Performance evaluation of furrow irrigation system on pepper (Melka-Shota) production at Tanqua Abergelle district, Tigray, Ethiopia

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ABSTRACT

The field experiment was conducted in north Ethiopia, Tigray at sub-district called Sheka-tekli. The objective of the study was to evaluate the performance of furrow irrigation systems on pepper production. The furrow irrigation treatments were i) Conventional Furrow (CF), ii) Alternate Furrow (AF), and iii) Fixed Furrow (FF). The experimental design was a randomized complete block design (RCBD) with three replications. The climatic data were obtained from Ethiopian Meteorological Agency and New_**Loc**Clim software. The crop water requirement and irrigation scheduling were estimated using Cropwat8 software. The collected agronomic data were subjected to one way ANOVA while irrigation water related performances indicators were computed using equations. Accordingly, the fresh pepper yield for CF (12250 kg h^{-1}) and AF (9670 kg h^{-1}) were not significant different. However, there was significant difference between CF and FF methods of furrow irrigation. The fresh crop yield for FF was 7670 kg h^{-1}. The water savings from AF and FF methods of irrigation as compared to the CF method was 30.62%.The economic irrigation water productivity was higher in AF (5.33 ETB m^{-3}) than CF (4.68 ETB m^{-3}) and FF (0.49 ETB m^{-3}). Irrigation water productivity was 1.95 kg m^{-3}, 2.22 kg $m^{-3}$and 1.76 kg $m^{-3}$for CF, and AF and FF methods of irrigation, respectively. Thus economic irrigation water productivity and environmental benefits for alternate furrow irrigation method (AF) was much superior as compared to other furrow irrigation methods.

Key words: Alternate; Furrow Irrigation; Water Productivity; Water Saving

1. INTODUCTION

Water plays a critical role in food production. Increasing water productivity is important in arid and semi-arid regions (Hamed *et al.*, 2011). It has been clearly stated that if Ethiopia is to feed its ever-increasing population, continuous and extensive effort should be geared towards using irrigation for agriculture. Furrow irrigation is a popular surface irrigation method and widely used in Ethiopia, particularly in Tigray region in almost all small scale irrigation schemes. It is known as conventional furrow irrigation (CF). In this case each furrow is irrigated during consecutive watering. However, CF method of furrow irrigation is less efficient particularly when there is shortage of irrigation water. It brings about excessive deep percolation at the upper end of the furrow and inefficient irrigation at the lower end (Hamed et al., 2011). Therefore, it is important to examine other methods of furrow irrigation like alternate furrow irrigation (AF). In case of AF method of furrow irrigation, water is applied to alternate furrows. The furrow in-between the irrigated furrow remains dry. This means each ridge receives water from one side only. However, the dry and irrigated furrows may be alternated in subsequent irrigations. The alternate furrow irrigation could decrease water losses such as deep percolation and runoff and thereby increases irrigation water productivity, economic water productivity, and result irrigation water saving. Thus additional land may be brought under irrigation (Du et al., 2010). In this regard, the present study was aimed at evaluating performances of different furrow irrigation systems for pepper crop production in central zone of Tigray, Ethiopia.

The objectives of this study were to evaluate the performance of different furrow irrigation systems for pepper crop production and to study irrigation water productivity (IWP) for different furrow irrigation systems.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

The field experiment was conducted in Tanqua Abergelle district at Mitswa small scale irrigation scheme. It is situated in the central zone of Tigray Regional State about 120 km away from the capital city of Tigray regional state, Mekelle (Figure 1).

The rainfall pattern of the district is mono-modal with a wet season of about two months from July to August. Agro ecologically, it is characterized as hot warm sub-moist low land (SM1- 4b) below 1500 m.a.s.l. The mean annual rain fall and temperature are 350 – 700mm and 24 - 41 ^{0}C, respectively (ENMA, 2014). It has diverse soil type such as sandy loam (63.73%), clay loam (30.47%) and silt loam (5.8%) with low organic matter content (BoARDTA, 2014).

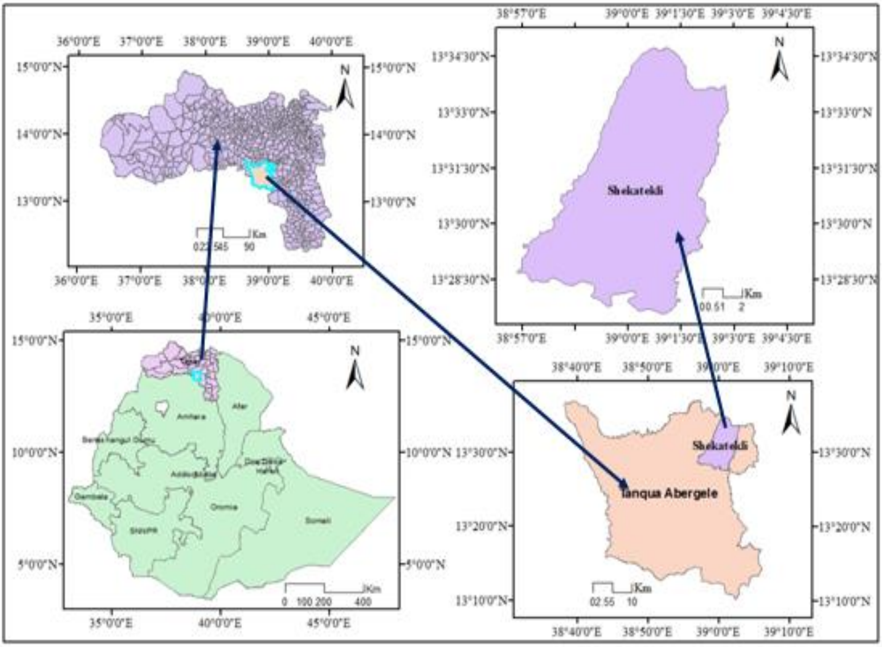

Figure 1. Location map of the study area

2.2. Experimental Design and Treatment Setting

An attempt was made to evaluate three different furrow irrigation systems namely i) Conventional furrow irrigation (CF), ii) Alternate furrow irrigation (AF) and iii) Fixed furrow irrigation (FF). Randomized complete block design (RCBD) with three treatment replications was employed to minimize soil and other related variability between experimental units. The inflow into each furrow was kept constant so as to supply the required amount of water. The pepper variety (Melka-shota variety) was sown on October 31, 2013 and transplanted on December 24, 2013 manually. The spacing between block, plot, furrow, and plant was 1m, 0.5m, 70cm, and 30cm, respectively. The total area of the plot was 5m × 7m (35m^2) whereas that of the experimental area was 22m × 17m (374m^2). At the time of transplanting, DAP (200kg ha^{-1}) was applied. In addition, urea (100kg ha^{-1}) fertilizer was applied through split application method (during transplanting and middle crop growth stage) to all experimental plots. Plants were initially well-watered to have suitable development of roots and favorable plant stand. The experimental layout is shown in Figure 2.

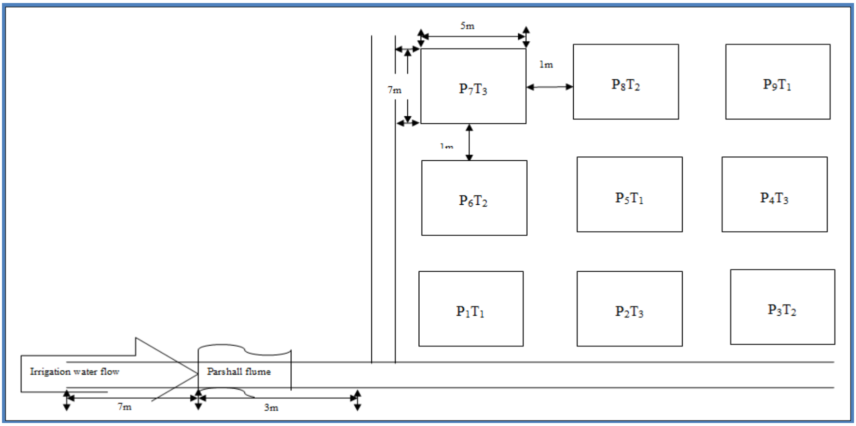

Figure 2. Layout of the experiment

2.3. Soil sampling and measuring field infiltration capacity

The composite soil samples were collected from the middle and each corner of the experimental area at the depth of 0 – 40 cm using soil auger and were analyzed at Mekelle Soil Research Center in Tigray. Furthermore, double ring infiltrometer was used to measure the infiltration rates of the soil.

2.4. Discharge measurement and water application duration

In order to measure the amount of irrigation water for all plots, gross irrigation water requirement (D_{ap}) was conveyed to experimental plots through two inch Parshall flume. The discharge was measured using Parshall flume installed at the entrance of the supply ditch channel (Figure 2). The water application duration was computed using Equation 1.

$$T = \frac{D_{ap} * L * W}{60 * Q} \qquad (1)$$

Where:-T = water application time (min),

D_{ap} = gross water application depth (mm),

L = furrow length (m)

W = furrow width (m), and

Q = discharge ($l\ s^{-1}$) of the Parshall flume.

2.5. Irrigation management

According to Abd El-Halim (2013), the amount of water for each furrow was determined until reaching 95% of furrow length on all furrows. This is according to flow of irrigation water. Time was recorded with a stopwatch to check the amount of water applied to each plot. However, water should not exceed the edge of the plot because it flows through the parallel furrows. The furrows designated for irrigation remained open-ended whereas other furrows not meant for irrigation were kept closed-ended. The water in the channel was controlled through minimum discharge (i.e. from

5cm to 10cm head of the Parshall flume) to maintain a constant head and provide required inflow rate during irrigation events.

2.6. Performance Indicators

Based on water consumptive use of the pepper and its production (fresh yield in kg ha-1), the performance of different methods of furrow irrigation systems were evaluated using the following performance indicators.

Agronomic data collected

The data collected included: pepper yield (fresh yield (kg ha^{-1})) and yield components (plant height (cm), fruit number per plant, fruit diameter (cm) and fruit length (cm)), which were affected by the application of different methods of irrigation water. These parameters were taken from the middle of the experimental plots (1m x 1m) so as to minimize the boarder effect and used in Equation 2.

$$\text{Yield obtain (kg ha}^{-1}\text{)} = \text{yield obtained per square meter (kg)} * 10^4 \quad (2)$$

Estimation of seasonal crop water requirement (CWR) in cubic meter per hectare of the pepper was estimated using Equation 3.

$$CWR\ (m^3) = D_{ap}\ (mm) * 10 \quad (3)$$

Irrigation water productivity (IWP)

Kijne *et al*. (2003) defined IWP as a key measure of the ability of agricultural systems to convert water into food. According to Molden *et al.* (2010), it is the net return for a unit of water used. In other words, it is a measure of output of a given system in relation to the water it consumes. Ali and Talukder (2008) and Heydari (2014) quantified irrigation water productivity as the ratio of crop yield to total seasonal irrigation water applied to the field as expressed by Equation 4.

$$IWP = \frac{\mathbf{Y}}{\mathbf{Dap}} \tag{4}$$

Where: IWP = irrigation water productivity (kg m^{-3}),

Y = fresh crop yield (kg ha^{-1}) and

Dap = water applied to the field gross irrigation (m^3 ha^{-1})

Economical irrigation water productivity (EIWP) (ETB m^{-3})

It relates the economic benefits per unit of water used and can be estimated using Equation 5.

$$EIWP = \frac{\textbf{Output or Value (ETB)}}{\textbf{Total amount of irrigation water consumed } (\mathbf{m^3})} \tag{5}$$

Where; EIWP = the economic irrigation water productivity (ETB m^{-3})

Out-put= the product of marketable yield and market price (ETB)

ETB is Ethiopian birr

Estimation of irrigation water saving (WS)

The amount of WS per hectare can be obtained by subtracting the amount of water consumption of a particular method of furrow irrigation from the convectional furrow irrigation with 100% ETc. WS was estimated using Equation 6.

$$WS\ (\%) = \frac{\mathbf{WCF - WAF/F}}{\mathbf{WCF}} \quad (6)$$

Where: WS = water saved (%),

W_{CF} = total water used (mm) with the CF method and

$W_{AF/FF}$ = total water used (mm) with the AF or FF method

Additional Irrigable Land (AIL)

The additional irrigable land can be estimated by using Equation 7.

$$AIL = \frac{(WCF - WAF\ /\ FF) * 1ha}{WCF} \quad (7)$$

OR AIL = WS*1 ha

2.7. Statistical analysis

One way analysis of variance (ANOVA) was used to determine statistical significance differences of the treatments by SPSS version 20. Contrast was employed to test the significance of mean separation ($P < 0.05$) using LSD equal variance assumption.

3. RESULTS AND DISCUSSION

3.1. Physical and chemical properties of the soil in the study area

The soil physiochemical properties of the study area are summarized in Table 1. The maximum and minimum infiltration rate was 27.92 mm day^{-1} and 25.51 mm day^{-1}, respectively (Table 1). The variation of the irrigation efficiency from 60% to 75% can be attributed to the application of the irrigation water (DTAWRME, 2013). The value for the present study was

75%. The total gross irrigation requirement was measured to be 628 mm (6280 m^3 ha^{-1}).

Table 1: Soil characteristics of the study area

Parameters						Texture			Class/ USDA	Max. Infiltration rate (mm/d)
pH	EC	OC	CEC	AVP	TN	Sand	Silt	Clay		
7.89	0.25	2.25	30.51	1.27	0.11	78	2	20	S-L	27.33
8.00	0.21	2.46	23.27	1.53	0.12	66	18	16	S-L	27.92
8.22	0.2	2.44	27.24	1.67	0.12	68	10	22	S-C-L	25.51
8.23	0.2	2.37	26.70	1.02	0.12	50	36	14	L	26.23
8.16	0.2	2.05	29.65	0.41	0.10	50	38	12	L	26.12

Where: EC (ms/cm) = electrical conductivity, OC (%)= organic carbon, CEC (meq/100g) = cation exchange capacity, AV.P(ppm) = available phosphors, TN (%) = total available nitrogen; Unit of sand, silt and clay (%).

Class USDA abbreviation: S-L=sandy loam, S-C-L=sandy clay loam, L=loam

3.2. The Effect of different furrow irrigation system for pepper yield and yield components

The pepper yield and yield components were significantly affected by the furrow irrigation systems. The crop yield, 12250kg ha^{-1} for CF was found to have statistically significant difference compared with the yield (7670 kg ha^{-1}) for FF. However, no statistically significant difference was observed with the amount of yield 9670 kg ha^{-1} for AF (Table 2). This can be attributed to the partial drying of root or watering only half of the root system at each irrigation event in FF. This watering system was assumed to be essential to maintain yields with a reduction in applied water. Therefore, this might suggest AF to be the most important furrow watering system for pepper irrigation because pepper responded well to irrigation water deficit without significant effect on the crop yield.

The results of the present study appear to be similar to that of Hamed *et al.* (2011). Their findings showed that there was no significant difference between CF and AF in terms of the biomass and dry matters. Nameer (2017) also found that grain yield decreased as irrigation water amounts decreased, but there were no significant differences in average grain yield between AF and CF following irrigation treatments.

Table 2.Yield and yield component of the experiment

Treatment	Plant height (cm)	Fruit length (cm)	Fruit number Per plant	Fruit Diameter (cm)	Fresh Yield (Kg ha^{-1})
Conventional(CF)	55.44^{a}	10.61^{a}	72.78^{a}	1.250^{a}	12250^{a}
Alternate (AF)	51.89^{a}	9.36^{ab}	48.94^{b}	1.10^{ab}	9670^{ab}
Fixed (FF)	41.61^{b}	8.03^{b}	34.83^{c}	0.950^{b}	7670^{b}
Sig (0.05)	0.011	0.008	0.00	0.005	0.028
SE (±)	2.22	0.39	5.123	0.44	0.87

Note: Similar superscript letters indicate there is no significant difference between the treatments

3.3. Irrigation water productivity (IWP)

The seasonal amounts of irrigation water (D_{ap}) applied for different treatments were 628, 435.7, and 435.7, mm ha^{-1} for CF, AF, and FF furrow irrigation treatments, respectively. The estimated values of IWP using Equation 4 for different furrow irrigation systems are given in Table 3. The values for CF, AF and FF furrow irrigation treatments were 1.95, 2.22 and

1.76kg m^{-3}, respectively. The results showed that alternative drying of the root zone had better performance than fixed drying of the root zone. This can be observed in AF which has more frequent events at fixed interval per stage i.e. 3, 5, 5, and 8 days for initial, development, mid and late, respectively. The crop yield for AF was almost similar to that of CF furrow irrigation system. This is attributed to the more availability of soil moisture during the irrigation cycle for alternate furrow irrigation than fixed furrow irrigation system. The distribution of the crop roots in both sides of the ridge might be ascribed to the increase in IWP and reduction in the crop yield of AF rather than CF system. This situation may lead to the increase in water and fertilizer uptakes when compared to FF system (Abd El-Halim, 2013 and Hamed *et al.*, 2011). The results showed that alternative drying of the root zone had better performance than fixed drying of the root zone. This caused further adaptation of the roots to uptake more water and fertilizer.

Ebrahimian *et al.* (2011) observed the highest biomass, 550 kg ha^{-1} and dry matters, 202 kg ha^{-1} in CF system. But AF had the highest IWP which equals to 2.82 kg m^{-3}. The IWP values for CF and FF were 1.61 and 1.31 kg m^{-3}, respectively. FF, which decreased the biomass and dry matters (273 and 83 kg ha^{-1}, respectively), had the lowest IWP in comparison to the other furrow irrigation systems. Slatni *et al.* (2011) reported the water productivity as 8.0, 8.7 and 5.9 kg m^{-3} for the AF, FF and CF treatments, respectively. Based on the results of the present study and earlier studies, AF system of furrow irrigation is very important for irrigable land and saving the irrigation water without substantially affecting the fresh crop yield of pepper.

3.4. Irrigation water saving (WS)

The estimated irrigation water saving for AF and FF irrigation systems in comparison to CF irrigation system was 30.62 (Table 3). It was assumed that the saved irrigation water can irrigate about 0.31ha. Alternate furrow irrigation was found to be far more important than different types of furrow irrigation based on fresh crop yield, water saving, and additional irrigable land. Shani *et al.* (2006) compared CF and AF irrigation for sugar cane crop in a warm arid area, and found that 26% of the irrigation water was saved in AF in comparison to CF system. Kang *et al.* (2006) found that water use was reduced by 34.4–36.8 % when two halves of maize root system was alternately exposed to drying and wetting. Nameer (2017) observed that AF reduced the quantity of applied irrigation water by 42 % when compared to CF system. Barrios-Marias and Jackson (2016) found that AF reduced irrigation water by 25% without causing decrease in crop yields in contrast to conventional furrow irrigation (CF).

Table 3. Estimated values of irrigation water productivity, water saving and additional irrigated land

Treatment	D_{ap} (mm ha^{-1})	FY (kg ha^{-1})	IWP (kg m^{-3})	WS (%)	AIL (ha)
Conventional(CF)	6280	12250	1.95	0	0
Alternate(AF)	4357	9670	2.22	30.62	0.31
Fixed(FF)	4357	7670	1.76	30.62	0.31

3.5. Economic Irrigation Water Productivity (EIWP)

The values of EIWP were 5.33, 4.68, and 0.49 ETB m^{-3} for AF, CF, and FF irrigation systems, respectively (Table 4). In this case, AF had the highest value whereas the FF irrigation system had the least value. Nameer (2017) found that the AF treatment brought about higher productivity of irrigation water with significant increment of 91.34 % in contrast to CF treatment. The increase in EIWP for AF was attributed to the decrease in water quantity and increase in irrigation water productivity. The results of the present study and previous studies indicate that alternate furrow irrigation is economically more productive than other furrow irrigating systems.

Table 4. Economic irrigation water productivity (EIWP)

Treatment	Yield ($kg ha^{-1}$)	Unit price per kg (ETB)	Total benefit (ETB)	D_{ap} (m^3 ha^{-1})	EIWP (ETB m^{-3})
Conventional(CF)	12250	24	294000	62800	4.68
Alternate (AF)	9670	24	232080	43570	5.33
Fixed (FF)	7670	24	184080	373160	0.49

4. CONCLUSIONS

Alternate furrow irrigation (AF) with continuous irrigation water flow is an appropriate furrow irrigation system. It can be used as an efficient method of furrow irrigation for pepper production in Tanqua Abergelle district area where production depends heavily on irrigation. It could be concluded that the AF treatment controlled stress irrigation without the risk of substantially reducing fresh crop yield. However, conventional furrow irrigation (CF) results in the highest fresh crop yield; but the alternate furrow irrigation (AF) significantly increased water productivity. The AF caused water saving up to 30.26 percent. By application of alternate furrow irrigation, the cultivated area could be increased especially in regions having extra irrigable land. The FF method of furrow irrigation not only decreased the fresh crop yield but also had the lowest irrigation and economic water productivity. The AF method efficiently used the irrigation water without substantially affecting the crop yield and demanding additional investment. The preference for AF treatment over other treatments is based on the fact that with AF there is increased return of applied water compared to the other methods. Therefore, it is recommended that the alternate furrow irrigation (AF) is essentially the best choice under the conditions of the study area.

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