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Performance Evaluation of Field Water Application at Tendaho Sugar Estate, Ethiopia

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Abstract

Sugarcane is fully irrigated crop in Ethiopia. Open canals are the main systems for supplying irrigation water in sugar farms. However, most of the schemes were frequently criticized for their low conveyance and field water application efficiencies. So far in Tendaho sugar estate; there was no previously done research on the performance evaluation of field water application of the surface irrigation system of furrow irrigation method. As a result, the actual performance of field water application of furrow irrigation of the study area and the level of achievement of the factory not known. This study has done with a purpose of identifying and understanding the current level of field water application efficiencies of Tendaho sugarcane farm using appropriate on-field irrigation performance indicators. Direct field data collection and some secondary data used to answer the planned objectives. Canal conveyance evaluation was done for tertiary canals based on priority of dominant conveyance defects observed in the sugar estate. Field water application evaluations were done during the normal irrigation practice of the sugar estate Tertiary conveyance was evaluated by using volume flow measuring method using Parshall flumes set at inlet and outlet of representative canals. From results, the mean conveyance efficiency of tertiary canal was 59.6% with high amount of water losses and the overall mean on-field water application efficiency of 56.57%, 70.30% storage efficiency and 91.93% distribution uniformity at target application depth.

Keywords: Performance evaluation; Field water application; Tertiary canal conveyance; Furrow irrigation

Introduction

Surface irrigation refers to water application systems in which water is applied and conveyed over the field surface by gravitational force. In coming futures, as the competition for water resources quickens and global population growth continues to escalate, surface irrigation will have to struggle with the difficult assignment of producing more food and fiber with less resources. Obviously, if the surface irrigation is to remain a sustainable and positive social and economic force in the 21st century, it needs to evolve into an efficient, cost effective, and environmentally kind technology [1].

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 [2]. Efficient management of irrigation water is more important, as the new sources of irrigation water supplies become scarce and new irrigation development requires huge investment. Thus, optimum utilization is becoming increasingly important for the maximum beneficial use.

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

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

So far, there was no previously done research on the performance evaluation of field water application of the estate sugar farm. As a result, the actual performance of field water application of furrow irrigation of the study area and the level of achievement of the factory's farm was not known. Relating to irrigation activities, there are visible structural and water application defects in this sugar estate. To be in the rage of study scope, the evaluation has started from tertiary conveyance system to the field water application levels.

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

Specific objectives:

1. To evaluate the performance of water conveyance of tertiary canals systems.

2. To assess the performance of field water application of furrow irrigation system.

Description of the study area

Location: The study was conducted at Tendaho Sugar estate which is located between latitude 11°30”- 11°50”N, and Longitude 40°45” - 41°03”E in the Eastern Afar Regional State. The altitude of the study area ranges from 340 to 365 masl. The slope is very mild from 0.05

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to 0.1 m per 1 km. The area is prone to flooding by river Awash that carries considerable amount of silt and has a tendency to change the course very often. The mean maximum monthly temperature of the command area varies between 32.9 and 43.2°C and the mean minimum varies between 18.3°C to 27.1°C. The average annual rainfall is about 184.1 mm. The mean monthly relative humidity varies between 33.7 to 57.4%. The wind speed varies from 158 km/day in February to 98 km/day in October. The sunshine hours varies between 6.8 to 9.9 h/day, (Appendix 1) (Figure 1).

Soil: There are three major soil mapping units in Tendaho Sugar Project farm area. From these, the soil type of area under the study lies on lacustrine sediments, Calcaric vertisols and Orthic solonchaks of FAO soil units (Silty clay/calcaric fluvisols and Silty clay loam/orthic

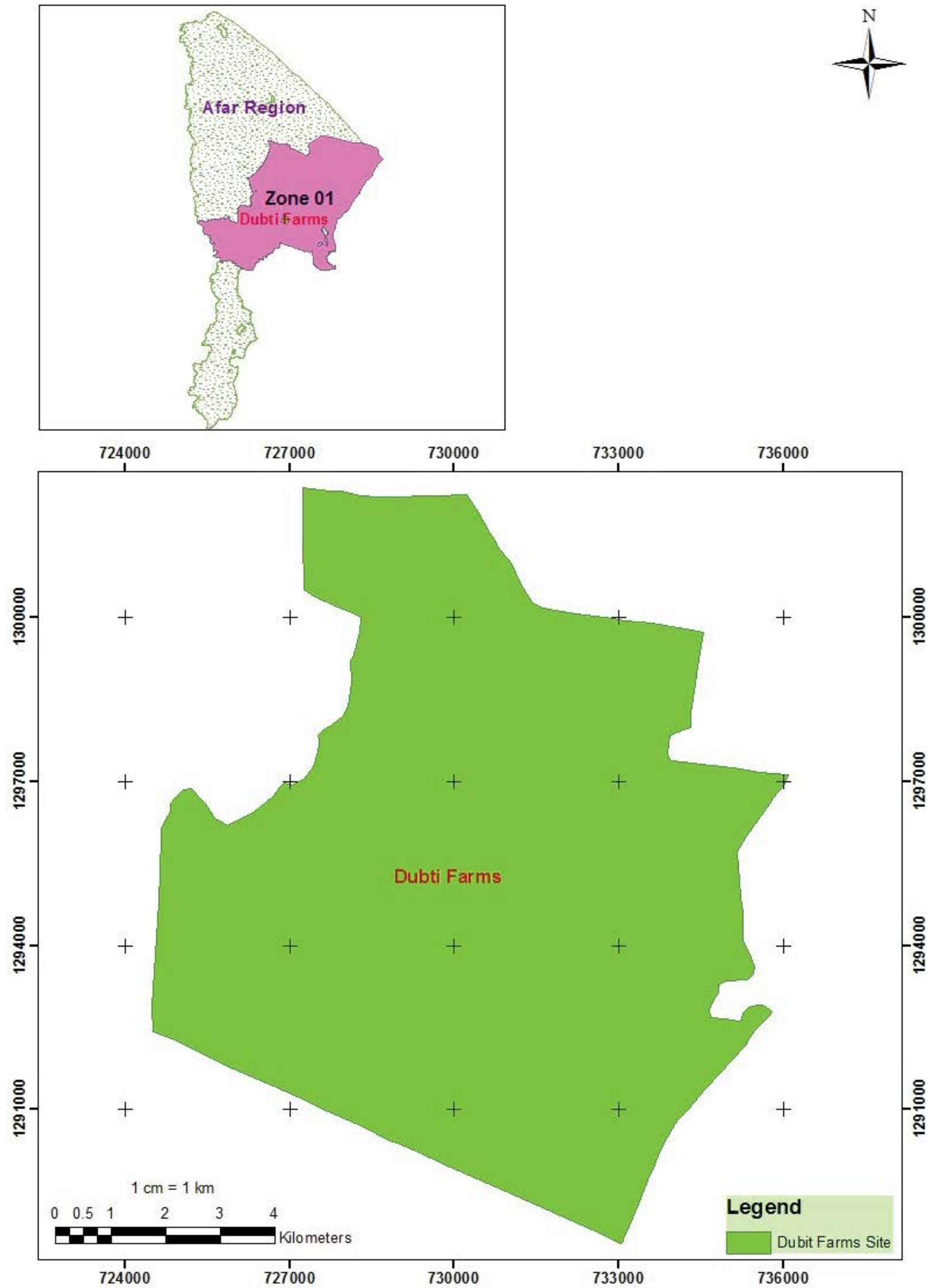


Figure 1: The map of studied area.

solonchaks textural classes). These two soil type's covers 9,367ha land of the sugar estate farm lands (Figure 2).

Research Method and Materials

Evaluation of tertiary canals conveyance efficiency

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

Evaluation of tertiary canals has been done at full operation depth and for full length of operation hours. The canals layout of Dubti area sugarcane farm is shown on Figure 3. The point from where representative canals are represented by upper case letters. Where, A is used to mean tertiary canal TC112, B=TC212, C=TC233, D=TC243, E=TC291 and F=TC2112; where TC stands for tertiary canal.

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

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

1. Six tertiary canals (Figure 4) were chosen and data were taken at upstream (A) and downstream (B) length of the canal for three replications over three irrigation events.

2. The canal discharges was measured at increasing time intervals.

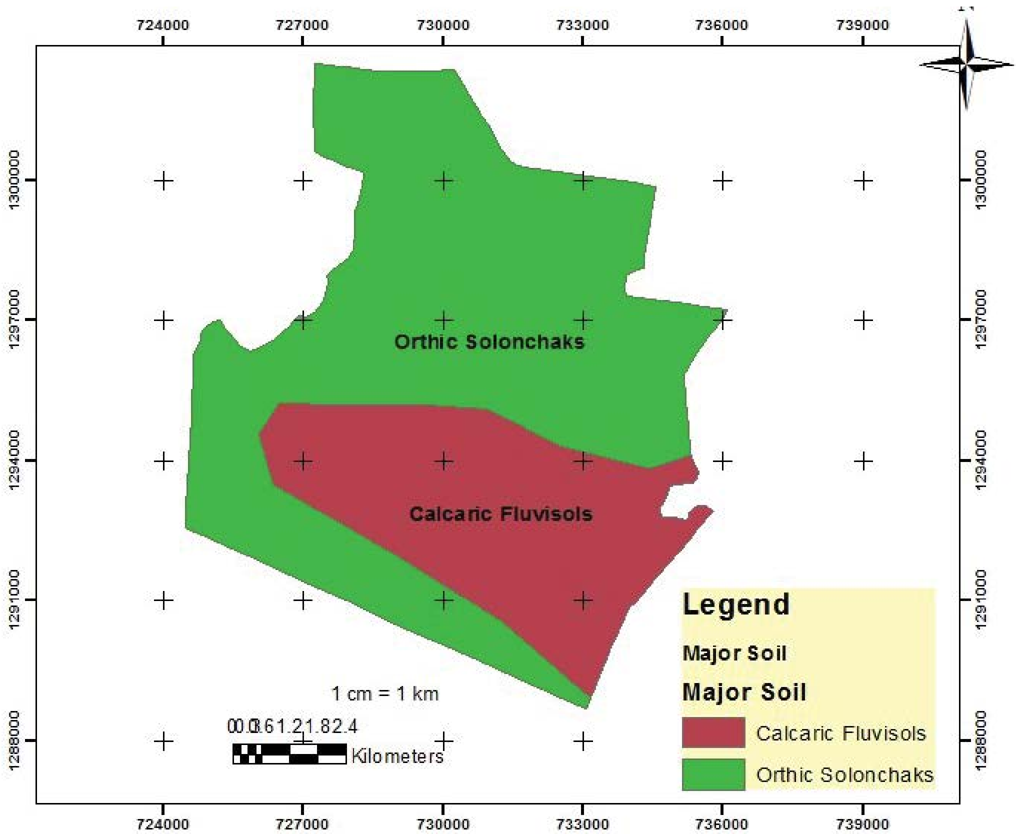


Figure 2: Soil map of the study area.

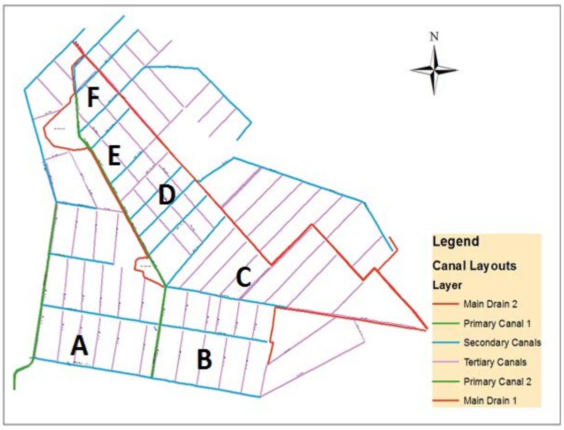
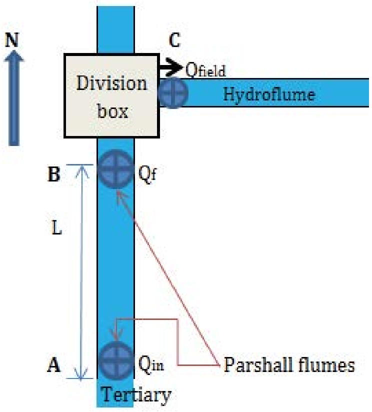


Figure 3: Canal layouts of Dubti area sugarcane farms.



L: Length of tertiary canal;

Q_{in}=inflow at upstream end of tertiary canal;

Q_f=outflow at downstream reach of the tertiary canal and A, B, C are benchmark points.

Figure 4: Setup of Parshall flumes for tertiary conveyance evaluation.

The discharges of each time interval were calculated against piezometric heads. The discharge corresponding piezometric head and throat of each Parshall flumes at two points were obtained from table of discharge characteristics which are readily available for standard widths.

3. The volume of water that has diverted from the secondary canal into tertiary (m³), and the volume of water reached the Outlet or division box of the tertiary (m³), which was measured by help of Parshal flumes installed at upstream and downstream of the canal.

4. After three replications, the collected data would analyse for each replications, and the discharge of the mean values of each replications would recorded, and finally after third repetition, the overall mean of three events would present as a mean result of conveyance efficiency of tertiary canals of the Tendaho sugarcane project.

Evaluation of discharges: The upstream head–discharge (ha–Q) relationship of Parshall flume of different sizes, as calibrated empirically, is represented by general equations as following;

$$Q = K^* h_a^u \quad (1)$$

$$Q=0.3812h_1^{1.58} \quad 1(a)$$

$$Q=0.6909h_1^{1.52} \quad 1(b)$$

Where, K=dimensional factor which is a function of the throat width. The exponent u varies between 1.522 and 1.60, Q is the modular discharge (m³/s), and h_a is the upstream gauge reading in meters. Eqn. (1a) was used for 6inch Parshall flume set at downstream of tertiary canal and eqn. 1(b) was used for 1ft Parshall flume set at upstream to estimate canal discharges.

Evaluation of field water application of furrow irrigation

The methodology used for evaluation of furrow irrigation follows Walker [3]; the measurements include furrow inflow, furrow cross-sections, advance and recession times, hydraulics roughness and infiltration. The evaluation procedure begins by defining the cross sectional area of flow at the field inlet by checking all dimensions (Figure 5).

The individual performance of over nine fields of the estate was monitored during this study. Fields were selected based on soils types, crop age, irrigation intervals and management practices. The furrow lengths were 100 m; points on each furrow length are marked with dyes or stakes at a regular interval.

Inflow measurements: Three inch Parshall flumes were placed at the upstream, middle and downstream of the field width for a three replicated irrigation events at inlet of the furrows, because furrows are close ended at downstream and there is no runoff at the outlet. Figure 6 shows number furrows taken for evaluation at upstream of

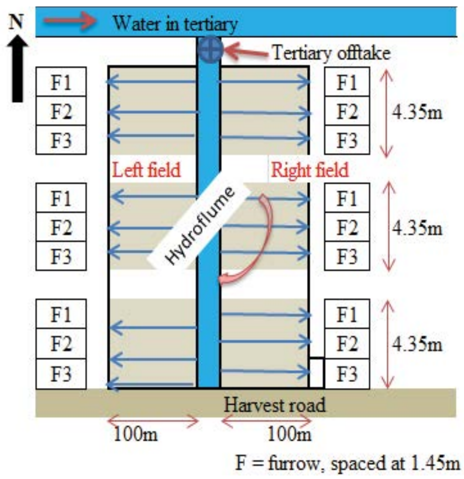


Figure 5: Layout of a sample field to evaluate field water applications of furrow irrigation.

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

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field, at middle and at downstream of the field per irrigation event and the setup points. The words left and right were used to indicate sides of irrigation using hydro flumes. Evaluation has done for three consecutive irrigation events. The replication was done to know distribution uniformity of applied water over the whole field widths. The inflow rate was maintained to be constant throughout the test. During the test, flow rates were initially measured every 2 min until the flow became stable; after stabilization when flow become uniform, intervals have increased up to 6 minutes. Generally, evaluation was done with no interference to the normal water application practice of the sugar estate.

Cut-off time: To supply the required amount of water to the full furrows with a given flow rate, a cut-off time was determined using eqn. (2) [4]. The most important effect of cut-off time is reflected on the amount of losses; deep percolation and surface run-off, and hence the efficiency as well as adequacy of irrigation. Proper combination of shape, spacing, length, slope, inflow rate and cut-off time can be achieved by improving performance of irrigation systems.

$$\text{Tco}=\left(\frac{\text{L}\times\text{S}\times\text{Zreq}}{60\times\text{Qo}\times\text{Ea}}\right) \qquad (2)$$

Where; Tco: Time of cutoff (min);

L: Furrow length (m);

S=Water surface width (m);

Zreq=Required depth of application (mm);

Q_o=Flow rate (l/s);

Ea=Application efficiency (fraction).

Determination of infiltration parameters: The infiltration characteristic of soil has been determined by ponding water in the metal double ring cylinders installed on each field at three 20 m radial distances to observe rate at which the water level is lowered in the cylinder. To determine the infiltration parameters (a, k and f_o) the Kostiakov-Lewis equation illustrated in chapter two (eqn. 2) was used. From the advance and recession times which were collected precisely at an interval of 20m to obtain best opportunity time were used to calculate soil infiltration depths (Figure 7).

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

$$Dn=\frac{(Q^{*}3600)}{(W^{*}L)} \qquad (3)$$

Figure 7: Determination of infiltration rate using double ring infiltrometer.

Where, D_n=Average depth of water application (cm) in an hour;

Q=Stream size (l/sec);

W=Furrow spacing (m);

L: Length of Furrow (m) Irrigated in an hour.

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

Determination of on-field application efficiency: It can be defined as the ratio of the volumes (depth) of water used by the plant to the volume (depth) of water applied to the field [5].

$$Ea=\frac{Var}{Vap} \qquad (4)$$

Where, Ea=Application efficiency (%);

Var=Volume of water used by the plant (m^3);

Va=Volume of water applied to a field (m^3).

After determining the depth of water actually applied into the fields using a three inches Parshal flume and the depth of the water retained in the root zone of the soil based on the soil moisture contents of the soils before and after irrigation.

Determination of storage efficiency: The water storage efficiency (Es) measures the effectiveness of the quantity of water stored in the root zone after irrigation [5] is presented here as:

$$Es=\frac{Var}{Vps} \qquad (5)$$

Where, Es=Storage Efficiency (%);

Var=Volume of water added to root zone storage (volume stored in root zone) (m^3);

Vps=Potential soil moisture storage volume (m^3).

Determination of distribution uniformity: According to Allen et al. [6], several parameters are used as indicators of the uniformity of water application to a field. The most commonly used index are: the Coefficient of Uniformity (CU) and Distribution Uniformity (DU).

Cu as the ratio of the difference between the average amount applied and the average deviation from the average amount applied to the average amount applied. It is given by:

$$Cu=100\left[1-\frac{\sum_{i=1}^{n}\left|zi-\overline{z}\right|}{N^{*}\overline{Z}}\right] \qquad (6)$$

Where: Z_i=Infiltrated amount at point i [m^3/m];

Z=Average infiltrated amount [m^3/m];

N: Number of points used in the computation of CU (%).

Distribution uniformity, DU, is a measure of how evenly water infiltrates across a field. It gives an indication of the magnitude of the uneven distribution and can be defined as the percent of average application amount in the lowest quarter of the field [7]. The lowest quarter fraction, d_{lq} (mm), has been used by the USDA since the 1940s and has proved to be useful in irrigated agriculture and is defined by the following [8]:

$$Dlq = \frac{Volume\ accumulated\ in\ 1/4\ totalarea\ of\ elementswith\ smallest\ depths}{Totalarea\ of\ 1/4\ of\ thetotalarea\ of\ elements} \quad (7)$$

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

$$DUlq = \frac{dlq}{davg} \quad (8)$$

Where, d_{lq}=Minimum infiltrate amount over the length of run (mm);

d_{avg}=Average depth of infiltrate water over the length of run of subjected area (mm).

Deep percolation: SIRMOD III manual (2001) defines deep percolation fraction as the ratio of the volume of water percolated below the bottom of the root zone as the subject area to the total volume admitted into the subject area and defined as:

$$Dp = \frac{Vdp}{Vwa} \quad (9)$$

Where,

Dp: Deep percolation ratio;

Vdp: Volume deep percolation, the infiltration depth beyond required depth (m^3);

Vwa: Volume of water added to a field (m^3).

Run-off fraction: Run-off, RO measures the relative proportion of the losses at the tribute to that of the total volume of the water delivered to the head end of the subject area [9], and formulated by:

$$RO=1-Ea-Dp \quad (10)$$

Where, RO: Run-off fraction;

Ea=Application efficiency;

Dp: Deep percolation ratio.

Determination of critical flow rate: The inflow rate (stream size) should be non-scouring (non-erosive amount) and shall give uniform and efficient irrigation. However, in block ended furrows inflow rate should be large enough to advance to the end is not greater than 1.5 times the flow capacity of the furrow, nor result in excessive erosion [10]. The maximum non-erosive flow rate, Q_{max} can be estimated by empirical relationship:

$$Q_{max} = 0.63 / S_o \quad (11)$$

Where, Q_{max}=Maximum non-erosive stream (l/sec);

S_o=Slope of furrow in direction of flow (m/m).

Materials used

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

Results and Discussions

Design condition of Tendaho irrigation systems

Parameters used for field evaluations

Furrow dimensions: Measurements of the top, middle and bottom widths and the depths of furrows were collected during field works. However, the furrow dimensions set during land preparation was: top width 60 cm, maximum depth 30 cm, middle width 40 cm, and bottom width 20 cm, with spacing of 1.45 m and slopes of 0.05% (Table 1). From Table 2, the current condition of furrow was not similar as designed dimensions. These irregularities were main points for having low irrigation efficiencies at the sugar estate.

Inflow rate–cutoff time: The existing inflow rate and cut-off data of cultural practice of the state cane farm was collected as presented in Table 3. The mean values of inflow rate vary in between 2.74 and 3.5 l/sec. These values were very low compared to expected designed discharge of 5 l/sec. The water leaks over all parts of the gated pipes body and outlets, reducing discharge. From the field observations, the main causes of the discharge variations are land levelling problems, low bed of hydrof lumes are not higher enough than level of furrow elevations so that they can discharge out a water with enough head, and poor skills of field irrigators. In this sugar estate the interconnection of furrow by cutting ridges at several intervals is very common [11]. They were making this, because there is land levelling problems, the furrows slope are not facilitating downstream flow and the water can't reach the downstream end of all furrows at uniform time. So, to make thing simple operators made this choice. But, this is causing a flow in a given furrow is not to going in the same furrow rather it mixed in middles or mixed by back flow (after reaching furrow end) to other furrow and speed up the advance time or can make not to get exact time in case of back flow of water coming back from other furrow overflow.

Soil moisture deficit: Soil moisture deficit (SMD) was estimated using gravimetric method for each irrigation events and cross-checked with calculated MAD values as shown in Table 4, which shows there is a variation in SMD during irrigation even within the same soil type

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

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

Table 1: The designed peak duty for different components of Canal System, Tendaho.

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

Table 2: Furrow dimensions of selected fields.

No	Fields codes	Replications	Inflow rate Q, (l/sec)	Mean Q, (l/sec)	Cut-off time, t_{co} (minutes)	Mean t_{co}, (minutes)
1	FC1143 (Silty clay soil)	Rp1	3.20	2.85	70	60.46
		Rp2	2.65		50	
		Rp3	2.70		61	
2	FC1153 (Silty clay soil)	Rp1	3.30	3.38	78	68.70
		Rp2	3.10		69	
		Rp3	3.74		59	
3	FC2326 (Silty clay soil)	Rp1	3.60	3.40	68	65.88
		Rp2	2.70		59	
		Rp3	3.90		70	
4	FC2332 (Silty clay soil)	Rp1	3.10	2.78	79	74.25
		Rp2	2.99		67	
		Rp3	2.25		76	
5	FC2414 (Silty clay loam)	Rp1	2.85	2.74	70	67.90
		Rp2	3.10		57	
		Rp3	2.27		77	
6	FC2423 (Silty clay loam)	Rp1	2.76	3.01	61	70.00
		Rp2	2.88		75	
		Rp3	3.39		73	
7	FC2441 (Silty clay loam)	Rp1	3.12	3.41	67	78.00
		Rp2	3.02		85	
		Rp3	4.09		82	
8	FC2913 (Silty clay loam)	Rp1	3.33	3.53	70	58.32
		Rp2	3.72		61	
		Rp3	3.54		44	
9	FC2-12-24 (Silty clay loam)	Rp1	3.51	3.23	57.22	65.67
		Rp2	2.89		69	
		Rp3	3.29		70	
	Mean		3.14	3.15	67.69	67.69
	Std. dev, %		0.46	0.31	9.68	6.16
	Coef. Var, %		14.49	9.72	14.30	9.09
	Standard errors		0.09	0.10	1.85	2.05

Table 3: Average on field measured inflow rate and cut off times.

Field No.	Soil type	Fc, %	Soil Parameters			Bd, g/cc	SMD, mm	MAD, mm
			PWP, %	AW, mm	Øi,%wt			
FC1143	SIC	38	20	54.00	22	1.33	62.39	24.38
FC1153	SIC	39	21	52.50	28	1.44	44.92	24.38
FC2326	SIC	38	21	49.50	34	1.38	15.01	24.38
FC2332	SIC	37	23	42.00	32	1.37	18.13	24.38
FC2414	SICL	41	22	57.00	29	1.43	51.52	25.50
FC2423	SICL	39	22	51.00	33	1.37	24.70	25.50
FC2441	SICL	39	21	54.00	26	1.40	55.27	25.50
FC2913	SICL	39	22	49.50	24	1.31	58.34	25.50
FC2/12/24	SICL	38	21	49.50	28	1.44	40.07	25.50

Fc: Field capacity (%); PWP: Permanent Wilting Points (%); AM: Available Moisture (mm); Wi=Initial soil moisture before irrigation (%); Bd=Soil bulk density (g/cc); SMD: Soil Moisture Deficit (mm); MAD: Manageable Allowable Depletion (mm).

Table 4: Soil moisture deficit and Management allowable depletion at top 30 cm soil depth.

indicating that variation in irrigation timings and amount of water application within the same soils.

Advance and recession times: The advance front's movement down the supply furrow is presented graphically in Figure 8. It took a mean of 46.01 minutes for the front to reach the end point at the last bed where the irrigation to commence. From Figure 8, the infiltration opportunity time is not fairly uniform which may relate to a problem of uneven slope along furrow length, low stream size and normal flow interruption of irrigators. The Figure also indicates there was longer recession time indicating higher opportunity time. This condition may result in ground water table rise beyond its permissible limit which can cause waterlogging problems. To prevent these problems, it is better to plan irrigation scheme in such a way that the land is prevented from getting waterlogged.

Evaluation of tertiary canals conveyance efficiency

The following problems were noticed before and during the actual evaluation activities have started.

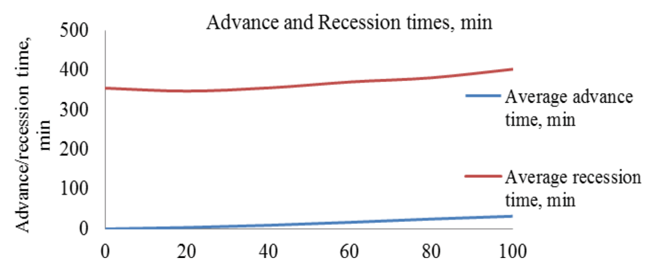

Figure 8: Flow rate at tertiary canal inflow and outflow hydrographs.

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

Table 5: Tertiary Canal Dimensions of representative tertiaries.

- The physical conditions: structures of some tertiary canals were not in the shape of their designed conditions. Side walls have eroded (widen widths), plants/grasses has grown inside the canals which can reduce the flow velocity, conveyance efficiency, irrigation speeds.
- Seepage through canal side walls along the canal length and Leakage from off-take points, which were more difficult to measure it are predominantly feasible in the area.
- The operational losses have observed.
- Dead storages were formed at different points inside the canals along the length of the canal which facilitates irrigation water loss via evaporation and deep percolation.
- Overtopping due to excess water released to canal or low embankments elevation. This would damage to fields and harvest roads [12].

Tertiary canal dimensions and canal flow hydrograph: On field collected data of the tertiary canal dimensions were presented in Table 5. From this table, the design dimensions and the actual practicing dimension were not similar. This might be due to not taking preventive care not to damage canal shapes and no routine maintenances, overtopping of water, effect of wild animals (mainly boars). The deviation between top widths or bottom widths were might occurred as result of unsafe canal cleaning, canal erosions due to repeated excess water flow above free board level, overtopping at some canal banks. A canal depth varying due to siltation resulted from canals side erosion and sediment particles brought to canals with irrigation water.

The mean canal flow hydrograph in selected tertiary canal has plotted against time elapsed as shown on Figure 9. From this Figure, it can be observed that the amount of irrigation water losing in the canal throughout operation was higher. Seepage losses along the canal length and leakages at canal reaches are the dominant losses in these tertiary canals. The normal carrying capacity of tertiary canal was 100 l/sec. However, there was a time at which the flow is above the mentioned carrying capacity, resulting in overtopping (Figure 9).

Generally, in both upstream inlet and downstream reach, the flow doesn't become zero as shown above. But the flow velocity becomes zero after some hours and water ponding starts in canals owing some depth which can be lost as deep percolation and evaporation.

Conveyance efficiency of selected canals: The overall mean tertiary canal conveyance efficiency was found as 59.6%. During evaluation each canals were showing different conveyance efficiencies [13]. This was due to some management activities and might be due to leakage in intakes/turnouts, overtopping due to low embankments, leakage through cracks of lined canal reach, seepage through porous canal reach, and increased efficiency as a result of canals maintenances and cleaned vegetated grasses and regulated water supply from operators.

It was observed that water was leaking from where the lined canals were broken, the flow in the canal network was not uniform, canals were heavily vegetated, water flows over the banks of the canals.

Finally, there observed a water diverted from secondary canal to tertiary canals with mean loss of 40.41% per 400m length of tertiary canals before water was reaching the farm gate. This amount of losses (deep percolation and seepage from canals) would make drainage necessary to maintain soil productivity. Canals and irrigated lands require adequate drainage to maintain capable of producing crops. Therefore, adequate drainage of fertile lands requires the lowering of shallow water table (Table 6).

Performance evaluation of field water application of furrow irrigation

Evaluations based on target application depths: Performance prediction by this approach provides comparable performance of irrigations over seasons. The evaluation has done for three consecutive replications irrigation events to measure: Ea, Es, DPR, Du and Cu (Table 7).

Application efficiency: From the results obtained in Table 8, the

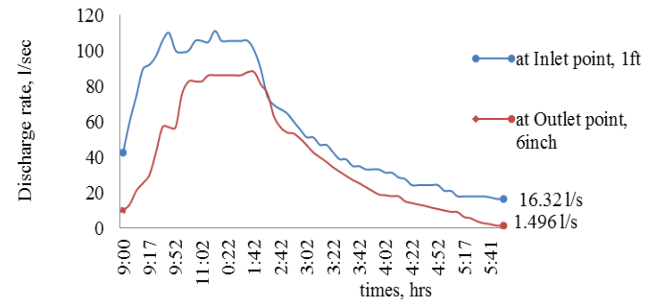

Figure 9: Flow rate at tertiary canal inflow and outflow hydrographs.

S. No	Tertiary canal code	Replications	Volume of water diverted from the source, m^3	Total volume delivered to farm, m^3	Total volume of water lost, m^3	Conveyance efficiency, %
1		Rp1	4459.06	2980.47	1478.59	66.84
	TC 233	Rp2	5342.75	3124.16	2218.60	58.47
		Rp3	4638.56	2432.67	2205.89	52.44
	Mean		4813.46	2845.77	1967.69	59.25
2	TC 291	Rp1	6585.04	3334.96	3250.09	50.64
		Rp2	6464.25	3545.25	2918.99	54.84
		Rp3	6945.65	3245.54	3700.11	46.73
	Mean		6664.98	3375.25	3289.73	50.74
3	TC 112	Rp1	4251.44	2626.78	1624.65	61.79
		Rp2	4012.33	2599.90	1412.44	64.80
		Rp3	4345.35	2745.64	1599.71	63.19
	Mean		4203.04	2657.44	1545.60	63.26
4	TC 243	Rp1	6440.36	4241.99	2198.37	65.87
		Rp2	5601.25	3441.35	2159.91	61.44
		Rp3	5789.58	3956.24	1833.33	68.33
	Mean		5943.73	3879.86	2063.87	65.21
5	TC 212	Rp1	6443.84	3857.98	2585.86	59.87
		Rp2	6312.41	3479.84	2832.57	55.13
		Rp3	6617.28	3899.15	2718.14	58.92
	Mean		6457.85	3745.66	2712.19	57.97
6	TC 2 11 2	Rp1	7159.40	4476.93	2682.47	62.53
		Rp2	6443.55	3641.34	2802.21	56.51
		Rp3	5978.99	3477.81	2501.18	58.17
Mean			6527.31	3865.36	2661.95	59.07
Mean of mean			5768.39	3394.89	2373.50	59.25
St. dev			1014.80	574.57	632.47	5.82
CV, %			17.59	16.92	26.65	9.82
St. errors			239.20	135.40	149.00	1.37

Table 6: Performance evaluation of tertiary conveyance efficiency for 400 m canal length.

Soil type	FC, %	PWP, %	ρ, depletion factor	Root depth, m	Zreq mm
SIC	37.63	21.13	0.60	1.0	99.00
SICL	39.00	21.60	0.60	1.0	104.40

Table 7: Calculated target application depths (perceived application depth).

overall mean application efficiency was 56.57% for which it varies in between 40.28% to 76.91%. The variation between consecutive irrigation events were happened because of variations in inflow rate and cut-off times (generally called decision variables) and a field parameters mainly soil infiltration characteristics, flow resistance, required depth of irrigation, and soil moisture depletion prior to irrigation [13]. When the application efficiency of the two soils were compared to each other, the application efficiency of the first four fields (silty clay) was better than the rest silty clay loam soil fields with an overall mean of 57.04 and 46.83% respectively.

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

On-field storage efficiency: From Table 8, the overall mean storage efficiency of evaluation result was 70.30% with a coefficient of variation of 3.95%. From results, under current water application practice, almost in whole part of the field water storage looks similar ranging in between 65 to 71%. Finally, variation in storage efficiency across irrigation events significantly correlated to the distribution uniformity and uniformity coefficients along the length of the furrow. Mainly depends on infiltration characteristics and also correlated to the higher deep percolation loss in the fields beyond the crop root zone.

Distribution uniformity: From evaluation, the replications mean distribution uniformity of the field was 91.93%; coefficient of variation is 3.95% obtained. Higher distribution uniformity was a result of having higher opportunity time due to ponded water rather than due to having good land levelling and good advanced water flows. The distribution uniformity depends on the applied depth through the couple of inflow rate and time for cut-off. The variation in distribution uniformity among each replications and different fields was a result of variation in cut-off time across irrigation events [14]. Blocking furrows would increase the opportunity time at the bottom of a furrow. However, blocking may or may not increase distribution uniformity depending on the increase in opportunity time.

Coefficient of uniformity (Cu): The mean uniformity coefficient was 95.20%, with coefficient of variation 2.20 %. Variation of coefficient of uniformity across the monitored fields significantly related with distribution uniformity and storage efficiency. From Table 8, the mean values of each replication may increase or decrease by standard error value as shown in table below. Similarly, the deviations of events from

Fields	Replication	Q (l/sec)	On-field Performance indicators, %					Ad(mm)
			Ea	DPR	Du	Cu	Es	
FC1143	Rep1	2.36	76.9	23.1	89.2	92.9	81.2	60.1
	Rep2	3.24	75.3	24.7	89.2	93.6	80.2	58.9
	Rep3	2.95	63.2	36.8	83.9	96.7	73.1	65.4
	Mean	2.85	71.8	28.2	87.5	94.4	78.2	61.5
FC1153	Rep1	3.38	48.8	51.2	94.5	98.0	66.2	102.1
	Rep2	3.05	49.0	51.0	91.2	95.3	66.2	81.5
	Rep3	3.46	52.4	47.6	96.0	98.7	67.7	79.0
	Mean	3.30	50.1	49.9	93.9	97.3	66.7	87.5
FC2326	Rep1	3.40	48.7	51.3	83.5	94.8	66.1	86.7
	Rep2	2.88	55.0	45.0	91.4	95.2	69.0	63.7
	Rep3	3.24	57.0	43.0	96.7	86.4	69.9	85.1
	Mean	3.17	53.6	46.4	90.5	92.1	68.3	78.5
FC2332	Rep1	2.54	45.1	54.9	91.3	93.3	64.6	83.0
	Rep2	3.00	55.0	45.0	89.2	91.4	69.0	72.7
	Rep3	2.80	58.0	42.0	85.6	96.7	70.4	80.8
	Mean	2.78	52.7	47.3	88.7	93.8	67.9	78.8
FC2414	Rep1	2.83	59.8	40.2	88.3	94.9	71.3	80.8
	Rep2	2.50	72.0	28.0	89.1	90.8	78.1	60.5
	Rep3	2.89	69.0	31.0	84.1	93.2	76.3	79.4
	Mean	2.74	66.9	33.1	87.2	93.0	75.1	73.6
FC2423	Rep1	2.93	50.7	49.3	98.1	98.3	67.0	67.9
	Rep2	3.15	60.0	40.0	97.8	98.6	71.4	89.7
	Rep3	2.95	58.0	42.0	94.5	96.8	70.4	81.8
	Mean	3.01	56.2	43.8	96.8	97.9	69.6	79.8
FC2441	Rep1	2.96	44.4	55.7	90.6	93.8	64.3	72.6
	Rep2	2.95	57.5	42.5	93.8	95.2	70.2	91.7
	Rep3	3.12	55.4	44.7	95.8	94.6	69.1	93.6
	Mean	3.01	52.4	47.6	93.4	94.6	67.8	86.0
FC2913	Rep1	3.34	57.4	42.6	94.2	94.8	70.1	85.0
	Rep2	3.80	63.5	36.5	98.1	97.2	73.3	84.3
	Rep3	3.45	59.4	40.6	96.8	99.4	71.1	55.2
	Mean	3.53	60.1	39.9	96.4	97.1	71.5	74.8
FC21224	Rep1	3.35	40.3	59.7	94.6	96.6	62.6	82.2
	Rep2	3.78	44.4	55.7	90.5	96.7	64.3	111.8
	Rep3	3.46	51.2	48.8	94.1	96.7	67.2	103.8
Mean		3.53	45.3	54.7	93.1	96.7	64.6	99.2
Mean of means		3.10	56.57	56.6	43.4	91.9	95.2	70.3
Standard deviations		0.30	8.39	8.4	8.4	3.6	2.1	4.3
CV, %		9.70	14.84	14.8	19.3	4.0	2.2	6.2
Standard errors		0.06	1.80	1.8	1.8	0.9	0.5	0.9

Table 8: Mean Performance evaluations of field water applications at target application depth.

Fields code	Q (l/sec)	Obtained constant	Required max value of a constant	Slope, %
FC1143	2.85	0.14		
FC1153	3.38	0.17		
FC2326	3.40	0.17		
FC2332	2.78	0.14	0.63	0.05
FC2414	2.74	0.14		
FC2423	3.01	0.15		
FC2441	3.01	0.15		
FC2913	3.53	0.18		
FC21224	3.53	0.18		
Mean	3.14	0.16		
St. dev	0.32	0.02		
CV, %	10.31	10.31		

Table 9: Evaluation of critical flow rate.

Fields	Replication	Q(l/sec)	On-field Performance indicators, %					Ad(mm)
			Ea	Dp	Du	Cu	Es	
FC1143	Rep1	2.36	78.9	21.0	89.2	92.9	82.5	60.1
	Rep2	3.24	75.3	24.6	89.2	93.6	80.2	58.9
	Rep3	2.95	73.2	26.7	83.8	96.6	78.8	65.4
	Mean	2.85	75.8	24.1	87.4	94.4	80.5	61.4
FC1153	Rep1	3.38	58.8	41.1	94.4	97.9	70.8	102.0
	Rep2	3.05	56.9	43.0	91.2	95.2	69.9	81.4
	Rep3	3.46	60.3	39.6	96.0	98.6	71.6	79.0
	Mean	3.30	58.7	41.2	93.9	97.2	70.7	87.5
FC2326	Rep1	3.40	52.7	47.2	83.4	94.7	67.8	86.7
	Rep2	2.88	59.5	40.4	91.4	95.2	71.2	63.72
	Rep3	3.24	60.4	39.5	96.7	86.3	71.6	85.0
	Mean	3.17	57.5	42.4	90.5	92.1	70.2	78.4
FC2332	Rep1	2.54	50.0	49.9	91.2	93.3	66.7	83.0
	Rep2	3.00	61.6	38.3	89.2	91.3	72.2	72.6
	Rep3	2.80	57.3	42.6	85.5	96.7	70.1	80.8
	Mean	2.78	56.3	43.6	88.7	93.8	69.6	78.8
FC2414	Rep1	2.83	67.2	32.7	88.3	94.9	75.3	80.8
	Rep2	2.50	70.3	29.6	89.1	90.7	77.1	60.5
	Rep3	2.89	72.4	27.5	84.1	93.2	78.4	79.3
	Mean	2.74	70.0	30.0	87.1	92.9	76.9	73.5
FC2423	Rep1	2.93	56.3	43.6	98.0	98.2	69.6	67.8
	Rep2	3.15	63.4	36.5	97.8	98.6	73.2	89.7
	Rep3	2.95	58.4	41.5	94.5	96.7	70.6	81.7
	Mean	3.01	59.4	40.5	96.7	97.8	71.1	79.7
FC2441	Rep1	2.96	54.3	45.6	90.5	93.8	68.6	72.5
	Rep2	2.95	65.4	34.5	93.7	95.2	74.3	91.7
	Rep3	3.12	68.3	31.6	95.8	94.6	75.9	93.6
	Mean	3.01	62.7	37.2	93.3	94.5	72.9	85.9
FC2913	Rep1	3.34	65.4	34.5	94.1	94.8	74.3	85.0
	Rep2	3.80	68.5	31.5	98.1	97.2	76.0	84.2
	Rep3	3.45	64.4	35.6	96.7	99.3	73.7	55.2
	Mean	3.53	66.1	33.8	96.3	97.1	74.7	74.8
FC21224	Rep1	3.35	53.2	46.7	94.6	96.5	68.1	82.1
	Rep2	3.78	62.3	37.6	90.5	96.7	72.6	111.7
	Rep3	3.46	57.2	42.7	94.1	96.6	70.0	103.8
	Mean	3.53		42.3	93.0	96.6	70.2	99.2
Mean of means		3.1	62.7	37.3	91.9	95.2	73.0	79.9
Standard deviations		0.30	6.6	3.6	3.6	3.7	5.1	10.5
CV, %		9.71	10.6	3.9	3.9	5.1	7.2	13.1
Standard errors		0.103	2.2	2.2	1.2	0.7	1.2	3.5

Table 10: Performance evaluations of field water applications at SMD.

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

Table 11: Mean performance at target application depth and SMD.

each other were described by standard deviation as shown above.

Determination of critical flow rate: The critical flow rate of each flow rate during all replication has showed lower results of critical flow which safe against cause erosion. The mean values critical flow has calculated as tabulated below at the existing slope of 0.05% (Table 9) [15].

Evaluations based on SMD of irrigation scheduling

The effect of irrigation scheduling on Z_{req} and infiltration behaviour of soils was considered under this section. Thus, the effect of irrigation scheduling on field application performance has computed considering SMD as Z_{req}. This done because the SMD before the irrigation events are different from calculated target application depth. But, this type evaluation may cause mistake on some performance indicators like application efficiencies which would be very high when soil is very dry and lower when irrigation is earlier (soil is still wet). However, it is possible to observe the relation between irrigation scheduling and field water application performances in this methodology.

Computing the performance parameters values which were obtained in the Tables 8 and 10, the results are tabulated in Table 11 as below. That irrigation scheduling affects all parameters of field water application.

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

Conclusions and Recommendation

Conclusions

The evaluation of Tendaho irrigation systems was of extreme importance. The result of tertiary canals evaluation showed mean conveyance efficiency of 59% over 400 m canals length. In this sugar estate, the extra leakages of water through the tertiary canals were due to eroded mortar, cracks and structural failure of the lined banks. In addition, the capacity of tertiary canal is also reduced due to silting, overtopping of flows at many sites [16].

From the field water application of furrow irrigation system, the on-field mean application efficiency of the estate farm indicated as 56%, storage efficiency of 70%, and distribution uniformity of 94%. These results have shown the level of field irrigation performances of furrow system that requires improvements. Irrigating the fields considering Soil Moisture Deficit resulted in higher application efficiency has obtained than considering target application depth. This happened because soils were dry enough to intake the applied amount of the late applied irrigation water in Soil Moisture Deficit cases.

Recommendations

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

1. To maintain irrigation system as efficient hydroflumes should checked at intervals and minor repairs should be carried out before major works required.
2. Collaborate with stakeholder; particularly with universities to overcome problems of irrigation and drainage system and to bring back them to their designed function.
3. Provide maintenance works for canals, fields and hydroflumes devices.
4. Rehabilitate tertiary off-take gates to reduce leakage, and release of unwanted water and to prevent accidental water not to enter farm and cause damage if gate is open.
5. Extensive land levelling and furrow making process have to done with care.
6. Improve water application; give attention to inflow rate and cutoff time over-irrigate or under irrigate the fields - flooding has to be improved.
7. Though there were lines of surface drainage system in the estate farms, they are not functioning; rehabilitate the existing drainage networks and construct additional cross drainage structures based on the recent conditions of the cane fields.

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