Optimization of Furrow Irrigation Decision Variables: The case of Wonji Shoa Sugarcane Plantation, Ethiopia.

Tokuma Adamu[1]*, Mekonen Ayana[2], Gebremeskel Aregay[3]

[1]*Lecturer, School of civil Engineering, Mekelle University, Mekelle, Ethiopia*

[2]*Associate Professor, Adama Science and Technology University, Adama, Ethiopia*

[3]*Assistant Professor, Head of Irrigation Engineering Chair, School of civil Engineering, Mekelle University, Mekelle, Ethiopia*

Abstract

Surface irrigation type is one of the most widely used in the world due to its low cost investment. However it is complex methods of applying water to soil, because of extremely difficult to achieve good control over the highly variable nature of the movement of water across a soil surface and its infiltration into the soil over a season. This complexity leads low efficiency of the system because of failure in management and design. In this study, it is attempted to optimize furrow irrigation decision variables at Wonji sugar estate using field experiment and two simulation models. The hydraulic performance of the existing system was evaluated using two systematically selected furrows. Accordingly, an application efficiency of 43% and 25% were obtained. The performance of the system was evaluated as poor due to excess application of water and less management skills of irrigation application. One experimental site was selected at field number of 85 for optimization of decision variables. The field data (before irrigation, during irrigation and after irrigation event) of experimental site (at field number 85) was measured as input for models and simulated using the SIRMOD software and Win SRFR software package. Furrow length of 32m, 48m, and 64m, slope of 0.05%, 0.075% and 0.1%, and flow rate of 3l/sec, 4l/sec and 5l/sec were analyzed with three replication using volume balance method and two simulation models. Therefore, from the current findings, the optimum decision variables that gave maximum application efficiency and distribution uniformity was slope 0.1%, furrow length 32m,and inflow flow rate 4 l/sec at cut-off time 15.79 minutes. Thus, to improve the performance of furrow irrigation practice, optimal furrow length, inflow rates and cut-off time found by this study could be adopted.

Keywords: Furrow Irrigation • Decision Variables • Optimization • Irrigation Efficiency

Abbreviations: AE= Application Efficiency • DU= Distribution Uniformity • ES= Storage Efficiency • FAO= Food and Agricultural Organization • TAW =Total Available Water • Tco =cut-off time • USDA= United State Development Agricultural • VBM =Volume Balance Model

Introduction

Surface irrigation is the most common method of irrigation and accounts for 95% of irrigation in the world. It is well suited for use on both small and large schemes [1]. Relatively to surface irrigation, pressurized irrigation method has high efficiency and requires high cost for its installation which may not be affordable for majority of the poor in developing countries. As an alternative, surface irrigation method is widely used due to low capital investment involved, low operating costs and ease of operation and maintenance [1]. Also surface irrigation systems are less affected by climatic and water quality characteristics. However, surface irrigation systems are typically less efficient in applying water than pressurized irrigation systems because of, extremely difficult to achieve good control over the highly variable nature of the movement of water across a soil surface and its infiltration into the soil over a season. Therefore, the land under surface irrigation tends to be more affected by water-logging and soil salinity if adequate drainage is not provided [2]. Even though, it is unrealistic to apply irrigation without loss. These loss appear in the application of irrigation water too less or too much and too short or too large of furrow length. Deep percolation results when water is applied too long to the field and/or the variation of intake opportunity time is too large (inflow rates are too small). These two problems can be remedied by adjusting the time of cutoff (tco) and inflow rate (Qo) [3].

Availability of irrigation water itself is becoming a constraint in some sites, possibly because more farmers have started irrigating than schemes were designed to support [4]. Adequate water management for irrigated agriculture holds a considerable significance for the future of the Ethiopian agriculture. Irrigation water for Wonji-Shoa Sugar Estate scheme is supplied via a pumping station on Awash River [5]. In Awash Basin, many industries and major cities abstract water from Awash River. This creates a risk as growing volumes of industrial effluent and urban wastewater are contaminating the water and causing scarcity by reducing the quality of surface water available for downstream users [6]. Further, stated there was a high water application rates compared to irrigation water requirement of crops in most irrigated areas [6]. Poor water management and excess irrigation water application in turn created the problems of environmental issues (water-logging and salinization), escalating multi-sectoral water demands in the basin and conflict between upstream user (Wonji) and downstream user (Merti) [7]. For this reason, water management at Wonji-Shoa Large-scale Irrigation Scheme needs critical attention which failed under low efficiency of the system because of failure in management and design [5].

Significant water savings can be achieved through improving the application of irrigation water at the field level by reducing the amount of water lost to the crop through deep percolation and surface runoff [8]. This can be achieved only by efficient irrigation systems designed at farm level combined with optimization of management decision variables like: the furrow discharge, cut of time and furrow length as decision support variables [9].

Decision variables are those parameters or variables that an irrigation designer or operator can adapt to find the best irrigation performance for given or selected field parameters. These are normally the field dimensions (length and width), the flow rate and the cutoff time [1]. The main design and managing irrigation events in surface irrigation considers choosing of decision variables [10]. These variables are unknown and should be specified by the optimization. The furrow length is a function of depth of irrigation water and bed slope of the furrow and soil texture. The optimized variables are used to modify future irrigations in order to achieve the desired level of performance. Based on principal of cost minimization and irrigation efficiency maximization described that result of the calculations related to inflow rate , length of furrow, irrigation

time and irrigation efficiency. The authors stated that with the minimization of cost results of minimized inflow rate and time cutoff in respect to the irrigation efficiency is maximized.

Okereke, also optimized the inflow rate using simulated advance and recession curves and gets 0.03m3/min/m. The authors stated that the optimized inflow rate gave satisfactory water distribution uniformity and application efficiency for three growth stages of maize: 87% and 89% for emergency stage, 75% and 60% for development stage, and 95% and 89% for maturing stage respectively.

In addition, for the existing furrow length (100m) with uniform inflow rate, obtained optimum inflow rate (5l/sec) and cut-off times (45min) that showed better application efficiency (81.16%) and better distribution uniformity (93.43%) of Irrigation System at Tendaho Sugar Estate.

Different researchers in Wonji/Shoa plantation estate have conducted researches focusing on performance assessment of pumps, canals and night storage reservoir. But for water use efficiency, an assessment of performance of on-farm irrigation is vital and resulted from optimization of decision variables which obtained by both numerical and simulation model. The objectives of this paper is to optimize furrow irrigation decision variables (inflow rate, cutoff time and furrow length) using algebraic equation and simulation model based.

Materials and Methods

Experimental site

The field experiments were carried out at Wonji Shoa Sugarcane Plantation, Oromia, Ethiopia located at latitude of 8030' to 8035' N and longitude of 39010' to 39020' E at an altitude of 1540 m above mean sea level [Fig. 1]. The Estate was established in 1951 G.C.by foreign private investors, Ethiopian government and Netherland's H.V.A. Company. Wonji sugar factory is one of the first modern sugar industry in Ethiopia with initial production capacity of 140 tons of sugar per day. Then, Shoa Sugar Factory was established in 1962 with 170 tons of sugar production capacity per day. The two factories are known by the name of Wonji Shoa Sugar Factory (WSSF) and administered as one factory **(Figure 1)**.

Climate

The estate experiences a bimodal rainfall pattern, receiving the major rains during July-September and March–April. Wonji-Shoa Sugar Estate has more than 30 year's weather data base including the rainfall, minimum temperature, maximum temperature, and average annual rainfall in the area. Mean maximum and minimum temperature of the area are 27.60°C and 15.30°C respectively. The mean annual, mean evapo-transpiration, Annual irrigation demand, and Average measured annual irrigation supply rainfall is about 820 mm, 4.6 mm/

day, 80 Mm^3 and 121 Mm^3 respectively.

Soil and crop type

Clay loam soil textures are the most dominant soil type in the area with few places of sandy loam, clay loam and silt loam. The main crops grown at the area is sugarcane that used as raw materials for the sugar industries' production.

Data Collection Techniques/Procedures

Prior to any activities, the land had sloped by machine to predetermined single (adjusted once) slope level which was adopted by organization and then, sloped furrow back leveled to zero percent by human power for experiment. After all furrows were leveled, change in elevation of each slope was calculated and drilled at downstream end of the furrow. The primary data was collected from field focusing on furrow irrigation practices and the secondary data also was collected from the Wonji Sugar Estate of planning and plantation office. The primary data used as basic input for SIRMOD and WinSRFR models were collected from the furrows field are: field topography; inflow rate; furrow geometries (furrow length, furrow depth, furrow width, furrow spacing, furrow bottom slope, furrow cross sectional area and wetted perimeter); soil infiltration parameters, soil roughness, application depth and cut-off time. The required data such as furrow characteristics and soil moisture contents were collected from March to June 2020. The experiment was prepared with aim of optimizing that furrow length, inflow rate and cut-off time of the existing system in practice. The treatments applied were slopes, furrow lengths and flow rates. Each treatment has three levels with three replications. The treatment levels were 0.05, 0.075, 0.1% furrow slopes (S), 32, 48, 64 m furrow lengths (L) and 3, 4, 5 lit/s flow rates (Q) depending on the maximum non erosive stream size with split-split plot design where slopes constituted the main plot factor, furrow lengths constituted the sub-plot factors and flow rates constituted the sub-sub-plot factors.

Each furrow set was consisting of four furrows having 5.8 m and flow rates were assigned randomly. The middle three furrows were used for testing of irrigation event parameters and the outer furrows used as a buffer to control the effects of lateral flow and the field layout was shown in **Figure 2**. The experiment was conducted under normal field conditions over two irrigation events. Amount of water to be applied during each event was determined based on soil moisture deficit level at root depth assuming equal to required depth of application during each irrigation event. Furrow cross sections were determined using profile-meter and the data were used to compute infiltration parameters by volume balance analysis following procedure. And the computed parameters values were shown in **Table 1**.

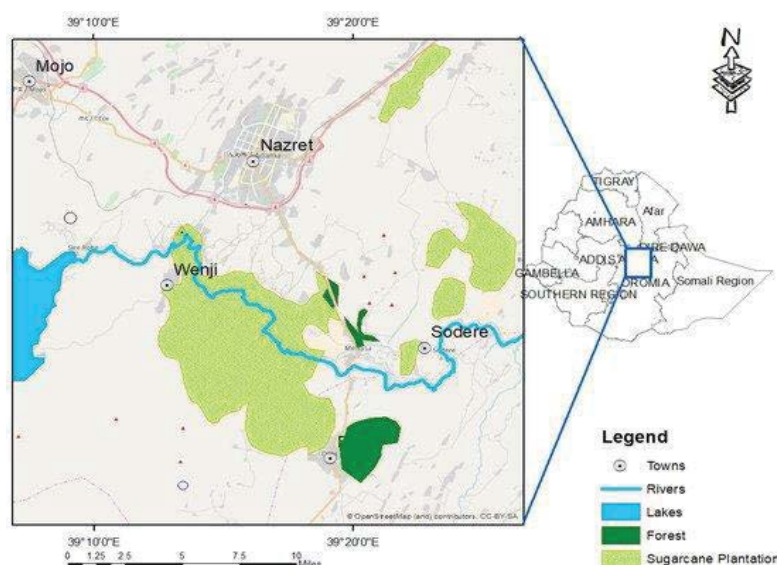The procedure begins by determining basic infiltration rate (f_0) from inflow-outflow hydrograph

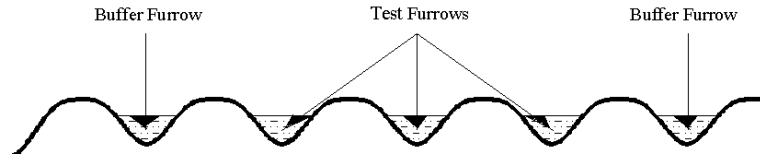**Figure 1.** Map of Study Area (Source: Degefa and Saito, 2017).

Figure 2. Field layout of the Experimental plot.

Table 1. Infiltration parameters.

Irrigation Event	Surface roughness(n)	f_o(m³/min/m)	k(mm//hrᵃ)	a(-)
First	0.04	0.00542	0.33567	-0.188
Second	0.03	0.00542	0.22911	-0.107

$$f_o = \frac{Q_{in} - Q_{out}}{L} \quad (1)$$

Next volume balance equation defined as: Where Ao = cross sectional area of flow at inlet, m²

$$Q_o t = \delta_y A_o x + \delta_z k t^a x + \frac{f_o t x}{1+r} \quad (2)$$

Qo = inlet discharge, m³/min

T= elapsed time since irrigation started, min

△y = surface storage shape factor (ranged 0.70 to 0.80)

δz = subsurface storage shape factor, defined as

$$\delta_z = \frac{a + r(1-a) + 1}{(1+a)(1+r)} \quad (3)$$

r = The exponent in power advance equation, defined as

$$= \frac{\ln(0.5)}{\ln\left(\frac{t_{0.5L}}{t_L}\right)} \quad (4)$$

Thirdly, using two point method the two empirical fitting parameters (a and k) are computed

$$a = \frac{\ln\left(\frac{V_L}{V_{0.5L}}\right)}{\ln\left(\frac{t_L}{t_{0.5L}}\right)} \quad (5)$$

$$K = \frac{V_L}{\delta_z t_L{}^a} \quad (6)$$

$$V_L = \frac{Q_o t_L}{L} - \delta_y A_o - \frac{f_o t_L}{1+r} \quad (7)$$

$$V_{0.5l} = \frac{2Q_o t_{0.5L}}{L} - \delta_y A_o - \frac{f_o t_{0.5L}}{1+r} \quad (8)$$

Where t $_{0.5L}$= advance time at one-half field length, min

T $_L$ = advance time to the end of field length, min

L= field length, m

V $_{0.5l}$ = infiltrated volume at one-half field length, m3/m

V$_L$= infiltrated volume at end of field length, m3/m

Furrow flow rates were measured using 3 inches Parshal-flumes which were placed at the upstream of the experimental plot, 5m far from inlet furrow. Prior to the test, the PVC pipe having 75 mm, 90 mm and 110 mm diameter buried at inlet of furrow to distribute flow rates over the replication equally. During the test, advance and recession times were measured for each treatment plots combination. Stakes were driven into the soil along the furrows at fixed interval of 16 m before irrigation events. Advance times were recorded at the time when water reach at each stakes while recession times (trec) were recorded

Table 2. Soil physical properties.

Soil depth (cm)	Particle size distribution (%)			textural class	Field capacity (%)	Permanent wilting point (%)
	Sand	Silt	Clay			
0-30	10	19	71	heavy clay	50.5ᵃ	24.2ᵃ
30-60	10	15	75	heavy clay	54.9ᵃ	24.4ᵃ
Average	10	17	73	heavy clay	52.4	24.3

Table 3. Bulk density of the study area.

Spot	Depth (cm)	core code	wet weight (g)	core weight (g)	bulk density (g/cm³)
1	0-30	01T	286.375	108.264	1.18793
	30-60	02T	289.278	103.87	1.10106
2	0-30	03T	288.563	106.353	1.01103
	30-60	04T	275.769	107.027	0.96182
3	0-30	05T	288.338	107.085	1.19363
	30-60	06T	254.236	108.242	0.91094
Average 1.1(g/cm³)					

at times when water fully infiltrated or disappeared from the furrow bed at observation sections. After determining the depth of water retained in the soil profile, performance indicators were calculated.

Soil data collection

Composite of undisturbed soil samples at two soil depths, 0-30 and 30-60 cm were taken from six spots for the field experiment. The collected undisturbed soil samples were analysed at Wonji Sugar Corporation Research Center Laboratory for bulk density determinations. Soil bulk density was determined using the methodology described.

$$\text{Bulk density}\left(\frac{g}{m^3}\right) = \frac{\text{dry weight of soil sample}(g)}{\text{Volume of core}(m^3)} \quad (9)$$

Using core samplers of known volume and the samples weighted and placed in Oven Dry at 105ºC for 24 h. Field capacity and permanent wilting were taken from the estate as secondary data. The percentage of sand, silt and clay of the composite soil sample were determined by hydrometer analysis method. After the percentage of sand, silt, and clay was graded, finally the soil textural class was assigned using the USDA textural triangle.

Results and Discussions

Soil Physical Properties

The soil data samples were taken from the field plot for determination of bulk density, soil texture and moisture content. As per the results obtained, which is presented in Table 3, the soil textural class is heavy clay type with Field capacity (FC) of 52.7% and Permanent Wilting Point (PWP) of 24.3% on weight basis. The bulk density of the study area sampled from six spot was found to be presented in Table 4. As a result observed the average bulk density of soil was 1.10 g/cm³ **(Table 2)**.

According to the result obtained the maximum and minimum soil moisture content before irrigation events was observed as 54 % and 35 % of volume base respectively. As this result indicated that the soil moisture content was average of 46.52% in volume base **(Table 3)**.

Soil infiltration and Surface Roughness

Typical value of roughness (n) was taken as 0.04 and 0.03 for first and later irrigation events respectively.

As the result indicated the infiltration function over the two events were formed in equation Z1 and equation Z2 respectively

Where: Z_1 = cumulative infiltrated depth for first irrigation event and

Z_2 = cumulative infiltrated depth for later irrigation event.

Hydraulic Performance Evaluation of Existing Furrow Irrigation System

Existing irrigation system was carefully evaluated to identify that may be effective and feasible in improving the systems' performance. As early stated the dominant soil type of the estate was heavy clay soil. Two fields were selected for furrow length of 32 m and 48 m and all input parameters were measured accordingly. The soil physical characteristics of the field like soil texture, field capacity, permanent wilting point, bulk density and soil moisture content before irrigation event were presented in tables 5 and 6 respectively (Table 4).

The result revealed that the heavy clay soil with particle size distribution of 10 %, 17% and 73 % sand, silt and clay respectively with required application depth of 14 mm which were computed before irrigation events by assuming required application depth equal to soil moisture deficit. The hydraulic performance of the field was evaluated over the irrigation events by using WinSRFR software package **(Table 5)**.

The estate applies 75 l/sec of flow rate per six furrows through tube at inlet of field. Each furrow inlet receives 12.5 l/sec according to the estate application. The two existing field number (16 and 108) of application efficiency and distribution uniformity were 43% and 86% for field number 16, and 25% and 44% for field number 108 respectively. The results of evaluation were presented in **Table 6**.

Narayana and Abate stated that the typical application efficiency range was between 60% and 80%. According to the evaluation indicated, the existing system of the estate was low performance. Application efficiency was affected by the rate of supply, bed slope, infiltration rate of soil, storage capacity of the root zone and land leveling. The water distribution profile from an irrigation event of existing indicated in **Figure 3**.

Table 4. Soil texture, field capacity and permanent wilting point of field number 108.

Soil depth (cm)	Particle size distribution (%)			textural class	Field capacity (%)	Permanent wilting point (%)	Bulk density
	Sand	Silt	Clay				
0-30	13	32	55	heavy clay	31.18	28.52	1.17
30-60	5	38	57	heavy clay	38.33	34.51	1.08
Average	10	17	73	heavy clay	34.755	31.515	1.13

Table 5. Soil moisture before irrigation event.

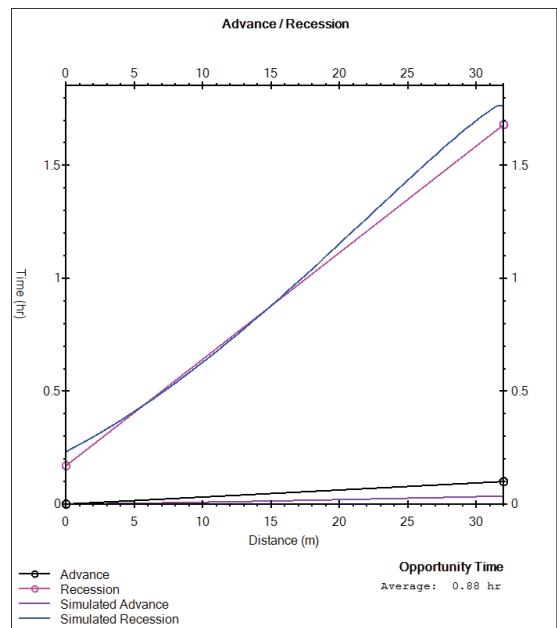| Furrow length interval (m)	Depth (cm)	can weight(g)	weight of dry sample(g)	soil moisture %
16	0-30	12.7808	29.0768	33.2103
	30-60	12.542	47.2242	39.4933
32	0-30	12.72	31.585	34.151
	30-60	11.791	37.398	44.7668
Average	0-30 cm			33.6807
	30-60 cm			42.1301

Figure 3. Advance/recession curve of existing system.

The system analyzed by WinSRFR software package and shows that the recession time delayed because of high application of inflow rate which is 75 l/sec per furrow set (6 furrows). In addition, the water advance the down end field quickly, the reason is that high flow rate used to increase gravity force that drive flow. The deep percolation of the result became high with heavy clay soil type because of the end condition of the field is closed and there is no surface runoff loss occurred. The only chance for loss is deep percolation. The result comes from insufficient design variables (furrow length and slope) and low level of management on-field practice. Since the irrigators assigned at each field number have different management skill, the irrigation efficiency at each field was varying. There was over irrigation that results high deep percolation loss. From less performance systems, maximum yield of production is unexpected. According to findings the relative yield has direct relationship with storage efficiency of the system. For this reason, the system should be improved to save water use (application efficiency) and to give maximum yield production (storage efficiency).

Measurement of Advance and Recession Time

Before any measurement was undertaken, the pharshall flume was installed at 5 m from furrow inlet as shown in figure 4. The measurement was taken at 2 min initially and increased 5min and 10min until the required head has reached. The relationship between stream size and head of 3-inch pharshall flume. After required stream size reached the four tubes installed at inlet furrow were opened at the same time **(Figure 4)**.

The time of advance water front was recorded by stopwatch at 16 m interval of distance starting from application of water to the inlet furrow along the length of 32 m, 48 m and 64 m which was presented in **Figure 5**.

The stream was cutoff when waterfront reached to the end of the furrows. The recorded advance and recession time of waterfront in experimental plot during both irrigation events were recorded. The advance relationships between the first and later irrigation events were developed by excel software and presented in **Figure 6**.

The result of revealed that the advance time of the first irrigation event was delayed than the later irrigation event because of, at first there is high infiltration than the later and at later there is moisture of the first irrigation that leads water to fast to the end of the field.

Optimal hydraulic performance parameters

The hydraulic performance indicators of the field were evaluated by assuming calculated target application equal with soil moisture deficit.

Figure 4. Measuring stream size by parshall flume.

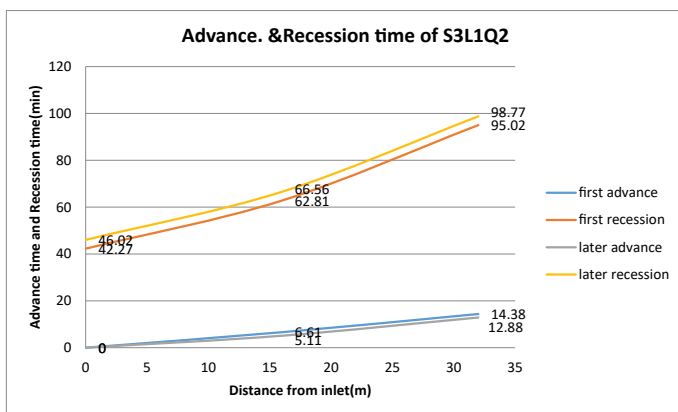**Figure 5.** Recording of Advance time.

Figure 6. Advance and recession curve of first and later irrigation events.

Optimal hydraulic performance parameters simulated with WinSRFR

The simulation model restricted to use Zero Inertia model because of the end condition of the furrow is blocked which is not applicable in Kinematic wave model **(Table 7)**.

Note: S(1,2,3)=Slope level 1,2,and 3   L(1,2,3)= Furrow length level 1,2,and 3 Q(1,2,3)= Furrow inlet discharge(Stream size) level 1,2,and 3

According to result indicated in table 8, the maximum application efficiency

Table 6. Evaluation of existing furrow system.

Field number	Hydraulic performance indicators			
	Furrow length (m)	Application efficiency (%)	Distribution uniformity (%)	Deep percolation (%)
16	48	43	86	57
108	32	25	44	75

of 86% and 34% obtained by S3L1Q2 treatment in first and later irrigation respectively. As the result observed the efficiency of the later irrigation has decreased due to less requirement depth which is based on soil moisture deficit with the same amount of applied of water. The result agreed with Solomon (2010) findings which stated that the application efficiency varies between irrigation events.

Optimal hydraulic performance parameters simulated with SIRMOD

After running the SIRMOD model, the simulated values of application efficiency, distribution uniformity, requirement efficiency, runoff and deep percolation loss percentages were obtained by feeding the inputs which were collected from field measurement in SIRMOD software. These predicted hydraulic performance indicators of the full Hydrodynamic and Zero Inertia were summarized in **Table 8**.

Note: Ae =Application efficiency. Re=Requirement efficiency/storage efficiency. DU=Distribution uniformity. Abs. Dis. U=Absolute Distribution Uniformity.

a=the solution has become unstable for these input value of discharge selected. That is the flow rate decreased to reach end of the furrow as furrow length increase.

As a result of optimization by SIRMOD viewed in Table 8 the high application efficiency of 77.72% was recorded at furrow length of 48 m, furrow stream of 4 l/s, furrow slope of 0.075% and at 43 min cutoff time (treatment S2L2Q2). The second maximum application efficiency (70.72%) was observed by treatment S3L1Q2, but the first maximum application efficiency in volume balance and in WinSRFR model. Therefore, the treatment S3L1Q2 were taken as optimum treatment comparing to other treatments over the three models (WinSRFR, SIRMOD and Volume balance). As the result indicated in table 9 the performance using full hydrodynamic and Zero inertia solution models are almost the same. But as the slope increase the relation was far each other which agree with Valipour findings.

The application efficiency simulated in the SIRMOD software under zero inertia and hydrodynamic models of furrow irrigation with closed end boundary condition was similar in comparison with WinSRFR software. Distribution uniformity and storage efficiency was also good indicating the same trend as that of application efficiency. The treatment S3L1Q2 screen output by SIRMOD model was viewed in **Figure 7**.

Calibration of the model

The model was calibrated by using calibration parameters which is manning's roughness coefficient 'n' stated by Solomon. The calibrated value of SIRMOD model presented in **Table 9**.

The most effective way to evaluate these systems is via use of a calibrated hydraulic simulation model. The role of field measurement is to collect enough information in order to calibrate this model so it can be as true as possible to the actual irrigation **(Table 10)**.

As the result viewed in table 10, the Average surface roughness of the field is 0.16 and 0.10 at first and later irrigation respectively.

Water Saving

Significant savings can be achieved through improving the application of irrigation water at the field level. The key is to improve the efficiency of irrigation by providing just enough irrigation water to match the available storage in the

Table 7. Performance indicators of WinSRFR output.

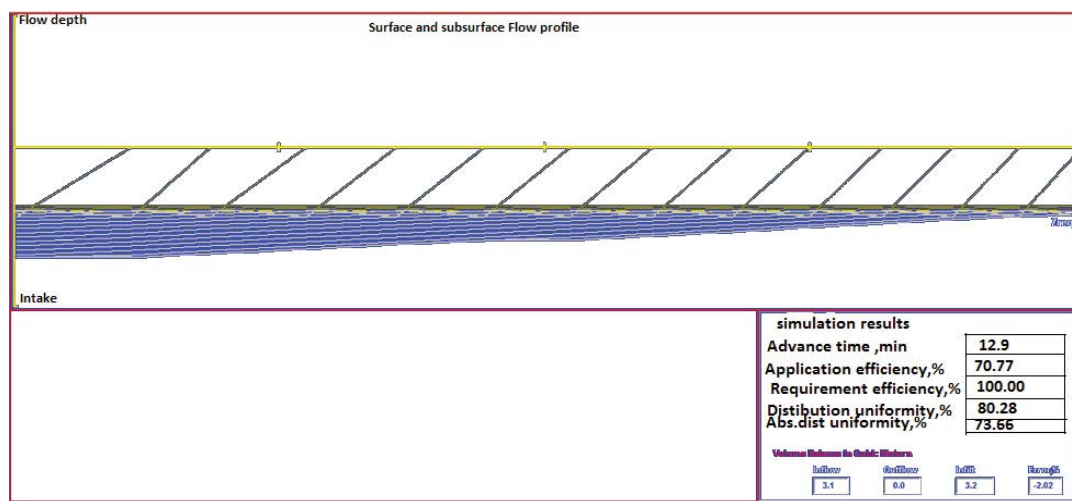| Treatments	Hydraulic performance indicators					
	First irrigation event			Later irrigation event		
	Application efficiency (%)	Distribution uniformity (%)	Deep percolation (%)	Application efficiency (%)	Distribution uniformity (%)	Deep percolation (%)
S1L1Q1	74	95	26	29	95	71
S1L1Q2	36	96	64	13	96	87
S1L1Q3	25	97	75	9	97	91
S1L2Q1	28	95	72	30	92	70
S1L2Q2	39	93	61	14	93	86
S1L2Q3	24	96	76	9	96	91
S1L3Q1	10	98	90	4	98	96
S1L3Q2	20	95	80	7	95	93
S1L3Q3	35	92	65	12	92	88
S2L1Q1	76	93	24	29	92	71
S2L1Q2	62	94	38	24	93	76
S2L1Q3	66	94	34	28	92	72
S2L2Q1	44	89	56	17	89	83
S2L2Q2	46	88	54	17	89	83
S2L2Q3	70	90	30	27	89	74
S2L3Q1	15	95	85	6	94	94
S2L3Q2	25	91	75	9	91	91
S2L3Q3	35	88	65	11	89	89
S3L1Q1	80	92	20	29	81	71
S3L1Q2	86	89	14	34	88	66
S3L1Q3	25	94	75	9	94	91
S3L2Q1	28	90	72	11	89	89
S3L2Q2	57	89	43	20	89	80
S3L2Q3	23	92	77	9	91	91
S3L3Q1	50	85	50	19	85	81
S3L3Q2	39	82	61	14	82	86
S3L3Q3	34	84	66	12	84	88

Figure 7. Window of SIRMOD output.

root zone, thus reducing the amount of water lost to the crop through deep percolation and surface runoff **(Table 10)**.

The result of table 11 revealed that 42.3% and 60.3% of water can be saved by the optimized decision variables. The amount of water saved was differing from field number to field number due to different management level of the irrigators over the field. Thus, the estate can save this much amount of water and can expand the irrigable land by saved water.

Conclusions

According to result obtained the application efficiencies of existing furrow irrigation were in the ranges of 25% to 43% for furrow length 48 m and 32 m respectively that indicate less performance of the system due to excess application of water and less management skills of irrigators during irrigation events. Thus, the existing furrow irrigation has revealed inefficient performance

Table 8. Performance indicators of SIRMOD output.

Treatments	Performance indicators							
	Full Hydrodynamic model				Zero Inertia model			
	Ae (%)	Re (%)	Du (%)	Abs.Dist.u (%)	Ae (%)	Re (%)	Du (%)	Abs.Dist.u (%)
S1L1Q1	53.15	97.05	63.03	11.6	53.26	97.26	64.71	11.06
S1L1Q2	26.66	100	67.6	43.73	26.66	100	66.41	43.51
S1L1Q3	18.51	99.92	66.05	13.02	18.53	100	74.81	59.65
S1L2Q1	13.57	69.69	0	75.7	13.57	69.69	0	76.84
S1L2Q2	45.25	100	73.28	60.93	45.25	100	70.6	58.18
S1L2Q3	17.66	100	66.89	24.39	17.66	100	70.72	56.27
S1L3Q1	0[a]	0[a]	0[a]	0[a]	0[a]	0[a]	0[a]	0[a]
S1L3Q2	10.23	72.26	0	56.25	10.23	72.25	0	56.02
S1L3Q3	47.74	100	65.19	45.05	47.74	100	65.02	46.94
S2L1Q1	50.96	96.91	63.32	12.34	50.94	96.88	62.66	12.12
S2L1Q2	47.92	100	81.42	73.84	47.92	100	80.01	71.7
S2L1Q3	61.33	100	84	76.75	41.04	89.22	45.78	64.79
S2L2Q1	18.18	59.68	0	100	21.11	69.29	0	42.41
S2L2Q2	77.72	96.87	96.64	54.69	77.26	96.29	67.37	54.77
S2L2Q3	55.47	100	72.1	59.99	56.47	100	75.45	62.36
S2L3Q1	0[a]	0[a]	0[a]	0[a]	8.68	54.81	0	0
S2L3Q2	12.65	72.18	0	50.68	12.65	72.18	0	68.63
S2L3Q3	17.73	74.68	0	97.42	17.73	74.68	0	97.24
S3L1Q1	56.37	96.66	60.5	17.39	56.31	96.55	59.67	17.14
S3L1Q2	70.77	100	80.28	73.66	70.77	100	78.84	69.71
S3L1Q3	17.82	100	67.3	20.96	17.82	100	75.1	55.59
S3L2Q1	13.5	69.69	0	76.6	0	0	0	0
S3L2Q2	48.28	99.27	62.36	18.07	48.63	100	69.21	50.11
S3L2Q3	17.6	99.97	67.36	14.21	17.61	100	72.23	58.49
S3L3Q1	16.23	47.19	0	100	16.23	47.2	0	100
S3L3Q2	16.66	62.19	0	100	16.66	62.19	0	100
S3L3Q3	17.6	74.68	0	96.48	0	0	0	0
MAX	77.72	100	96.64	100	77.26	100	80.01	100

Table 9. Calibrated SIRMOD model.

Treatments	Performance indicators							
	Full Hydrodynamic model				Zero Inertia model			
	Ae (%)	Re (%)	Du (%)	Abs.Dist.u (%)	Ae (%)	Re (%)	Du (%)	Abs.Dist.u (%)
S1L1Q1	53.15	97.05	63.03	11.6	53.26	97.26	64.71	11.06
S1L1Q2	26.66	100	67.6	43.73	26.66	100	66.41	43.51
S1L1Q3	18.51	99.92	66.05	13.02	18.53	100	74.81	59.65
S1L2Q1	13.57	69.69	0	75.7	13.57	69.69	0	76.84
S1L2Q2	45.25	100	73.28	60.93	45.25	100	70.6	58.18
S1L2Q3	17.66	100	66.89	24.39	17.66	100	70.72	56.27
S1L3Q1	0[a]	0[a]	0[a]	0[a]	0[a]	0[a]	0[a]	0[a]
S1L3Q2	10.23	72.26	0	56.25	10.23	72.25	0	56.02
S1L3Q3	47.74	100	65.19	45.05	47.74	100	65.02	46.94
S2L1Q1	50.96	96.91	63.32	12.34	50.94	96.88	62.66	12.12
S2L1Q2	47.92	100	81.42	73.84	47.92	100	80.01	71.7
S2L1Q3	61.33	100	84	76.75	41.04	89.22	45.78	64.79
S2L2Q1	18.18	59.68	0	100	21.11	69.29	0	42.41
S2L2Q2	77.72	96.87	96.64	54.69	77.26	96.29	67.37	54.77
S2L2Q3	55.47	100	72.1	59.99	56.47	100	75.45	62.36
S2L3Q1	0[a]	0[a]	0[a]	0[a]	8.68	54.81	0	0
S2L3Q2	12.65	72.18	0	50.68	12.65	72.18	0	68.63
S2L3Q3	17.73	74.68	0	97.42	17.73	74.68	0	97.24
S3L1Q1	56.37	96.66	60.5	17.39	56.31	96.55	59.67	17.14
S3L1Q2	70.77	100	80.28	73.66	70.77	100	78.84	69.71
S3L1Q3	17.82	100	67.3	20.96	17.82	100	75.1	55.59
S3L2Q1	13.5	69.69	0	76.6	0	0	0	0
S3L2Q2	48.28	99.27	62.36	18.07	48.63	100	69.21	50.11
S3L2Q3	17.6	99.97	67.36	14.21	17.61	100	72.23	58.49
S3L3Q1	16.23	47.19	0	100	16.23	47.2	0	100
S3L3Q2	16.66	62.19	0	100	16.66	62.19	0	100
S3L3Q3	17.6	74.68	0	96.48	0	0	0	0
MAX	77.72	100	96.64	100	77.26	100	80.01	100

Table 10. Water saving.

Field number	Ae of Existing practice (%)	Ae of Improved practice (%)	Water saving(%)=Existing Ae-improved Ae
16	43	85.3	42.3
108	25	85.3	60.3

which needs careful design of the furrow geometry and good management practices. The measured data of experimental site was inserted in the SIRMOD software and WinSRFR software package. Furrow length of 32m, 48m, and 64m, slope of 0.05%, 0.075% and 0.1%, and flow rate of 3l/sec, 4l/sec and 5l/sec were analysed using volume balance method and simulation model

It was observed that first irrigation event treatments had better application efficiencies than that of later irrigation event treatments. Maximum values simulated by WinSRFR model were 86% and 34% first irrigation event and later irrigation event treatments respectively. This is due to decrease of water required depth in later case with the same application of flow rate which increases deep percolation. The optimum decision variables were observed that gave maximum application efficiency which reflects the overall use of water. From the study, interaction factor that gave performance indicators above the recommended was S3L1Q2 which is third level of slope which is 0.1%, first level of length (32m), and second level of flow rate (4 l/sec). The interaction gave maximum values during both irrigation events. The optimum design factor of the system was found that furrow length of 32 m which was already abundantly used at the estate and furrow slope of 0.1% which needs improvement. In addition the management factors were also found from the study. The management factors which on-field operators (irrigators) should care were flow rate of 4 l/sec and cutoff time 15.79 minutes.

Acknowledgments

Conflict of Interest

The authors have not declared any conflict of interest.

Data Availability Statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

References

1. Jurriens M, Zerihun D, Boonstra J and Feyen J, et al. "Surface Irrigation Software .Design, Operation, and Evaluation of Basin, Border, and Furrow Irrigation." Wageningen, the Netherlands (2001).

2. Wallington HR. "FAO: *Guidelines for Water Management and Irrigation Development."* International Commission on Irrigation and Drainage, Institute of Hydrology (2007).

3. Wynn R Walker. "*SIRMOD III:* Surface Irrigation Simulation, Evaluation and Design." Logan, Utah State University (2003).

4. Kaur. "Small-scale irrigation in the Ethiopian highlands, What potential for poverty reduction and climate adaptation?" (2010).

5. Zeleke Agide Dejen. "Hydraulic and Operational Performance of Irrigation Schemes in View of Water Saving and Sustainability" *PHD. Thesis* (2015).

6. Dereje Hailu, Daneal F.Selassie, Yenesew Mengiste and Azage G, et al., "The Study of Water Use and Treated Wastewater Discharge charge" Report on Charge System for Irrigation Water Abstraction and Use. *Addis Ababa* (2018).

7. Beatrice Mosello, Roger Calow, Josephine Tucker and Helen Parker, et al., "Building adaptive water resources management in Ethiopia." *Overseas Development Institute* (2015): 1 - 100.

8. Martin Burton. "Irrigation Management Principles and Practices.*"* (N. F. Wilford, Ed.) Itchen Stoke: Printed and bound in the UK by CPI Antony Rowe Ltd (2010): 1 – 375.

9. Flores I Carlos, Eduardo A Holzapfel, Octavio Lagos. "A dynamic decision support system for farm water Management in surface irrigation: model development and application". *Chilean J Agric Res* 70(2010): 278-286.

10. McClymont David. "Development of a Decision Support System for Furrow and Border Irrigation" A Dissertation for the award of Doctor of Philosophy. *University of Southern Queensland* (2007).