Irrigation & Drainage Systems Engineering

Research Article Open Access

Determining the Optimum Decision Variables and Rescheduling the Irrigation System of Tendaho Sugar Estate, Ethiopia

Tadesse Gobena Shonka[1] and Guchie Gullie[2]*

[1]Ethiopian Sugar Corporation, Wonji Research and Development Centre, Ethiopia
[2]Department of Water Resources and Irrigation Engineering, Arba Minch University, Ethiopia

Abstract

Irrigation scheduling, flow rate and cut-off time are the three field irrigation variables currently affecting irrigation performance of Tendaho Sugar estate (Northeast of Ethiopia). As result, the study was initiated with the objective of improving existing irrigation scheduling and determining significant decision variables (flow rate and cut-off time). The long year's climatic data were collected and analyzed by CROPWAT8.0 software to calculation of the right amount of water needed for the irrigation of crop fields, and soil samples were collected from representative cane fields to analyze soil characteristics. Parshall flumes were used to measure inflow rates at each field. The results of irrigation scheduling have showed slighter irrigation intervals than existing intervals. Therefore, to improvement of irrigation scheduling have proposed based on soil, crop ages and climatic casus of the area. Besides, the inflow rate and cut-off time of two major soils of study area were proposed to be 5 liters per second and 45 minute for 100 meter length of furrows as best decision variables of the sugar estate. Finally, the author trusts the right combination of these critical variables will help the sugar estate to overcome its existing irrigation problems, and result in better field water application and field conditions.

Keywords: Decision variables; Irrigation scheduling; Inflow rate; Cut-off time; Sugarcane

Introduction

Shortage of water has becoming a major concern through all countries. This scarcity is not only the result of unwise management, but also a demand of water for other segments and the need to protect the resource itself. Irrigation is one of a vast category that highly consumes this scarce resource (nearly 37% US global water use, 2010). Therefore, efficient and uniform irrigation practice is a healthier choice. Better irrigation water management involves decision regarding how much and when to irrigate. According to United States Department of Agriculture [1] definition, irrigation water management (IWM) is the act of timing and regulating irrigation water application in a way that will satisfy the water requirement of the crop without wasting water, soil, and plant nutrients and degrading the soil resource.

According to Pereira et al. [2] irrigation scheduling affects field application performance. The importance of proper irrigation scheduling is beyond optimal cane productivity; it saves water, energy, labor costs, and ensures sustainable agriculture by preventing and mitigating long-term impacts of improper water applications in scheme. Therefore, determining when and how much irrigation water to apply is significant part of the irrigation management. However, crop water requirement or crop evapotranspiration (ETc) is not easily determined. Nevertheless, many methods were developed to estimate the rate of ETc based on climatic factors. Studies have shown that the Penman-Monteith method is more reliable for any length period than methods that use less climatic data [3]. Besides the accuracy and reliability, the advantage of this method is allied to the fact that inexpensive, requiring only meteorological data to estimate reference evapotranspiration (ETo) which is then multiplied by a crop coefficient (Kc) to represent the relative rate of ETc under a specific condition [4].

Tendaho sugar estate is located at Northeast of Ethiopia in Afar Regional State. To supply water continuously to cane farming and make irrigable land, a dam (Tendaho Dam) with a capacity of holding 1.8 Billion cubic liters of water diverted from Awash River with a main canal discharge of 78,000 cubic metre per second to irrigate 50,000 hectare land [5].

The sugar estate is running surface irrigation system of furrow irrigation method for sugarcane plantation. The normal irrigation scheduling of the sugar state ranges from 7 to 30 day for cane age of zero to greater than 12 months. Until recently fixed irrigation interval of 8 days was being using; and there was some beginning of soil moisture monitoring through feel method.

In this estate, mainly due to irrigation scheduling, inflow rate and cut-off time the field irrigation application is showing unwise use of water resource. Most of the farm fields are nearly flooded where others irrigated insufficiently. These combined problems were causing inefficient irrigation water use, yield reduction, and the excess use of irrigation water is favoring the rise of ground water table and formation of salinization in the sugar estate. The Piezometers inspection were showing the level of ground water table is around the root depths and the soil above this level was wet; that's why rescheduling was proposed to be reconsidered. Therefore, this study has done having the following broad objectives:

1. To improve the existing irrigation scheduling of the sugar estate.

2. Determining optimum decision variables (inflow rate and cut-off time).

Materials and Methods

Description of the study area

The study was conducted at Tendaho Sugar estate which is located between latitude 11°30" to 11°50"N, and Longitude 40°45" to 41°03"E. The altitude of the area ranges from 340 to 365 m.a.s.l. The mean

***Corresponding author:** Guchie Gullie, Department of Water Resources and Irrigation Engineering, Arba Minch University, Ethiopia, Tel: +251 46 881 4986; E-mail: guchie4@yahoo.com

Received November 12, 2017; **Accepted** December 16, 2017; **Published** December 28, 2017

Citation: Tadesse Gobena Shonka (2017) Determining the Optimum Decision Variables and Rescheduling the Irrigation System of Tendaho Sugar Estate, Ethiopia. Irrigat Drainage Sys Eng 6: 200. doi: 10.4172/2168-9768.1000200

maximum monthly temperature varies between 32.9°C to 43.2°C and the mean minimum varies 18.3°C to 27.1°C. The annual rainfall is about 184.1 mm. The mean monthly relative humidity varies 33.7 to 57.4%. The wind speed at 2m height 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).

According to FAO classification, the soil of the study area has categorized shown in Appendix 2. There are three major soil-mapping units in Sugar estate. From these, the soil type of area under the study lies on lacustrine sediments, which covers 9,367-hectares of the sugar estate farmland.

Methodologies

Information regarding climatic and crop characteristics has collected from secondary sources and soil characteristics were determined by collecting representative soil samples from each soil groups. The long year's climatic data (16 years) were collected from Tendaho metrological station and analyzed by compute reference CROPWAT8.0 software. Information for some important crop characteristics (growth stages, crop co-efficients) were used from literatures, as they are not yet determined for local this condition. For water balance analysis, the elements of Water balance was estimated using standards equations, empirical formula and consideration of inflow and out flows to root zone in the particular study area. More particularly, ETo were estimated using FAO Penman Monteith method. Effective rainfall was estimated using United States Soil Conservation Society (USSCS) method, and water-holding capacities were estimated using standard equations. Irrigations water application strategy of refilling depletion at 55 to 65% total soil moisture depletion has considered. Predetermined irrigation schedule for furrow irrigation was determined, it is an irrigation schedule resolved before the actual season-based on crop characteristics, soil properties and historical climatic and hydrological conditions. After all the inflow and outflow element of water balance were estimated, net irrigation requirement was proposed using water balance equation and the irrigation schedules and other parameters were estimated using the following equations.

Irrigation interval: $I = \frac{(TAW^{*}\rho^{*}Dr)}{NR} = \frac{RAW}{NIR}$

Where, I=Irrigation interval (days);

TAW-Total water holding capacity per meter (mm/m);

ρ–Allowable depletion (decimal);

Dr=Effective root zone depth (mm);

NIR=Net irrigation requirement (mm/day);

RAW=Readily available water (mm).

Infiltration parameters: The infiltration characteristic of soil has determined by pooling water in the metal double ring cylinders installed on each field at three 20 metre radial position to observe a rate at which the water level is socking into the soil. To determine the infiltration parameters (a, k and f_o) the Kostiakov-Lewis equation:

$$Z = K\tau^{B} + f_0\tau$$

$$a = \frac{In[(Z_1 - fo^{*}t_1)/(Z_2 - fo^{*}t_2)]}{In\left(t_1/t_2\right)} \quad k = \frac{(Z_2 - fo^{*}t_2)}{t_2^{a}}$$

Where, Z1=Initial infiltrated water depth (mm);

Z2=Average infiltrated water depth (mm);

k=Intake constant (mm/mina);

a=Intake power (-);

fo=Final intake rate (mm/min);

τ=The design intake opportunity time (minutes);

t1=Corresponding time (minutes) to the infiltrate Z1;

t2=Intake opportunity time (minutes).

Required depth of water application: The required depth of application (Dn) was estimated from field measurements of the soil water content before irrigation in the root zone. The average depth of water application was computed by the equation:

$D_n = \rho^{*}TAW^{*}Dr$

Where, Dn=Net depth of application (mm);

ρ=Allowable depletion (fraction);

Dr-Depth of root (m);

TAW-Total water holding capacity per meter (mm/m).

Rainfall management: Effective rainfall would analyze using United States Soil Conservation Service method FAO recommended the following formula to estimate effective dependable rainfall. Pe=0.8P-24, for P>70 mm/month where Pe=dependable effective rainfall, Pe=0.6P-10, for P<70 mm/month where Pe=monthly mean rainfall.

Soil Moisture Deficit, SMD was estimate by gravimetric method for each irrigation events and compared with the calculated MAD values.

$$SMD = \sum_{i}^{n}\left(\frac{WFci - Wi}{100}\right)^{*} Asi^{*}Dri$$

Where, SMD-Soil moisture deficit (mm);

Wfci=Moisture content at field capacity (%);

Wi=Moisture content before irrigation (%);

Dri=Depth of the soil layer within root zone (mm);

Asi-Apparent specific gravity of that soil layer (ratio of bulk density to water density) (decimal).

Readily available water (RAW) for plant use in the root zone was computed as the difference in moisture content between field capacity and critical water content (cri) given by James [6].

$$RAW = \sum_{i}^{n}(0fci - 0cri)^{*} Asi^{*}Dri$$

Where, RAW-Readily available water (mm);

Fci=Moisture content at field capacity at i^{th} layer of soil (%);

Cri=moisture content at critical point (lower moisture level for full irrigation) in i^{th} layer of soil (%);

As it is apparent specific gravity of that soil layer (decimal) Driis depth of the soil layer within root zone (mm) (Appendix 3).

Evaluation of inflow rate and cut-off time: Four fields (two from SIC and two from SICL) have been selected for evaluation of inflow rate and cut-off time evaluations. The evaluation was done with aim of checking that inflow rate and cut-off time now in practice is needs modifications. The field variables have been taken as it is whereas

decision variables, inflow rate of different rate are used to examine the cut-off time. Furrows of 100-meter lengths were used. Advance and recession times were recorded at different time intervals and to determine the amount of water applied during each irrigation events, heights of water passing through 3-inch Parshall flume together with starting and ending time of irrigation were recorded at inlet of three furrows (block ended furrows). Finally, after three replications irrigation events, the inflow rate and cut-off time were estimated.

Data analysis

Composite of undisturbed soil samples at two soil depths, 0-30 and 30-60 cm were taken from five spots for each field. The collected undisturbed soil samples were analyzed at WWDSE Laboratory (Addis Ababa) for field capacity (Fc), bulk density and permanent wilting point (PWP) determinations. The percentage of sand, silt and clay of the composite soil sample were determined by sieve analysis (sand and silt) and hydrometer method (clay). After the percentage of sand, silt, and clay was graded, finally the soil textural class was assigned using the USDA textural triangle. Soil bulk density was determined using the methodology described in Walker (1989). Using core samplers of known volume and the samples weighted and placed in Oven Dry at 105°C for 24 h.

Materials used

The materials which were used in this work were: Augers, Core samplers, Graduated buckets, Shovels, Stopwatch, Measuring tapes, Pegs, Oven Dry, Plastic bags, Weight Balance, Meters, Rulers, Double Ring Infiltrometer and Hammer. CROPWAT8.0 software, ArcGIS9.3, and Microsoft spread sheets and Microsoft excels optimizer.

Results and Discussions

Evaluation of inflow rate and cut-off time

Consideration of both management and field variables were done to evaluate these two critical decision variables of the sugar estate. For the study the following adjusting data were used for the existing 100 m length of the furrow: a) inflow rate was adjusted to be 5 l/sec, b) the target depth of application (Table 1) were used, c) infiltration parameters of two major soils (Table 2), d) furrow lay out is similar to the existing practice (100 m length and with 0.05% slope), e) furrow dimensions of 0.6 metre top width, 0.4 metre at middle width, 0.3 metre maximum depth, and 0.2 metre bottom width is used (furrow design dimensions used by the sugar estate).

After three replicated evaluations of four commercial fields, the results of optimum inflow rate and cut-off times of these events were presented in Table 3 as shown below. Though these parameters requires other simulation software, the results of field management leaded to decide analytic corrections which were showed a better performance parameters for the existing furrow length, with uniform inflow rate. In both soil types, better performance has obtained at target application depth and existing infiltration rates. That is the inflow rate showed better application efficiency, better distribution uniformity over the existing furrow length (Table 4). By improving the irrigation practices, a better water saving would achieved in both soil types under different irrigation event.

Optimizing irrigation scheduling and management

Reference evapotranspiration: The reference evapotranspiration for the months of the year was calculated using CROPWAT8.0 is tabulated as Table 5 below.

Crop coefficient/crop factor: According to Robertson et al. [7] the crop coefficient (Kc) value of sugarcane during initial growth stage was found around 0.5 and then gradually increased during vegetative phase. Growth stage of sugarcane can be classified to four stages [8] (Table 6).

In addition to these above mentioned Kc values, for irrigation scheduling, rooting depth data corresponding to cropping stages were obtained from previous survey data made at Metahara sugar estate (Ethiopia) by Dilsebo [9] and Mulugeta [10]; relatively because the same cane varieties grown and cane management practices done in Ethiopian sugar estates, and in this study the same root depths were used given in Table 7.

Tate [11] recommended, considering top 60 cm as an effective rooting depth was appropriate to estimate soil moisture deficit for irrigation timing of sugarcane. This was to protect the crop from moistures stress in its effective root area.

Crop water requirement: From Table 8, the crop evapotranspiration of cane varies with crop development stages and cropping seasons. Initially, the crop water requirement was lower and gradually increases and higher in third growth stage which would decrease after fourth growth stages [12].

Effective rainfall: Feeding the rainfall data in CROPWAT8.0, the effective rainfall was estimated as shown below. Table 9 Monthly effective rainfalls of the area.

Readily available water: Readily available water in root zone for the two soils was calculated for corresponding allowable factor of depletion and considering the maximum effective root zone of 0.6 metres (Table 10).

Net irrigation requirement

Net irrigation requirement (NIR, mm/day) of sugarcane is the amount of water needed to be applied as irrigation to supplement the water received through rainfall and soil water contribution in meeting the water needs of the crop for optimum growth and yield. For crops age less than 3 months, the net irrigation requirement was intentionally made equals to crop water requirement (ETc) to provide more frequent irrigation water requirement (Table 11).

Soil type	FC (%)	PWP (%)	ρ depletion factor	Root Depth (m)	Z_{req} (mm)
Silty clay soil	37.63	21.13	0.60	1.0	99.0
Silty clay loam soil	39	21.60	0.60	1.0	104.40

Table 1: Considered target application depths (perceived application depth).

Soil type	a	K(m/min^a)	f_o(m/min)
Silty clay soil	0.433	0.0027	0.00023
Silty clay loam soil	0.398	0.0036	0.00055

Table 2: Infiltration parameters.

Fields	Replication	Field measurements				On-field Performance indicators, %			
		Q, l/sec	L, m	W, m	Tco, min	Ea	DPR	Du	Es
FC2326	Rep1	5.00	100	1.45	45	77	23	93	81
	Rep2	4.80	100	1.45	45	83	17	91	86
	Rep3	5.20	100	1.45	45	82	18	94	84
	Mean	5.00	100	1.45	45	81	19	92	84
FC2332	Rep1	4.80	100	1.45	45	82	18	94	84
	Rep2	5.00	100	1.45	45	82	18	93	84
	Rep3	5.00	100	1.45	45	82	18	95	84
	Mean	4.93	100	1.45	45	82	18	94	84
FC2414	Rep1	5.10	100	1.45	45	82	18	93	84
	Rep2	4.80	100	1.45	45	80	20	92	83
	Rep3	5.00	100	1.45	45	83	17	94	86
	Mean	4.97	100	1.45	45	82	18	93	84
FC2423	Rep1	5.20	100	1.45	45	82	18	91	84
	Rep2	4.90	100	1.45	45	78	22	92	82
	Rep3	5.00	100	1.45	45	83	17	94	85
	Mean	5.03	100	1.45	45	81	18	92	84

Where, Rep: Stand for replication; Q: Flow rate; L: Furrow length; W: Furrow width; Tco is cut-off times (minutes), Ea: Application efficiency; DPR: Deep percolation ratio; Du: Distribution uniformity: Es: Storage efficiency.

Table 3: Estimation of most favourable field management variables from field data.

Soil types	Decision variables			Performance parameters, %		
	Q(l/sec)	Tco, min	Ea	DPR	Du	Es
Mean values for SIC	5	45	81.16	18.84	93.43	84.18
Mean values for SICL	5	45	81.69	18.31	92.92	84.54

Where, SIC: Silty Clay Soil; SICL: Silty Clay Loam Soil.

Table 4: Summary of recommended inflow rate and cut-off time.

Months	Min temp (°C)	Max temp (°C)	Humidity (%)	Wind Km/day	Sunshine (h)	RAD (MJ/m²/day)	ET_o (mm/day)
Jan	18.7	32.9	57	148	8.8	19.9	4.74
Feb	19.2	34.7	53	158	9.1	21.8	5.44
Mar	21.8	37.1	50	155	7.6	20.8	5.73
Apr	27	39.1	48	139	9.6	24.3	6.57
May	25.6	41.6	42	110	9.9	24.4	6.48
Jun	27.1	43.2	34	126	7.5	20.4	6.40
Jul	26.8	41.6	42	147	6.8	19.5	6.38
Aug	25.7	39.5	50	127	7.2	20.4	5.87
Sept	25.1	39.8	48	99	7.0	19.9	5.47
Oct	21.8	38	48	98	9.6	22.8	5.58
Nov	19	35.5	51	113	9.6	21.3	5.04
Dec	18.3	33.4	55	120	9.3	20.1	4.57
Average	23	38	47	128	8.5	21.3	5.69

Table 5: Reference evapotranspiration for each months.

Level	Days	Growth	Canopy coverage, %	Kc
0 to 3 months	90	Stage 1	0-25	0.5
3 to 6 months	182	Stage 2	25-100	0.8
6 to 15 months	365	Stage 3	100	1.3
>15 months	425	Stage 4	100	0.8

Table 6: Growth stages of sugarcane at Tendaho sugar estate.

Age group (months)	Root depth (cm)
0-3	30
3-6	45
6-15	60
12 and above	90

Table 7: Root depth at different growth stages.

Months	ETo (mm/day)	ETC (mm/day)			
		0 to 3 months	3 to 6 months	6 to 2 months	> 12 months
Jan	4.74	2.37	3.79	5.45	3.79
Feb	5.44	2.72	4.35	6.26	4.35
Mar	5.73	2.87	4.58	6.59	4.58
Apr	6.57	3.29	5.26	7.56	5.26
May	6.48	3.24	5.18	7.45	5.18
Jun	6.40	3.20	5.12	7.36	5.12
Jul	6.38	3.19	5.10	7.34	5.10
Aug	5.87	2.94	4.70	6.75	4.70
Sept	5.47	2.74	4.38	6.29	4.38
Oct	5.58	2.79	4.46	6.42	4.46
Nov	5.04	2.52	4.03	5.80	4.03
Dec	4.57	2.29	3.66	5.26	3.66

Table 8: Crop evapotranspiration, ETc for the months and crop stages.

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
Rain (mm)	3	3	9	24	4	1	39	67	14	8	5	7	184
Effective Rainfall (mm)	3	3	8.9	23.1	4	1	36.6	59.8	13.7	7.9	5	6.9	172.7

Table 9: Monthly effective rainfalls of the area.

Growth stage (months)	0 to 3	3 to 6	6 to 12	12 and above
Root depth (cm)	30	45	60	60
Raw SIC	24.50	41.30	60.10	60.10
Raw SICL	20.80	44.10	64.08	64.08

Where, SIC: Silty Clay Soil: SICL: Silty Clay Loam Soil.

Table 10: Readily available water in root zones for different growth stages and soil types.

Months	0 to 3 months	3 to 6 months	6 to 2 months	Above 12 months
	NIR	NIR	NIR	NIR
Jan	2.37	3.70	5.35	3.70
Feb	2.72	4.24	6.15	4.24
Mar	2.87	4.30	6.30	4.30
Apr	3.29	4.49	6.79	4.49
May	3.24	5.05	7.32	5.05
Jun	3.20	5.09	7.33	5.09
Jul	3.19	3.92	6.16	3.92
Aug	2.94	2.77	4.82	-
Sept	2.74	3.92	5.83	2.77
Oct	2.79	4.21	6.16	4.21
Nov	2.52	3.87	5.63	3.87
Dec	2.29	3.43	5.03	3.43

NIR: Net Irrigation Requirement.
(-) means irrigation is not required, since rainfall is sufficient in this month.

Table 11: Estimation of net irrigation requirement.

Net irrigation depth and actual irrigation requirements: Net irrigation depth and actual irrigation required per irrigation events is shown in Table 9 (Table 12) [13].

Irrigation intervals

Irrigation intervals of the table below can be used as reference; but during implementation of it, the following points have to be considered. Exact interval cannot give for young plants of less than two months the intervals depends on the normal weather condition and the depth of root penetrations. In this early age, soil aeration is the most important. Therefore, drier condition is preferred at germination and tillering stages. In determining irrigation intervals, auguring test has to take by irrigation expertise to decide the next date of irrigation (Table 13) [14].

Conclusions

The performance of irrigation system of Tendaho sugar estate was shown significant relationship to field decision variables: irrigation scheduling inflow rate and cut-off times. An increase in irrigation application efficiency and uniformity was achieved by modifying the cut-off times and inflow per unit width. Combining these two critical variables with light irrigation intervals would result in optimal cane productivity, saves water, energy, labor costs, and ensures sustainable agriculture sustainability. Therefore, improved practices have a positive impact on the water use in terms of water savings. From the study, inflow rate of 5 litre per second and cut-off time of 45 minute were suggested for the two major soil groups of study area. Similarly, the

Fields	Inflow rate (l/sec)	Time (min)	L (m)	S (m)	Dn (mm)	d (mm)
FC1143	2.85	60.46	100	1.6	77	58.5
FC1153	3.38	68.70	100	1.5	91	64.6
FC2326	3.40	65.88	100	1.6	86	60.6
FC2332	2.78	74.25	100	1.4	85	59.8
FC2414	2.74	67.90	100	1.6	74	55.3
FC2423	3.01	70	100	1.5	80	57
FC2441	3.01	78	100	1.6	85	58.6
FC2913	3.53	58.32	100	1.6	83	71.1
FC21224	3.53	65.67	100	1.4	93	72.1
Mean	3.14	67.69	100	1.58	84.28	61.9

Where, L: Furrow length; S: Furrow spacing; Dn: Net irrigation depth; d: Depth of actual irrigation application

Table 12: Net irrigation depth and Actual irrigation requirement.

Texture class of soil mapping units									
Irrigation interval for each month	Silty clay soil texture					Silty clay loam soil texture			
	Cane age, month	0 to 3	3 to 6	6 to 12	> 12	0 to 3	3 to 6	6 to 12	> 12
	Jan	10	11	11	16	9	12	12	17
	Feb	9	9	10	14	8	10	10	15
	Mar	9	9	9	13	7	10	10	14
	Apr	7	8	8	11	6	8	8	12
	May	8	8	8	13	6	8	9	12
	Jun	8	8	8	12	6	9	9	13
	Jul	8	8	8	12	7	9	9	13
	Aug	8	9	9	*	7	9	9	*
	Sept	9	9	10	14	8	10	10	15
	Oct	9	9	9	13	7	10	10	14
	Nov	10	10	10	15	8	11	11	16
	Dec	11	11	11	16	9	12	12	18

The star sign (*) show no need to irrigate a field for there is sufficient rainfall in that month. The previously existing irrigation scheduling was widely scheduled (Appendix 3). Thus this wider irrigation interval was affecting the amount of irrigation water, crop growth and millable sugarcane of the estate.

Table 13: Irrigation interval for silty clay and silty clay loam soil.

current irrigation scheduling of the sugar estate was not well suited to the current conditions of soil and crop growth stages. Based on the results, irrigation intervals of current condition (climate, soil and crop root and age) were proposed as tabulated in Table 13 much different from Appendix 4.

References

1. Schaible G, Aillery M (2006) Irrigation water management. Agricultural resources and environmental indicators.
2. Pereira LS, Gilley JR, Jensen ME (1996) Research agenda on sustainability of irrigated agriculture. Journal of irrigation and drainage engineering 122: 172-177.
3. Jensen ME, Burman RD, Allen RG (1990) Evapotranspiration and irrigation water requirements. ASCE.
4. Allen RG, Pereira LS, Raes D, Smith M (1998) Crop evapotranspiration-Guidelines for computing crop water requirements. FAO Irrigation and drainage-Rome 300.
5. Tumebo BA (2008) Water allocation study of upper awash valley for existing and future demands (Doctoral dissertation, Addis Ababa University.
6. James LG, (1993) Principles of Farm Irrigation System Design. John Wiley &Sons.
7. Robertson MJ, Wood AW, Muchow RC (1996) Growth of sugarcane under high input conditions in tropical Australia. I. Radiation use, biomass accumulation and partitioning. Field Crops Research 48: 11-25.
8. Kakde JR (1985) Sugarcane production. Metropolitan.
9. Dilsebo H (2001) Evaluation of irrigation water application practices at Fincha Sugarcane Plantation. A Research Report, Ethiopian Sugar Industries Support Center Sh. Co.
10. Mulugeta S (2010) Evaluation of irrigation scheduling and Field application performance of Hydroflumes furrow irrigation at Metahara Sugar Estate. MSc research thesis, Arba Minch University.
11. Tate B (1994) Irrigation Operations and Maintenance Manual. Finchaa Sugar Project.
12. Allen RG, Pereira LS, Howell TA, Jensen ME (2011) Evapotranspiration information reporting: I. Factors governing measurement accuracy. Agricultural Water Management 98: 899-920.
13. Walker WR (1989) Guidelines for Designing and Evaluating Surface Irrigation System: Irrigation and drainage 45.
14. Zerihun D, Feyen J, Reddy JM (1996) Sensitivity analysis of furrow-irrigation performance parameters. Journal of irrigation and drainage engineering 122: 49-57.