from Appendix Table 7:3.

4.7. Sensitivity Analysis of the Input Variables on the Performance Efficiencies

4.7.1. Discharge Rate (Q_o)

The parameters (L, T_{co} and S_o) remaining constant as the actual value by changing the discharge value the application efficiency is slightly increased as the discharge decreased and it increased by 6% during 3 l/s discharge rate from the actual value (4.65l/s value) (See figure 4:4, a and Appendix Table 7:1) and similarly, the distribution efficiency changed is low as discharge rate changed and influenced and declined by 4% from the actual value during 3 l/s discharge rate. Storage efficiency is the most sensitive on discharge changes and had inversely proportional with it (Es increasing with discharge decreasing). It increased by 37%, 38% and 40% for estimated, SIRMOD and WinSRFR simulation values, respectively when discharge decreased from 4.65 l/s to 3 l/s. Moreover, next to Es, TWR is the second performance index sensitive for discharge. The maximum contribution of discharge on TWR is 13% during 3 l/s furrow discharge rate thus had directly proportional with discharge. During 3 l/s TWR is decreased by 9%, 10% and 13% from the actual values (4.65 to 3l/s) for SIRMOD, estimated and WinSRFR simulation values, respectively (See Appendix Table 7:1). This result had similar idea with the (Basem, 2012) report done in the Parc Agrari del Baix Llobregat area.

4.7.2. Length of the Furrow (L)

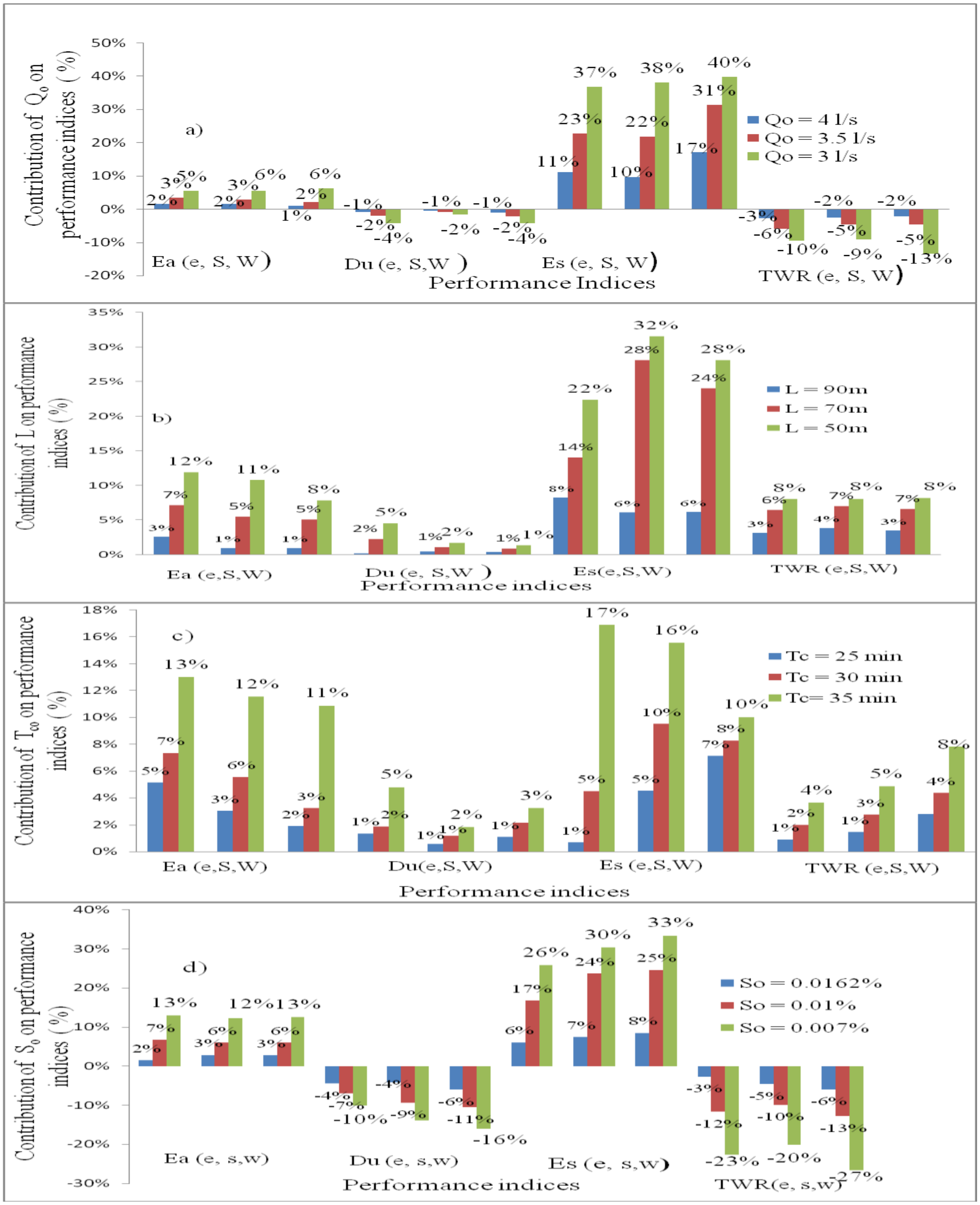
The parameters (Qo, T_{co} and S_o) remaining constant as the actual value by changing the furrow length value the application efficiency is increased as the furrow length decreased and the maximum contribution of length on it is 12% during 50 m length Ea was increased by 8, 11 and 12% WinSRFR, SIRMOD simulation and estimation condition, respectively (See figure 4:4, b) and similarly, the distribution efficiency is slightly increasing with low change of value when furrow length decreased and increased by 4% from the actual value during 50 m furrow length. Storage efficiency is the most sensitive on furrow length and had inversely proportional with it (Es increase with furrow length decreasing). It increased by 22%, 28% and 32% for SIRMOD, WinSRFR simulation and estimation values, respectively when the furrow length decreased from 100 m to 50 m. Moreover, TWR is the second performance indices sensitive for furrow length. The maximum contribution of furrow length on TWR is 8% during 50 m furrow length thus had inversely proportional with furrow length. During 50 m length TWR increased by 8% from the actual value (i.e. 100m values) (See Appendix Table 7:1) the result found is agree with the idea of (Jurriens *et al*., 2001; and Holzapfel *et al*., 2009).

4.7.3. Time of Cutoff (T_{co})

The parameters (Qo, L and S_o) remaining constant as the actual value by changing the cutoff time value the application efficiency is increased as the time of cutoff increased and the contribution of T_{co} on Ea is increased by 11, 12 and 13% WinSRFR simulation, estimation and SIRMOD simulation condition, respectively during 35min (See Figure 4:4, c) and similarly, the distribution efficiency is slightly increasing with time of cutoff increasing and influenced by 5% increased from the actual value during 35min. Storage efficiency changed whit changed and had directly proportional with T_{co} (Es increased with T_{co} increased). It increased by 10, 16 and 17% for WinSRFR simulation, estimation and SIRMOD simulation condition, respectively during 35min when the time of cutoff increased from 23.4min to 35min. Moreover, TWR is the third performance indices sensitive for time of cutoff. During 35min length TWR was increased by 4%, 5% and 8% from the actual value for SIRMOD, estimated and WinSRFR simulation value, respectively (See Appendix Table 7:1). This result had similar trend as (Assefa.*et.al*, 2017).

4.7.4. Furrow slope (S_o)

The parameters (Qo, L and T_{co}) remaining constant as the actual value by changing the furrow slope value the application efficiency was increased as the S_o decreased and the contribution of S_o on Ea is increased by 12, 13 and 13% WinSRFR simulation, SIRMOD simulation and estimation condition, respectively during 0.007% (See figure 4:4, d) and similarly, the distribution efficiency is slightly decreasing with decreasing S_o and it influenced by16% in a decreasing trend from the actual value during 0.007% furrow slope. Storage efficiency had lowest sensitive from others parameter sensitivity and had directly proportional with it (Es increased with S_o decreased). It increased by 26%, 30% and 33% for estimation, SIRMOD simulation and WinSRFR simulation condition, respectively during 0.007% when the S_o decreased from 0.018 to 0.07%. The maximum change of TWR by the change of S_o is 27% during 0.007% furrow slope thus had inversely proportional with S_o. when the slope decreased 0.018 to 0.007% TWR is decreased by 20, 23 and 27% from the actual value for SIRMOD, estimated and WinSRFR simulation value, respectively (See Appendix Table 7:1).



Note; (e, S, W) represents estimated, SIRMOD and WinSRFR simulation values, respectively.

Figure 4:4. Contributions of the input variables in the performance efficiencies by estimated and simulated models

5. SUMMARY, CONCLUSION AND RECOMMENDATION

5.1. Summary

Evaluation of farm irrigation system plays a fundamental role in improving furrow irrigation and in providing information used to advice irrigators how to improve their system operation.

In order to evaluate the performance of Belles sugarcane farm furrow irrigation system, a soil laboratory and field measurements (field layout, furrow geometry, time of cutoff, discharge) were made. In order to know the continuity of irrigators practice during irrigation time on performance, these performance indices were measured during two irrigation events.

A volume balance model two point method was used to evaluate the furrow irrigation system in the study area. A sensitivity analysis was made on the response of the model to changes in specific parameters

The five important performance indices used to evaluate the furrow irrigation system under study were application efficiency (Ea), storage efficiency (Es), distribution uniformity (D_u), runoff ratio (TWR), and deep percolation ratio (DPR).

Total available water holding capacity of the soil found 215.4 mm from which 130.2 mm is soil moisture deficit or to be required irrigation water for sugarcane.

The result of performance evaluation indicated that the average application efficiency 62.1%, 65.3% and 68.5% for SIRMOD, estimated and WinSRFR simulated values; distribution efficiency 90.4%, 92.4% and 95.5% for estimated, SIRMOD and WinSRFR simulated value; storage efficiency 24.1%, 26.4% and 32.8% for SIRMOD, WinSRFR simulated and estimated values; TWR 31.2%, 34.2% and 37.9% for WinSRFR, estimated and SIRMOD simulated values, respectively were found and deep percolation ratio for all estimation is null.

The Irrigation Performances indices obtained from the observed and simulation through SIRMOD and Win SRFR models were evaluated by computing four standard statistical performance evaluation criteria. Comparing criteria for the evaluation of the simulated models' performances indices the following statistical parameters; coefficient of determination (R^2), root mean square errors (RMSE) and mean absolute errors (MAE) are used. The Win SRFR simulated model provides good fitter than the SIRMOD simulation to the measured data.

The sensitivity of parameters contribution on performance indices are; The furrow slopes were higher sensitive than other parameters on influencing the application efficiency by 12%, 13% and 13% for SIRMOD, WinSRFR simulated and estimated values, respectively . The effects of furrow lengths were highly influencing on TWR by 8% for estimated and SIRMOD simulated and 8.1% for WinSRFR simulated values and the effect of discharge was highly influencing on the storage efficiency by 36.8%, 38.1% and 39.9% for estimated, SIRMOD and WinSRFR simulated values, respectively whereas the time of cutoff was highly affect on distribution efficiency by 2%, 3% and 5% for SIRMOD, WinSRFR simulated and estimated values respectively.

5.2. Conclusion

Based on the results obtained and discussed in the preceding sections the following conclusions with respective objectives have been drawn:

The project has a recommended value of application efficiency and distribution efficiency however; Water applied for irrigation shouldn’t meet the available water-storage capacity of the soil profile and losses of water through runoff are to be concern. All irrigation performance indicators were highly affected by the change of the parameters such as furrow length, flow rate, time of cutoff and furrow slope.

The furrow slopes are higher sensitive than other parameters on influencing the application efficiency. The effects of furrow lengths are highly influencing on TWR. It showed a general decreasing trend with increase in furrow length (i.e. As the furrow length increases largest portion of water infiltrate to the soil rather than lost as tail water drainage since it has better opportunity time for infiltrate). The effect of discharge influence on the storage efficiency also high with compared to others whereas the time of cutoff is highly affect on distribution efficiency.

5.3. Recommendation

Based on field experiences and major findings reported, the following recommendations are forwarded.

1. In-order to solve the problems of performance within a required time evaluation parameter data should be collect periodically from the system to refine management practices and identify the changes in the field that occur over the irrigation season or from year to year
2. The result showed that the depth of water infiltrated in the soil is not satisfied the soil moisture deficit on the irrigation practice so that to meet the available water-storage capacity of the soil profile based on the parameters contribution the water use management system would strategically practiced especially the runoff losses escaped from irrigated furrows flow to downstream fields to be reused beneficially and applying irrigation water until the optimal time of cutoff.
3. Evaluation by direct field measurement for commercial fields is expensive and time consuming with results limited to the range of conditions investigated. Therefore, in future using appropriate models like WinSRFR model can solve such problems and predict the actual performance with reasonably good accuracy.
4. The sensitivity analysis was undertaken by changing inflow rates, furrow length, time of cutoff and furrow slope to get better performance. Hence further research work should also be done by incorporating shape of furrow.

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7. APPENDIX

Appendix 7:1. Sensitivity analysis o of the input variables change on the performance efficiencies by estimated and simulated models

Input parameters		Ea			Du			Es			TWR		
		Estimated	SIRMOD	WinSRFR	Estimated	SIRMOD	WinSRFR	Estimated	SIRMOD	WinSRFR	Estimated	SIRMOD	WinSRFR
Qo	4.65	65.3	62.0	68.0	90.4	95.8	93.0	31.9	25.9	26.1	36.5	38.5	32.0
	4	61.4	62.9	68.7	89.7	95.5	92.0	35.4	28.4	30.6	35.5	37.1	31.3
	3.5	65.7	63.7	69.5	88.7	95.2	91.0	39.1	31.6	34.3	34.3	36.3	30.5
	3	67.0	65.4	72.3	86.7	94.8	89.0	43.6	35.8	36.5	33.0	34.6	27.7
L	100	65.3	62.0	68.0	90.4	95.8	93.0	31.9	25.9	26.1	36.5	38.1	32.0
	90	66.1	62.5	68.6	90.6	96.0	93.3	34.5	27.5	27.7	37.6	39.5	33.1
	70	68.1	65.3	71.4	92.5	96.4	93.8	36.3	33.2	32.4	38.8	40.7	34.1
	50	71.1	68.6	73.3	94.5	96.8	94.2	39.0	34.1	33.4	39.4	41.1	34.6
Tco	23.4	65.3	62.0	68.0	90.4	95.8	93.0	31.9	25.9	26.1	36.5	38.1	32.0
	25	66.8	63.8	69.3	91.7	96.1	94.0	32.1	27.1	28.0	36.8	38.6	32.9
	30	68.2	65.4	70.2	92.1	96.5	95.0	33.3	28.4	28.3	37.2	39.1	33.4
	35	70.8	69.1	75.4	94.8	96.9	96.0	37.3	30.0	28.7	37.8	39.9	34.5
So	0.018	65.3	62.0	68.0	90.4	95.8	93.0	31.9	25.9	26.1	36.5	38.1	32.0
	0.0162	66.4	63.7	69.9	86.4	93.2	87.4	33.8	27.8	28.3	35.5	36.3	30.1
	0.01	67.8	65.7	72.1	84.1	90.0	83.2	37.2	32.1	32.5	32.2	34.3	27.9
	0.007	71.8	69.6	76.5	81.3	87.2	78.1	40.1	33.8	34.8	28.2	30.4	23.5

Appendix 7:2. The inputs and outputs of the SIRMOD model to simulate the performance

Parameters	**F1**	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**F9**	**F10**	**F11**	**F12**	**Average**
						Furrow section parameters							
Field L (m),	100	100	100	100	100	100	100	100	100	100	100	100	**100**
Field slope,	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	**0.018**
Manning's *n*	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	**0.2**
T_{max}	1.2	1.2	1.15	1.2	1.1	1.15	1.15	1.23	1.1	1.2	1.2	1.2	**1.17**
T_{mid}	0.79	0.75	0.7	0.79	0.65	0.6	0.65	0.75	0.62	0.7	0.7	0.7	**0.7**
Base	0.45	0.42	0.38	0.45	0.3	0.35	0.37	0.42	0.36	0.38	0.35	0.37	**0.38**
Y_{max}	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	**0.12**
ρ1	0.190	0.167	0.158	0.190	0.155	0.122	0.126	0.151	0.128	0.137	0.140	0.138	**0.15**
ρ2	2.746	2.691	2.668	2.746	2.660	2.533	2.590	2.666	2.585	2.627	2.638	2.630	**2.65**
γ1	5.397	5.192	5.443	4.027	5.706	8.440	6.727	5.766	6.493	6.406	6.417	6.410	**6.04**
γ2	0.608	0.681	0.718	0.608	0.761	0.904	0.818	0.715	0.820	0.776	0.778	0.777	**0.747**
σ1	1.815	1.880	1.861	1.815	1.977	2.514	1.891	1.955	1.798	1.994	2.086	2.023	**1.968**
σ2	1.381	1.415	1.440	1.381	1.507	1.507	1.467	1.429	1.462	1.464	1.490	1.473	**1.451**
						Inflow rate and cutoff time							
Inflow rate,(l/s)	4.6	4.6	4.6	4.6	4.6	4.72	4.72	4.72	4.72	4.72	4.72	4.72	**4.6^{1}**
	4.8	4.8	4.8	4.8	4.8	4.5	4.5	4.5	4.5	4.5	4.5	4.5	**4.8^{2}**
cut-off Time,(min)	25	23	24	28	24	23	23	22	21	23	21	22	**23.25^{1}**
	23	23	22	25	19	25	26	24	24	25	23	25	**23.67^{2}**
						Power coefficient							
p	5.626	6.310	7.900	5.626	8.221	5.626	6.204	6.964	6.964	5.626	6.310	5.626	**6.417^{1}**
	6.310	8.606	6.964	5.577	9.272	6.310	6.310	7.900	7.155	6.310	7.155	7.900	**7.148^{2}**
r	0.894	0.881	0.821	0.894	0.849	0.894	0.853	0.838	0.838	0.894	0.881	0.894	**0.869^{1}**
	0.881	0.782	0.838	0.866	0.748	0.881	0.881	0.821	0.866	0.881	0.866	0.821	**0.845^{2}**
						Surface and subsurface coefficient							
σ_y	0.778	0.778	0.778	0.778	0.778	0.778	0.778	0.778	0.778	0.778	0.778	0.778	**0.778^{1}**
	0.778	0.778	0.778	0.778	0.778	0.778	0.778	0.778	0.778	0.778	0.778	0.778	**0.778^{2}**
σ_z	0.720	0.712	0.713	0.731	0.716	0.709	0.712	0.709	0.702	0.712	0.703	0.709	**0.712^{1}**
	0.716	0.716	0.710	0.725	0.696	0.714	0.718	0.711	0.709	0.716	0.707	0.716	**0.713^{2}**

Note $^{1, 2}$ represents Irrigation Events row

Appendix 7:3**.** Comparison of SIRMOD and Win SRFR models in terms of infiltrated water and performance indices estimation

	Irrigation Event	Measured						simulated											
		Z (m^3)	performance indicators					SIRMOD						Win SRFR					
								Z (m^3	performance indicators					Z (m^3	performance indicators				
			Ea	DU	Es	DP	TWR		Ea	DU	Es	DP	TWR		Ea	DU	Es	DP	TWR
F$_1$	1	4.6	66.0	93.2	27.1	0.0	38.7	4.2	61.3	96.0	27.1	0.0	38.7	4.7	68.0	94.0	27.7	0.0	31.0
	2	4.4	66.9	93.6	34.0	0.0	33.1	3.9	59.6	96.6	23.4	0.0	40.4	4.3	65.0	92.0	25.3	0.0	35.0
F$_2$	1	4.4	69.2	85.8	33.7	0.0	30.7	4.4	68.8	94.5	25.8	0.0	31.2	4.7	74.0	89.0	27.7	0.0	25.0
	2	4.2	65.6	90.5	31.9	0.0	34.4	4.0	63.6	95.7	23.8	0.0	36.4	4.4	70.0	92.0	26.1	0.0	30.0
F$_3$	1	4.5	67.9	89.9	34.6	0.0	32.1	4.3	64.9	95.1	25.4	0.0	35.1	4.7	71.0	93.0	27.7	0.0	29.0
	2	4.1	65.2	89.0	31.7	0.0	34.8	3.9	62.0	94.5	23.2	0.0	38.0	4.4	70.0	92.0	26.1	0.0	30.0
F$_4$	1	5.4	69.6	89.8	41.3	0.0	30.4	5.2	67.7	94.5	31.0	0.0	32.3	5.6	73.0	95.0	33.0	0.0	27.0
	2	4.9	67.4	93.4	37.3	0.0	32.6	4.4	61.7	96.1	26.3	0.0	38.3	4.8	67.0	94.0	28.4	0.0	33.0
F$_5$	1	4.8	72.9	85.9	37.1	0.0	27.1	4.9	73.6	93.3	28.8	0.0	26.4	5.1	79.0	84.0	30.7	0.0	21.0
	2	3.3	60.4	88.0	25.4	0.0	39.6	3.1	55.1	96.3	17.8	0.0	44.9	3.4	62.0	90.0	20.0	0.0	37.0
F$_6$	1	4.3	65.8	91.1	32.9	0.0	34.2	3.8	58.7	95.9	22.6	0.0	41.3	4.3	66.0	93.0	25.3	0.0	34.0
	2	4.5	66.5	91.9	34.5	0.0	33.5	4.1	60.6	95.2	24.2	0.0	39.4	4.5	67.4	95.0	26.9	0.0	32.6
F$_7$	1	4.2	65.0	91.5	32.5	0.0	35.0	3.9	59.2	96.1	22.8	0.0	40.8	4.3	66.0	93.0	25.3	0.0	34.0
	2	4.8	68.6	89.9	37.0	0.0	31.4	4.6	65.9	94.3	27.4	0.0	34.1	5.0	72.0	94.0	29.9	0.0	27.0
F$_8$	1	4.1	65.8	89.7	31.5	0.0	34.2	3.9	63.1	95.7	23.3	0.0	36.9	4.3	70.0	92.0	25.3	0.0	30.0
	2	4.3	66.9	88.6	33.3	0.0	33.1	4.2	64.2	95.2	24.6	0.0	35.9	4.5	70.0	93.0	26.9	0.0	29.0
F$_9$	1	3.6	61.1	89.3	27.9	0.0	38.9	3.4	57.2	96.7	20.1	0.0	42.8	3.8	64.0	91.0	22.3	0.0	36.0
	2	4.4	67.3	89.7	33.5	0.0	32.7	4.2	64.7	94.7	24.8	0.0	35.3	4.5	71.0	93.0	26.9	0.0	29.0
F$_{10}$	1	4.2	64.1	91.8	32.1	0.0	35.9	3.8	58.9	96.3	22.7	0.0	41.1	4.3	65.0	93.0	25.3	0.0	34.0
	2	4.4	65.7	91.8	34.0	0.0	34.3	4.1	60.7	95.6	24.3	0.0	39.3	4.5	67.0	94.0	26.4	0.0	33.0
F$_{11}$	1	3.6	59.8	88.5	27.3	0.0	40.2	3.4	56.4	96.9	19.8	0.0	43.6	3.8	64.0	92.0	22.3	0.0	36.0
	2	3.9	63.4	91.6	30.3	0.0	36.6	3.6	58.4	96.4	21.5	0.0	41.6	4.0	65.0	93.0	23.8	0.0	34.0
F$_{12}$	1	4.1	66.2	89.8	31.7	0.0	33.8	3.9	63.0	95.7	23.2	0.0	37.0	4.5	70.0	92.0	26.1	0.0	29.0
	2	4.4	65.6	91.8	34.0	0.0	34.4	4.1	60.7	95.7	24.2	0.0	39.3	4.5	67.0	94.0	26.7	0.0	33.0
Average		4.31	65.3	90.4	32.8	0.0	34.2	4.0	62.1	95.5	24.1	0.0	37.9	4.4	68.5	92.4	26.5	0.0	31.2

Appendix Figure 7:1. During soil sample pit take photos

Appendix Figure 7:2. During field data measurement photos