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Effect of Decision Variables on Irrigation Performance Parameters Under Different Irrigation Systems

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Abstract: Furrow irrigation has low irrigation performances due to inescapable irrigation water loss through runoff and deep percolation. This study was conducted under small farmers to study combined influence of furrow irrigation flow rate and irrigation systems on irrigation performance parameters. The purposes of study were to evaluate outcome of furrow irrigation flow rate and irrigation systems on application efficiency, distribution efficiency, storage efficiency and deep percolation loss using field experiment. The field experiment had two factors of three furrow irrigation system (AFI, FFI & CFI) and four furrow irrigation inflow rate (Q1, Q2, Q3 & Q4). Field experimental plot was made in randomized complete block design with factorial arrangement of twelve treatment combinations and three replications. The collected field variables were management variables (irrigation performances) and site variables (soil type, soil moisture and furrow bed slope). The results show that, influence of furrow irrigation inflow rate and irrigation systems on irrigation performance parameters were highly significant (P<0.01). However, no significant difference among irrigation systems were observed in case of distribution uniformity (Du) expect furrow inflow rate. Interaction effect of irrigation systems and furrow inflow rate on irrigation performance parameter such as Ea, Du and DP were significant (p<0.05) expect storage efficiency. The highest values of distribution uniformity were 93.45% was observed under CFIQ4 treatment combination while the least value of distribution uniformity was 81.58% was observed under AFIQ1 treatment combination. The highest values of application efficiency 68.35% was observed under AFIQ4 treatment combination and the least value of application efficiency 53.60% was observed for CFIQ1 treatment combination. However, the highest values of deep percolation loss 46.60% was obtained under CFIQ1 treatment combination and the least value of deep percolation loss 31.65% was found under AFIQ4 treatment combination. It can be concluded that best result in improving application efficiency, distribution efficiency, and storage efficiency with the reduction of deep percolation loss were obtained under Alternative furrow irrigation with maximum non erosive furrow inflow rate.

Keywords: Irrigation System, Inflow Rate, Performance Parameter, Deep Percolation Loss

1. Introduction

In surface irrigation, furrow irrigation is the most widely used and considered as low water application efficiency and distribution uniformity. Proper design and best management of the furrow irrigation can led to increased water use efficiency and cultivated area [1]. Inappropriate management and design are the central causes for deprived performance of furrow irrigation systems. However, furrow irrigation method has the shortcoming of inducing soil erosion in the irrigated farms there by posing a great threat to sustainability of surface irrigated agricultural productivity. The rate and severity of soil loss is not ever a function of specific element,

nevertheless, interactive effect of field parameters, design variables and irrigation management systems.

Even though, its application efficiency remaining relatively low not sufficient exertion is being made to keep modifying its management and efficiency. Still now, Irrigators face Severe rivalry for limited water resources from other divisions of economic activity But, the query is which type of furrow irrigation methods (conventional, Alternative and fixed furrow irrigation system) used with combination of furrow irrigation decision variables are urgent problem under small holder farmer in order to maximize benefits and minimize water use.

In Ethiopia, irrigation efficiencies are normally low, order of 25 to 50% and owing to this, problem of rising of water table

and salinity was now emerging [2]. In the furrow irrigation system, inflow rates are the principal management and design variables influencing irrigation performances [3]. Until now, information gap that still exist on the combined effects of furrow irrigation Inflow rate and irrigation systems on irrigation efficiency to inform decision making on furrow irrigation. Therefore, the purpose of this paper was to investigate the effect of furrow irrigation decision variables on performance parameters under different irrigation systems.

2. Materials and Methods

2.1. Description of the Study Area

The field experiment was conducted at Bako Tibe woreda, West Shewa Zone about 250 km away from Addis Ababa. Field experiment was located an altitude of 1590 meters above sea level and lies in 9°06' N and 37°09' E Latitude and longitude respectively.

2.2. Experimental Design and Treatment

Treatment considered for this experiment was two factor i.e., three irrigation systems and four levels of furrow irrigation inflow rates. Irrigation systems are AFI, FFI and CFI and four levels of furrow irrigation inflow rates are Q1, Q2, Q3 and Q4. These flow rates were prepared by rating of 50%, 70%, 85% and 100% of the maximum non-erosive flow rate. The amount of water applied to the field was measured by using Parshall Flume. The experimental plots were prescribed in randomized complete blocks design with 3x4 factorial experiments and three replications.

Table 1. Combination of Treatment.

Irrigation system	Furrow irrigation inflow rate			
	Q1	Q2	Q3	Q4
AFI	50% Qamx	7o%Qmax	85%Qmax	100%Qmax
FFI	50%Qamx	7o%Qmax	85%Qmax	100%Qmax
CFI	50%Qamx	7o%Qmax	85%Qmax	100%Qmax

Where; AFI=Alternative furrow irrigation, FFI=Fixed furrow irrigation, CFI=Conventional furrow, Q1=50% Qmax, Q2=70%Qmax, Q3=85%Qmax, Q4=100%Qmax, respectively.

2.3. Collection of Soil Sample and Analysis Methods

Soil Physical properties of experimental site such as bulk density, texture, infiltration, field capacity and permanent wilting point were done by using core sampler method, pipette method, Inflow out flow method, pressure plate apparatus, respectively.

Table 2. Soil properties of the experimental site.

Soil Depth	BD (g/cm^3)	FC (%)	PWP (%)	TAW (mm/m)	Particle size distribution (%)			Textural class
					Sand	Silt	Clay	
0-20cm	1.29	31.32	16.21	194.92	31	34	35	Clay loam
20-40cm	1.30	30.27	15.43	192.92	35	30	35	Clay loam
40-60cm	1.31	29.3	13.54	206.5	31	30	39	Clay loam
Average	1.30	30.30	15.06	198.11	32.33	31.33	36.33	Clay loam

Note: BD=Bulk density, FC=Field capacity, PWP=permanent wilting point, TAW=total available water, EC=electrical conductivity

2.4. Soil Moisture Determination

For purpose performance evaluation the soil samples of each plot were collected before and two days after irrigation at the initial and midseason growth stages of the crop for performance from three points, Initial, mid (1/2L), and end of the furrow (L) along furrow length from each plot at three depths (Table 2), using a soil auger.

2.5. Field Evaluation Parameters

2.5.1. Determination of Furrow Characteristics

For measuring Cross-sectional area of furrow at the inlet, a furrow profilometer was done from round bars with 8mm in diameter and 500mm length and 1200mm wooden base. From these parameters characterizing the furrow geometry like depth of furrow, top width, mid-top width and base width of furrow were measured. Cross-sectional area at the inlet furrow (Ao) was determined from the manning equation and furrow geometry parameter coefficients [4].

$$A_o = \left(\frac{nQo}{60\rho 1 So^{0.5}} \right)^{1/\rho_2} \tag{1}$$

Where; $\rho_2 = \frac{10}{3} - \frac{4\gamma_2}{3\delta_2}$ and $\rho_1 = \frac{\delta_1^{10/3}}{\gamma_1^{4/3}}$

The values of values of furrow shape parameters coefficients γ_1, γ_2, δ_1 and δ_2 can be computed based on known measurements of furrow geometry as described by [5].

2.5.2. Infiltration Characteristics of the Soil

Knowledge of infiltration characteristics of the soil is very important for design and management of furrow irrigation system, without it difficult to accurately judge system performance, application efficiency, and uniformity [4]. Two-point method was used to calculate the infiltration characteristics based on the modified Kostiakov equation as shown equation (2)

$$Z = K\tau^a + fo\tau \tag{2}$$

Where;
Z=the cumulative infiltration per unit length of furrow (m^3/m/m)
τ=the intake opportunity time (min), for any point X
fo=the basic intake rate (m^3/min/m)
K and a=Infiltration parameters

Parameters of kostiakov Lewis equation 'K and a' were determined by two-point method using a simple volume balance equation.

2.6. Furrow Irrigation Decision Variables

The maximum non-erosive furrow inflow rate was determined using the equation developed by [6].

$$Qmax = \frac{\alpha}{S^\beta} \qquad (3)$$

Where; Qmax=Maximum furrow inflow rate (l/s)
S=Furrow bed slope (%)
α and β are coefficients of parameters based on soil group

Table 3. Coefficient parameters for furrow maximum flow rate.

Soil group	α (l/s)	β
Heavy textured soil	0.892	0.937
Medium heavy textured	0.988	0.55
Medium Texture	0.613	0.733
Light texture	1.111	0.615
Very Light texture	0.665	0.548

(Source: Hamad and Stringham [6])

The slope of the furrow was determined using line-level by measuring at 10m interval along furrow length. The experimental plot had an average of furrow bed slope of 0.6% and clay loam in textural class which categorized as medium-heavy textured soil group [7]. Based on these the value of α and β were determined (Table 3). Therefore the maximum non-erosive furrow inflow rate (Qmax) obtained above formula was 1.31L/s and the three levels of furrow inflow rate, 50%, 70%, 85% and 100% of Qmax were 0.7, 0.65, 1.12 and 1.31L/s, respectively.

2.7. Determination of Irrigation Performance Parameters

2.7.1. Application Efficiency (Ea): Was calculated as Shown in Equation 4)

$$Ea = \frac{Zs}{Z} \times 100 \qquad (4)$$

Where; Zs=depth of water retained in the root zone (mm)
Z=depth of water applied to the furrow (mm)

2.7.2. Storage Efficiency (Es): Was Resolute as Shown Equation (5)

$$Es = \frac{ZS}{Zreq} \times 100 \qquad (5)$$

Where; Z_S=depth of water stored in the root zone (mm)
Zreq=Water required in root zone prior to irrigation (mm)

2.7.3. Distribution Uniformity (Du): Was Determined as Shown Equation (6)

$$DU = \frac{Zmin}{Zav} \times 100 \qquad (6)$$

Where; Zmin=the minimum infiltrated depth (mm) and
Zav=the mean of depths infiltrated over the furrow length (mm)

2.7.4. Deep Percolation Loss: Was Determined as Shown Equation (7)

$$DP = 100 - Ea - RR \qquad (7)$$

Since the study was conducted under farmers' field conditions, the furrows were closed-end (end dyked) and runoff ratio (RR) was neglected.

2.8. Method of Data Analysis

The collected data were analyzed using SAS 9.0 statistical software. For comparing means of the treatments that indicated significant result, the least significant difference test at 5% and 1% probability level were applied.

3. Results and Discussion

3.1. Infiltration Characteristics of the Soil

The infiltration characteristics of the soil were determined by using inflow-out flow method. Average of basic infiltration rate was found to be 0.0000967m/min or 5.8mm/hr), which is in the range value for clay loam [8]. The values of furrow geometric parameters and basic infiltration rate were used as input in the determination of infiltration parameters 'k and a' in Kostiakov-Lewis equation. The infiltration parameters 'k and a' were found to be 3.64 mm/min^a and 0.47 respectively, using a volume balance method. Based on these, the depth of water infiltrated along furrow length determined using the following equation

$$Z = 3.64t^{0.47} + 0.0967t$$

Where; z=depth of water infiltrated along furrow length (mm) and
t=intake opportunity time (min)

3.2. Effect of Furrow Inflow Rate on Irrigation Performance Parameters Under Different Irrigation Systems

Analysis of variance indicated that (Table 4), the influence of furrow inflow rate and irrigation systems were highly significant (p<0.01) on irrigation performance parameters and their interaction were significant (p<0.05) expect storage efficiency.

Table 4. Analyses of variance for inflow rate and irrigation systems on irrigation Performance parameters.

Source of variation	Irrigation performance parameters			
	E_a (%)	E_S (%)	D_U (%)	DP (%)
Flow Rate (Q)	37.6**	49.5**	30.68**	37.6**
Irrigation system (IS)	24.8**	27.5**	21.4**	24.8**
Q X IS	3.15*	2.30ns	5.40**	3.15*
CV	8.61	2.82	10.45	9.8
LSD (0.05)	2.75	1.89	3.45	2.75

Where; [NS] Non significant, [*]Significant, [**]Highly significant, Q=Flow rate, Q X IS=Interaction of irrigation system and flow rate, E_a=Application Efficiency, E_S=Storage Efficiency, D_U=Distribution uniformity, D_P=Deep percolation loss

3.2.1. Application Efficiency

Influence of furrow irrigation inflow rate and irrigation systems on application efficiency (E_a) were highly significant at (P<0.01) (Table 4). Minimum E_a was obtained under conventional furrow irrigation which was 58.32% and maximum E_a was obtained under AFI which was 65.43% (Table 5). This might be due to encouragement of lateral movement of water across the ridge, which reduces the forward movement of water along the furrow compared to CFI system. This minimizes the loss of irrigation water due to deep percolation loss below the effective root zone of the crop. This is consistent with [9, 10].

Table 5. *Interaction effect of furrow inflow rate and irrigation systems on Application Efficiency.*

Irrigation systems	Mean of Application Efficiency (%)				Mean
	Furrow irrigation inflow rate (l/s)				
	Q1	Q2	Q3	Q4	
AFI	62.75a	64.86e	65.75c	68.35s	65.43m
FFI	61.85b	63.45n	65.47j	67.35t	64.53m
CFI	53.60d	57.35k	60.89l	61.45m	58.32k
Mean	59.40k	61.89b	64.04e	65.72j	62.76
LSD (0.05)		1.58			
CV (%)		4.65			

* Means of the same letter are not significantly different

The minimum E_a was obtained under small flow rate which was 59.40% and maximum Ea was obtained under maximum flow rate which was 65.42% (Table 5). This might be due to small furrow inflow rate has a slow advance time that leads to made maximum deep percolation loss, which contributes to decrease application efficiency and maximum flow rate has faster advance, which contribute to minimize deep percolation loss and increasing the application efficiency. This report was agreed with [11].

3.2.2. Storage Efficiency

Effect of furrow irrigation inflow rate and irrigation systems on storage efficiency (Es) were highly significant at (P<0.01) (Table 4). But interaction between furrow irrigation flow rate and irrigation systems on storage efficiency were non-significant (P<0.05). The minimum E_S was obtained under conventional furrow irrigation which was 75.04% and maximum E_S was obtained under Alternative furrow irrigation which was 78.12% (Table 6). The E_S of conventional furrow irrigation system was significantly different from Alternative furrow irrigation, But there was no significant difference between AFI and FFI systems (Table 5). This is because of the irrigation system, as all furrows was getting an chance of irrigated at once in conventional furrow irrigation system, also it was turn by turn in AFI. The minimum ES was obtained under maximum flow rate which was 74.07% and maximum E_S was obtained under small flow rate which was 80.22%. This trend was agreed with [12].

Table 6. *Effect of furrow inflow rate and irrigation systems on Storage Efficiency.*

Storage Efficiency	Irrigation Systems			Furrow irrigation inflow rate			
	AFI	FFI	CFI	Q1	Q2	Q3	Q4
E_S	78.12ba	77.70ba	75.04cd	80.22d	77.70b	75.83c	74.07f
Mean				76.95			
CV (%)				6.86			
LSD (0.5)				2.35			

* Means of the same letter are not significantly different
Where; AFI=Alternative furrow irrigation, FFI=Fixed furrow irrigation, CFI=Conventional furrow, Q1=50% Qmax, Q2=70% Qmax, Q3=85% Qmax, Q4=100% Qmax

3.2.3. Distribution Uniformity

ANOVA Reveal that effect of furrow irrigation inflow rate and irrigation systems on distribution uniformity (Du) were highly significant (P<0.01) (Table 4). As shown on Table 8, D_U CFI system and Q4 were significantly different from AFI system and under different furrow irrigation inflow rate, respectively. But, no significant difference between CFI, FFI and AFI (Table 7). This is consistent with [13]. However, furrow irrigation inflow rate was significantly affected by distribution uniformity. The minimum distribution uniformity was obtained under small flow rate which was 84.18% and maximum distribution uniformity was obtained under larger flow rate which was 90.98% (Table 7). This is due to increases of furrow flow rates reduces the difference in wetting along the furrow length contribute to increases the distribution uniformity. This trend was agreed with [14].

Interaction between furrow irrigation flow rate and irrigation systems on D_U were significant (P<0.05) (Table 4). Distribution uniformity of AFI system at inflow rate of Q1 was significantly affected the remaining furrow inflow rate under different irrigation system. Furthermore, interaction of Convectional furrow irrigation (CFI) with maximum flow rate (Q4) give better distribution uniformity 93.45% which was significantly different from the enduring furrow irrigation inflow rate. Distribution uniformity under different furrow irrigation inflow rate increases due to soil water potential difference and variation of intake opportunity time.

Table 7. *Interaction effect of furrow inflow rate and irrigation systems on distribution uniformity.*

Irrigation systems	Mean of distribution uniformity (%)				Mean
	Furrow irrigation inflow rate (l/s)				
	Q1	Q2	Q3	Q4	
AFI	81.58h	88.45b	90.85r	91.25e	88.03c
FFI	85.68j	86.97d	89.23n	91.45e	88.33c
CFI	86.45m	87.68d	87.69d	93.45b	88.23c
Mean	84.57s	87.70t	89.26n	92.05b	88.20
LSD (0.05)		1.89			
CV (%)		3.50			

* Means of the same letter are not significantly different

3.2.4. Deep Percolation Loss

ANOVA Reveal that consequence of furrow irrigation inflow rate and irrigation systems on deep percolation loss were highly significant (P<0.01). The minimum deep percolation loss was obtained under Alternative furrow and fixed furrow irrigation which was 34.57 and 35.47%, respectively and maximum deep percolation loss was obtained under conventional furrow irrigation which was 41.68% (Table 8). While, there was no significant difference between AFI and FFI systems (Table 8). This report was agreed with [10]. The minimum deep percolation loss was obtained under larger flow rate which was 38.55% and maximum deep percolation loss was obtained under small flow rate which was 46.60% (Table 8). Similarly,[15] have got a decreasing trend of deep percolation loss as furrow inflow rate increases. Combined effect of irrigation systems and furrow irrigation inflow rate on deep percolation loss was significant (p<0.05) (Table 4). In this study, the highest deep percolation loss 46.40% was observed for treatment interaction of conventional furrow irrigation (CFI) minimum flow rate (Q1). The lowest application deep percolation loss 31.65% was observed in the interaction of Alternative furrow irrigation (AFI) with maximum flow rate (Q4) (Table 8).

Table 8. *Interaction effect of furrow inflow rate and irrigation systems on Deep percolation loss.*

Irrigation systems	Mean of Deep Percolation loss (%)				
	Furrow irrigation inflow rate (l/s)				
	Q1	Q2	Q3	Q4	Mean
AFI	37.25g	35.14d	34.25j	31.65n	34.57f
FFI	38.15g	36.55d	34.53j	32.65n	35.47f
CFI	46.40f	42.65c	39.11k	38.55r	41.68c
Mean	40.60b	38.11g	35.96d	34.28j	37.24
LSD (0.05)	1.58				
CV (%)	4.65				

* Means with the same letter are not significantly different

4. Conclusion and Recommendation

Understanding the irrigation efficiencies for different types of irrigation systems would help farmers made decisions about choice of irrigation management which improve their production and productivity. Considering above issue, study was conduct to investigate influence of variable furrow irrigation inflow rate under different irrigation systems on irrigation performance parameters. The result shows that, influence of furrow irrigation inflow rate and irrigation systems on application efficiency (Ea) and storage efficiency (Es), and deep percolation loss (Dp) were highly significant (P<0.01). However, no significant difference among irrigation systems were observed in case of distribution uniformity expect furrow inflow rate. The results of this study showed that better performance in improvement of application efficiency, distribution efficiency, storage efficiency with reduction of deep percolation loss were obtained under Alternative furrow irrigation system with combination of maximum non erosive furrow inflow rate.

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