Vol. 17(9), pp. 1221-1228, September, 2021
DOI: 10.5897/AJAR2021.15653
Article Number: 2BFFADA67784
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Effect of drip and furrow irrigation at different irrigation levels on water use efficiency and economics of maize (*Zea Mays* L.) at Werer, Middle Awash, Ethiopia

Fikadu Robi Borena[1*] and Teshome Seyoum[2]

[1]Ethiopian Institute of Agricultural Research, P. O. Box 2003, Addis Ababa, Ethiopia.
[2]Haramaya University IOT, School of Water Resource and Environmental Engineering, P. O. Box 138, Dire Dawa, Irrigation Engineering Department, Dire Dawa, Ethiopia.

Received 1 June, 2021; Accepted 7 July, 2021

Water is a vital resource to sustain civilizations and pecuniary development and most importantly agriculture. Agriculture is the main contributor to the Ethiopian economy. The field experiment was conducted at Werer Agricultural Research center to evaluate the effects of drip and furrow irrigation under different irrigation levels on maize water use efficiency. The experiment was laid out in an RCBD split-plot arrangement where drip and furrow irrigations were assigned as the main plot and irrigation levels (100, 85, 70, and 55% of ETc) were assigned in the subplot arrangement with three blocks. The highest seasonal water requirement of maize was 701.7 mm at 100% ETc under conventional furrow irrigation which is considered as control while the lowest was 321.6 mm at 55% ETc under alternative furrow irrigation. The interaction effects of irrigation systems and irrigation levels have shown a highly significant ($p<0.01$) effect on water use efficiency. The highest (2.38 kg/m^3) and the lowest (0.60kg/m^3) water use efficiency were recorded from the plots treated with drip irrigation at 100% ETc and conventional furrow irrigation at 100% ETc treatments, respectively. In terms of water use efficiency and economic prominence, irrigating with a drip irrigation system with 100% ETc can be recommended for the production of maize in the study area.

Key words: Agriculture, efficiency, irrigation, main plot, split plot.

INTRODUCTION

The uniformity in distributing water in soil with alternative furrow surface irrigation is mainly associated with the soil and field condition and implementation of the process of regular irrigation (Kashiani et al., 2011). Holding the current rates of agricultural water use efficiency constant, an estimated additional amount of 5700 km^3 of freshwater will be required annually to meet the estimated food demand in 2050 (Rost et al., 2009). The advance of water-saving technologies in the agricultural sector can alleviate the risk of water shortage. To cope up with periods of water shortage, efficient use of irrigation water is becoming increasingly important, and water-saving agriculture is an important option. Pressurized methods, such as sprinkler and drip irrigation, have proven to be

*Corresponding author. E-mail: fikadurb@gmail.com.

successful in terms of water use efficiency and increased yield for a wide range of crops and environments (Ati et al., 2012). The identification of the best irrigation management strategies (methods, levels, and timings) remains an important issue to improve water management at the farm level in semi-arid environments where water is scarce. Drip irrigation is an irrigation method that allows precisely controlled application of water and fertilizer by allowing water to drip slowly near the plant roots through a network of valves, pipes, tubing, and emitters (Poh et al., 2009).

Increasing the water use efficiency in semi-arid regions is very essential. Effectual irrigation systems design at the farm level appear to be a very significant feature for the irrigated agriculture and a key factor due to the competition for water resources with other sectors and to allow the economic and environmental sustainability of agriculture. Programs throughout the crop growing period, coupled with appropriate irrigation techniques that are applicable also in semi-arid environments, have been suggested in earlier studies (Pereira et al., 2002; Tagar et al., 2012). Maize is critical for food security in Ethiopia. Over 9 million smallholder farmers grow maize on about two million hectares (14% of total land area in Ethiopia) and around 88% of their production is used for food consumption (Abate et al., 2015). The country needs to continue the recent observed increase in cereal yield (of which maize makes up the largest share) to maintain its current food self-sufficiency rate of 95% in 2050, as by as the population will have probably more than double and consumption per capita levels have increased in line with higher projected income level. This would be equivalent to a yield increase to around 50% of the water-limited potential yield of cereals. If the yield level stays at the present level, Ethiopia will only be able to produce 40% of its cereal needs in 2050, which is a potential risk for food security (Van et al., 2020).

Crop failure due to moisture stress in Ethiopia is a common experience especially in the moisture stress area of the country which is caused by low and erratic rainfall distribution. Different researchers worldwide and in the country also show the diverse effect of moisture stress on crop production (Dağdelen et al., 2009; Khalili et al. 2013). Because of the limited water resource in the semi-arid regions specifically, in middle Awash and the sensitivity of maize crop to moisture stress, this research is aimed at determining the water use efficiency and appropriate irrigation system during the maize crop growing period and producing optimum yield by using appropriate irrigation system with optimum irrigation amount that is economically feasible.

MATERIAL AND METHODS

Description of the study area

The experiment was conducted in 2019/20 at Werer Agricultural Research Center experimental site, located in Afar Regional State and 280 km far away from Addis Ababa. It is located (Figure 1) at 9° 16 '8" latitude; 40° 9' 41" E longitudes and 740 m above mean sea level. According to the classification of Agro-ecological zones by the Ministry of Agriculture and Rural Development (MoARD, 2005), the area is classified as semi-arid with an average annual rainfall of 590 mm. Based on the meteorological data recorded at Agro meteorological observatory (Werer) the average minimum and maximum temperature is 19 and 40.8°C, respectively. The topography of the middle awash Valley reflects the history of the middle awash valley, through which deposits from the Awash River have constructed an extensive alluvial plain. Gradients are generally very low, predominantly lying in the range of 1-2 percent (Awulachew et al., 2007).

Soil of the study area

The soils are brown and turn to dark brown when moist. Generally, the widespread occurrence of salinity and sodicity problems in the irrigated area of Amibara District farms is mainly due to weathering of Na, Ca, Mg, and K rich igneous rocks and poor irrigation water management. A recent study indicated that the salt-affected soils were generally clayey to silt clay loam in both soil types, slightly alkaline to strongly alkaline (7.53 to 8.45) and low in organic matter with high soluble salt.

Bulk density

The bulk density undisturbed soil sample of known volume was taken using a core-sampler from six representative places in the trial plot at three different depths (0-30 cm, 30-60 cm, and 60-90 cm). The sampled soil was oven-dried at 105 °C for 24 h to a constant weight and weighed to determine the dry weight fraction. Then the bulk density was calculated as the ratio of dry weight of the soil to known cylindrical core sampler volume (Hillel, 2004).

$$\rho_b = \frac{M_c}{V_t} \tag{1}$$

Where, ρ_b = Bulk density (g/cm^3); M_c = Dry weight of soil (g); V_t = Volume of core cutter (cm^3)

The total available water (TAW in mm) of the experimental field was determined by using the following equation (Allen, 2000).

$$\text{TAW(mm)} = \left(\frac{(FC - PWP) * \rho d * D}{100}\right) * \frac{1}{\rho_w} \tag{2}$$

Where, TAW = Total available water (mm); FC = Field Capacity (%);
PWP = Permanent wilting point (%); ρ_d = Bulk density (g/cm^3); D = Effective root depth of crop (m); ρ_w = Water density (g/cm^3).
The moisture content (cm/cm) is obtained by the following formula (Batjes, 2012).

$$\text{MC(\%)} = \frac{W_{ws} - W_{ds}}{W_{ds}} * 100 \tag{3}$$

Where, MC (%) = Moisture content (gm); Wws = Weight of wet soil (gm); Wds = Weight of dry soil (gm).

Climate condition of the study area

Werer Agricultural research center meteorological data (Figure 2) shows that the average annual rainfall is 590 mm. More than 85%

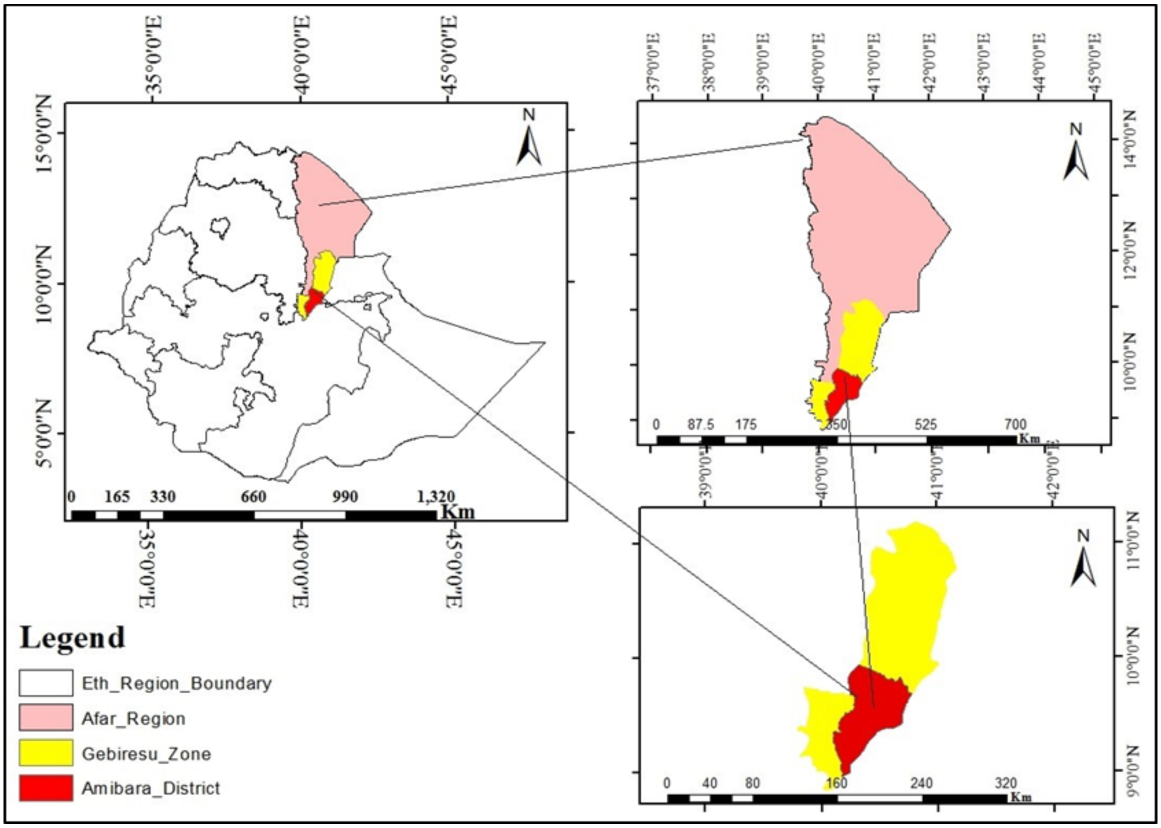

Figure 1. Study area map.

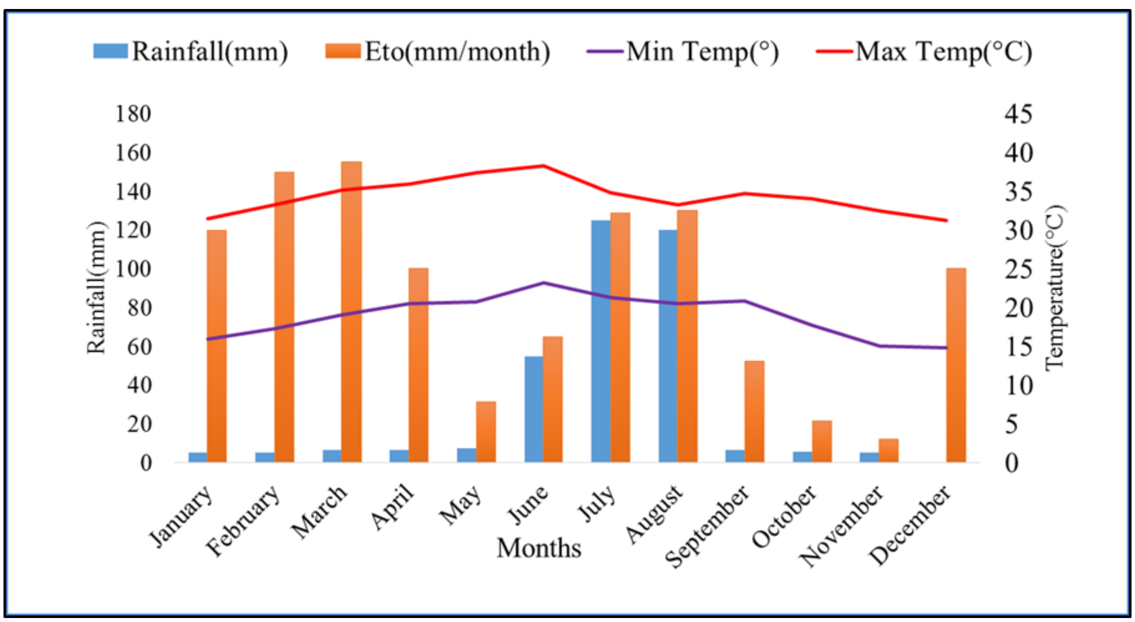

Figure 2. Climate of Study Area (1990-2019).

of the rain occurs from June to September, with July and August being the wettest months. The average minimum and maximum temperature is 19 and 40.8°C, respectively. Mean relative humidity is lowest in June at 36% and the maximum in August which is 58%.

Table 1. Treatment combination.

Main plot		Sub-plot Irrigation level	Treatment designation
Furrow Irrigation (MP1)	CFI	100% ETc	T1
	AFI	100%ETc	T2
	AFI	85% ETc	T3
	AFI	70% ETc	T4
	AFI	55% ETc	T5
Drip Irrigation MP2	DI	100% ETc	T6
	DI	85% ETc	T7
	DI	70% ETc	T8
	DI	55% ETc	T9

The annual evapotranspiration rate of Amibara is 2829 mm. According to Werer Agricultural Research Center's long-term climatic data (1990 - 2019), the relative humidity ranges between 37 and 52.5%. The mean monthly rainfall distribution indicates that July and August are the main rainy season followed by March and April (short rainy season).

Water use yield response

The water use-yield relationship was determined using the Stewart model in which dimensionless parameters in relative yield reduction and relative water consumption are used (Doorenbos and Kassam, 1979). Ky is defined as a decrease in yield per unit decrease in ETc (Lovelli et al., 2007).

$$1 - \frac{Y_a}{Y_m} = K_y \left(1 - \frac{ET_a}{ET_m}\right) \quad (1)$$

Where, Ya = Actual yield; Ym = Maximum yield; Ky = Yield response factor; ETa = Actual evapotranspiration; ETm = Maximum evapotranspiration

Experimental treatments and design

The experimental treatments (Table 1) include irrigation systems, viz., furrow (alternate furrow) and drip irrigation, and four irrigation levels (100, 85, 70, and 55%ETc) and considering conventional furrow irrigation (CFI with 100%ETc) as control.

The experiment was designed as split-plot in an RCBD design arrangement with three blocks. The experimental field was divided into 27 plots and a single plot size of 4.5 m by 6.0 m to accommodate six ridges with 6 m length, representing a single treatment. The plots and blocks had a buffer zone of 1.5 and 3 m length, respectively.

Irrigation scheduling

Atmospheric evaporating power (ET_o)

Atmospheric evaporating power (ETo) expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider crop characteristics and soil factors (Jabloun and Sahli, 2008).

$$ETc = ETo*Kc \quad (2)$$

Where, ETo = Reference evapotranspiration (mm/day); Kc = Crop coefficient.

To estimate the reference evapotranspiration by using or applying the FAO Penman-Monteith equation on a daily or shorter timescale, the equation and some of the procedures for calculating meteorological data should be adjusted for the smaller time step. The atmospheric evaporating power rate was estimated by the following equation (Allen et al., 1998).

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{37}{T_{hr}+273}U_2(e^o(T_{hr}) - e_a)}{\Delta + \gamma\,(1 + 0.34U_2)} \quad (3)$$

Δ, Saturation slope vapour pressure curve at Thr [kPa °C-1]; Rn = Net radiation at the grass surface [MJ m^{-2} $hour^{-1}$]; G = Soil heat flux density [MJ m^{-2} $hour^{-1}$]; γ = Psychometric constant [kPa $°C^{-1}$]; Thr = Mean hourly air temperature [°C]; e^o = Saturation vapour pressure at air temperature; e^a = Average hourly actual vapour pressure [kPa]; U_2; Average hourly wind speed [m s^{-1}]

Drip irrigation has been scheduled by considering the estimation of the fraction of surface area wetted, depth of irrigation water applied, and wetted diameter of drip emitter. Therefore, two soil water distribution parameters have been taken as the primary indicator of interest for describing water distribution around drip emitter and for irrigation scheduling. Those parameters estimated during the on-field management of the experiment mentioned as follows.

Fraction of surface area wetted

Fraction of surface area wetted is estimated by the following equation (Doorenbos, 1975).

$$P = \frac{w}{l_e * l_r} \quad (7)$$

Where, P = Fraction of surface area wetted; W = Surface area wetted (m^2); Lr = Plant row spacing (m); Le = Emitter spacing (m).

Depth application determined by using the following equation (Doorenbos, 1975):

$$d = \frac{(p*TAW*Drz)*P}{E_U*E_a} \quad (8)$$

where, d = Depth of application (mm); TAW = Total available soil water (mm/m); Drz = Plant root zone depth (m); E_a = Field application efficiency (%); E_{Uf} = Emission uniformity (%); p = Soil

Table 2. Main effect of irrigation method on growth and certain yield parameters.

Treat	WFC(g)	WFCS(g)	WTS(g)	BM(kg/ha)	Yld(kg/ha)	WUE(kg/m3	HI (%)
Drip	207.30[a]	929.63[a]	326.53[a]	22067.9[a]	11368.3[a]	1.96[a]	51.1[a]
Furrow	192.07[b]	837.66[b]	298.96[b]	14181.1[b]	5065.8[b]	0.96[b]	35.5[b]
Lsd(0.05	14.6	61.23	18.52	1827.4	797.07	0.25	5.26
CV	8.84	8.39	7.16	12.43	12.19	12.13	14.92

WFC= weight of five cobs, WFCS= weight of five cobs seed, WTS=weight of thousand seed weight, BM= Biomass, Yld= Yield, WUE=water use efficiency, HI= harvest index.

water depletion fraction; P = Fraction of surface wetted.

The number of days between irrigations during periods without rainfall was determined by using the following formula (Doorenbos, 1975)

$$i = \frac{(p*TAW)*Drz*P}{ETc} \quad (9)$$

Where, I = Irrigation interval (day); ETc = Crop Water Requirements (mm/day); p = Soil water depletion fraction; P = Fraction of surface area wetted.

Working time was calculated by using the following equation (Doorenbos, 1975),

$$T=\frac{d*I_r*I_e}{q_e} \quad (10)$$

Where, T = Flow duration (hr.); q_e = Emitter flow rate (l/hr)

Determination of drip lateral hydraulics

One empirical equation frequently used is the Hazen and Williams formula. Also, because of the possibility of laminar, turbulent, or fully turbulent flow in trickles Darcy Weisbach equation was used to compute the head loss due to pipe friction (Liou, 1998).

$$H_f=\frac{fLV^2}{2gd} \quad (11)$$

Where, H_f = Head loss due to friction (m); f = Friction factor; L = Length of pipe(m); V = Velocity(m/s); g = Acceleration due to gravity(m/s^2) ; d = Pipe diameter(mm)

The flow variation was estimated by the following formula (Wu et al., 1979).

$$Q_{var}=1-(1-H_{var})^{x} \quad (12)$$

Where, Q_{var} = Flow variation; H_{var} = Pressure head variation; X=0.5 For laminar flow regime.

Pressure variation along the drip line was estimated by using the following equation (Wu et al., 1979).

$$H_{Var} = 1 - \frac{h_{min}}{h_{max}} \quad (13)$$

Where, H_{var} = Pressure head variation along the line; h_{min} = Minimum pressure along the line; h_{max} = Maximum pressure along the line.

RESULTS AND DISCUSSION

Analysis of variance showed that the mean values of plant height were statistically significant ($p \leq 0.05$) different due to the main effect of the irrigation system (Table 2).

Statistically significantly higher mean yield (11368.3 kg/ha) was recorded from drip and a lower mean yield (5065.8 kg/ha) was recorded from the furrow irrigation method. While there was a statistically ($p \leq 0.05$) significant difference between drip and furrow irrigation system in weight of five cobs, the weight of five cobs seed, the weight of thousand seed, above ground biomass, yield, water use efficiency, and harvest index.

Effects of irrigation system and irrigation level on water use efficiency

Effects of irrigations system and irrigation levels on yield parameters and grain yield production of maize are significantly influenced by irrigation system in combination with different irrigation level. The result of the study (Table 3) revealed that the water use efficiency of maize is significantly ($p \leq 0.01$) influenced by irrigation systems and irrigation levels. The highest water use efficiency was obtained from drip irrigation with 85%ETc (2.38 kg/m^3) and minimum obtained from Conventional furrow irrigation (0.60 kg/m^3). Using a drip irrigation system with 100%ETc shows that there is an increase in the maize yield production by 57.53% and save 33.7% of irrigation water as compared to conventional furrow irrigation (farmers practice); but compared to alternative irrigation with 100%Etc there is 71.5% of maize yield increase and 24.58% loss of irrigation water over alternative furrow irrigation. Deficit irrigation levels with drip irrigation have lower impacts on yields of maize grain production (Darouich et al., 2014).

The result of using alternative furrow irrigation with 100% ETc shows 32.8% of yield reduction and 49.99% saves irrigation water compared to conventional furrow irrigation; but, using a drip irrigation system with 100%ETc can increase the maize grain yield production by 57.53% and save 33.7% of irrigation water as compared to conventional furrow irrigation (farmers practice); compared to alternative furrow irrigation with 100%Etc there is 71.5% of maize yield increase and 24.58% loss of irrigation water over alternative furrow irrigation. Deficit irrigation levels with drip irrigation have

Table 3. Effect of irrigation system and irrigation levels on yield and water use efficiency.

Treat	BM	Yld	TSW	WUE	HI
CFI(100%ETc)	16049[b]	7078.2[d]	292.58[b]	0.60[f]	0.44[bcd]
AFI(100%ETc)	13704[b]	4753.1[ef]	322.01[ab]	0.81[ef]	0.34[efd]
AFI(85%ETc	14609[b]	4711.9[ef]	294.17[b]	0.95[ef]	0.32[ef]
AFI(70%ETc)	12963[b]	4732.5[ef]	301.05[b]	1.18[de]	0.37[c-f]
AFI(55%ETc)	13580[b]	4043.7[f]	258.02[b]	1.26[cde]	0.31[f]
DI(100%ETc)	26132[a]	16666.6[a]	369.20[a]	2.15[ab]	0.64[a]
DI(85%ETc)	24897[a]	12962.9[b]	332.24[ab]	2.38[a]	0.52[b]
DI(70%ETc)	23251[a]	9465.0[c]	330.20[ab]	1.77[bc]	0.42[b-d]
DI(55%ETc)	13992[b]	6378.6[ed]	289.43[b]	1.56[cd]	0.46[bc]
Lsd	3852.5	1680.4	53.01	0.56	11.10
CV	12.43	12.19	7.16	12.13	0.15

**Treatment with the same letter has no significant difference. AFI=Alternate furrow irrigation, BM= above ground biomass, CV=Coefficient of variation, DI=Drip irrigation, HI= Harvest index Lsd=Least significance difference, TSW= Thousand seed weight, Yld= Yield, WUE= Water use efficiency.

Table 4. Partial budget, MRR and BCR analysis.

Treatment	UnYld (kg/ha)	AdYld	Tot/price	TVC (ETB)	NB (birr/ha)	MRR (%)	BCR
T-3	4711.9	4240.	63,610.65	13,500.00	50,110.65	-	3.7
T-5	4043.7	3639	54,589.9	13,500.00	41,089.95	D	3.0
T-4	4732.5	4259	59,629.50	14,500.00	45,129.50	774.10	3.1
T-2	4753.1	4277	62,027.96	14,821.55	47,206.40	645.90	3.2
T-1	7078.2	6370	76,444.56	17,533.73	58,910.83	313.9	3.4
T-7	12962.9	11666	349,998.3	198852.0	151,146.3	50.9	0.8
T-9	6378.6	5740	172,222.2	198852.0	-26,629.80	D	-0.1
T-8	9465	8518	255,555	198852.00	56,703.00	D	0.3
T-6	16666.6	14999	449,998	210538.00	251,146.2	855.7	1.2

UnYld= Unadjusted yield, AdYld= Adjusted yield, Tot= Total, TVC= Total variable cost, NB= Net benefit, MRR= Marginal rate of return, BCR= Benefit cost ratio, ha= Hectare, ETB = Ethiopian birr, Treat= treatment, D= Dominancy analysis.

lower impacts on yields of maize grain production (Darouich et al., 2014).

Economic analysis and evaluation

According to CIMMTY (1988), the average yield was adjusted by 10% downwards. This is why researchers have a better agronomic management and better application of wisdom than farmers. Based on this, the recommended level of 10% was adjusted from all treatments to get the net yield of maize. Moreover, to attain the gross net benefits, it was vital to know the field price value of one kg of maize during harvesting time. Any treatment that has net benefits less than or equal to those of a treatment with lower costs that vary is dominated and denoted by 'D'(CIMMYT, 1988). The market price varies according to grain qualities. The gross returns were estimated by multiplying average market price rate with yield of respective treatments at the time of harvesting. The seasonal gross expenditure, net return and BC ratio for each treatment were estimated (Table 4).

According to the CIMMTY (1988) procedure for the dominance analysis, the treatment was arranged in order of increasing total variable cost (Table 3). Treatment (T-3) showed the least variable cost (13,500.00 birr) and treatment (T_6) showed the maximum variable cost (210538.00 birr) and all the remaining treatments were confined between these two treatments. As it is indicated in Table 3, treatment (T-4) had TVC of (14,500.00birr) and a net benefit of 45,129.50 birr was lower than treatment (T-6) as explained in Table 3. However, treatments T-5, T-8, and T-9 are dominated and not included in further analysis of the marginal rate of return. Dominated treatments (D) have a high total cost of

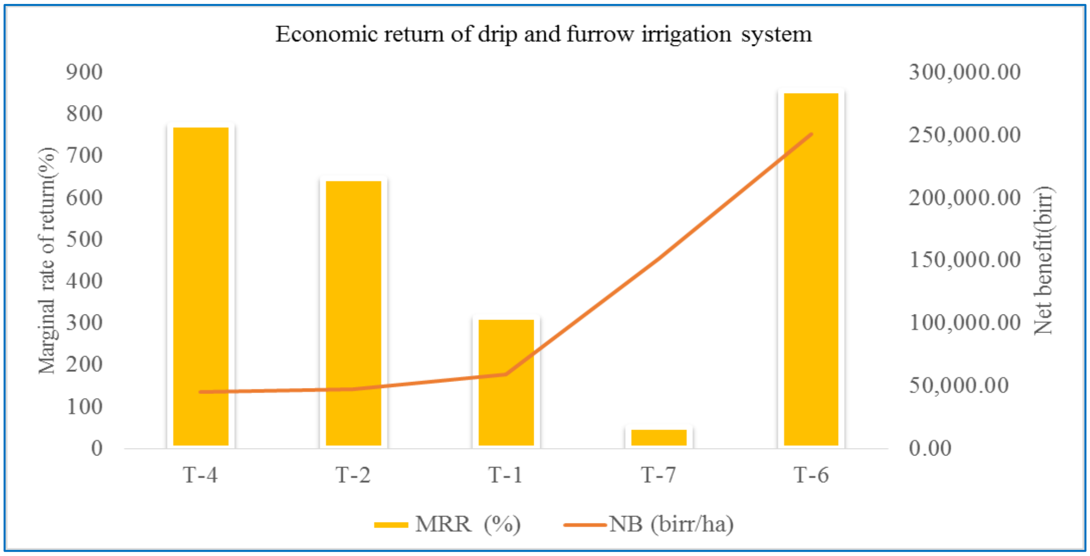

Figure 3. Economic gain of drip and furrow irrigation system with different irrigation level.

variable but lower net benefit. Though, the rest of the treatment had both higher variable cost and net benefit, hence not dominated and was considered for the marginal rate of return.

The economic analysis revealed that the highest net benefit of (251,146.2 birr) with higher total variable cost (210538.00 birr) was recorded from the application of 100%ETc with drip irrigation (T-6) and marginal rate of return 855.7%. The treatment (T-4) application of alternative furrow irrigation with 70%ETc gave the minimum benefit (45,129.50 birr) and marginal rate return of 774.10%. According to international maize and wheat improvement center (CIMMYT), the minimum acceptable marginal rate of return (MARR %) should be between 50 and 100% (CIMMYT, 1988). This showed (Figure 3) that T-1, T-2, T-4, and T-6 treatments are economically important as the MRR is greater than 100%.

Hence, the most economically attractive for small-scale farmers with lower total variable cost and higher net benefits were in the application of alternative furrow irrigation at 70% ETc (T-4). Conversely, for resource full producers (investors), application of drip irrigation at 100% ETc (T-6) was also gainful with higher cost, and the highest net benefit is recommended as an alternative option.

Conclusion

Drip irrigation has improved water use efficiency by increasing yield of crop. The main objective of the study was to find the best irrigation system for maize production with higher water use efficiency and possibility of lower grain yield reduction of Maize production in limited irrigation water areas. Based on the objective, among the treatments used in this experiment, drip irrigation with 100%ETc was the best treatment selected for the investors and alternative furrow irrigation with 70%ETc selected for local farmers. When comparing drip with furrow irrigation there is a significant difference in grain yield production, yield parameter and water use efficiency.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENT

The authors are thankful to Ethiopian Institute of Agricultural Research and Haramaya University Institute of Technology for the financial and technical support to conduct this experiment and also thankful to Werer Agricultural Research Center and staff members of Irrigation and Water Harvesting Research Division for their support and technical assistances in the field experimentation.

REFERENCES

Abate T, Shiferaw B, Menkir A, Wegary D, Kebede Y, Tesfaye K, Kassie M, Bogale G, Tadesse B and Keno T (2015). Factors that transformed maize productivity in Ethiopia. Food Security 7(5):965-981.

Allen RG (2000). Using the FAO-56 dual crop coefficient method over an irrigated region as part of an evapotranspiration intercomparison study. Journal of Hydrology 229(1-2):27-41.

Allen RG, Pereira LS, Raes D, Smith M (1998). Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. Fao, Rome 300(9):D05109.

Ati AS, Iyada AD, Najim SM (2012). Water use efficiency of potato (*Solanum tuberosum* L.) under different irrigation methods and potassium fertilizer rates. Annals of Agricultural Sciences 57(2):99-103.

Awulachew SB, Yilma AD, Loulseged M, Loiskandl W, Ayana M, Alamirew T (2007). Water resources and irrigation development in Ethiopia, Iwmi.

Batjes NH (2012). ISRIC-WISE derived soil properties on a 5 by 5 arc-minutes global grid (ver. 1.2). ISRIC-World Soil Information.

Cimmyt (1988). From agronomic data to farmer recommendations: an economics training manual, CIMMYT.

Dağdelen N, Yeşilırmak E, Gürbüz T, Yılmaz E, Akçay S (2009). Effect of different water stress on the yield and yield components of second crop corn in semiarid climate.

Darouich HM, Pedras CM, Gonçalves JM, Pereira LS (2014). Drip vs. surface irrigation: A comparison focussing on water saving and economic returns using multicriteria analysis applied to cotton. Biosystems engineering 122:74-90.

Doorenbos (1975). Guidelines for predicting crop water requirements. Food and Agriculture organization. Rome, Irrigation Drainage paper P 24.

Doorenbos J, Kassam A (1979). Yield response to water. Irrigation and Drainage Paper 33:257.

Hillel D (2004). Introduction to environmental soil physics Elsevier Academic Press. Amsterdam.

Jabloun MD, Sahli A (2008). Evaluation of FAO-56 methodology for estimating reference evapotranspiration using limited climatic data: Application to Tunisia. Agricultural Water Management 95(6):707-715.

Kashiani P, Saleh G, Osman M, Habibi D (2011). Sweet corn yield response to alternate furrow irrigation methods under different planting densities in a semi-arid climatic condition. African Journal of Agricultural Research 6(4):1032-1040.

Khalili M, Naghavi MR, Aboughadareh AP, Rad HN (2013). Effects of drought stress on yield and yield components in maize cultivars (*Zea mays* L.). International Journal of Agronomy and Plant Production 4(4):809-812.

Liou CP (1998). Limitations and proper use of the Hazen-Williams equation. Journal of Hydraulic Engineering 124(9):951-954.

Lovelli S, Perniola M, Ferrara A, Di Tommaso T (2007). Yield response factor to water (Ky) and water use efficiency of Carthamus tinctorius L. and Solanum melongena L. Agricultural Water Management 92(1-2):73-80.

Pereira LS, Oweis T, Zairi A (2002). Irrigation management under water scarcity. Agricultural Water Management 57(3):175-206.

Poh BL, Simonne EH, Hochmuth RC, Studstill DW (2009). Effect of splitting drip irrigation on the depth and width of the wetted zone in a sandy soil. Proceedings of the Florida State Horticultural Society 2009:221-223.

Rost S, Gerten D, Hoff H, Lucht W, Falkenmark M, Rockström J (2009). Global potential to increase crop production through water management in rainfed agriculture. Environmental Research Letters 4(4):044002.

Tagar A, Chandio F, Mari I, Wagan B (2012). Comparative study of drip and furrow irrigation methods at farmer's field in Umarkot. World Academy of Science, Engineering and Technology 69:863-867.

Van M, Morley T, Van Loon M, Reidsma P, Tesfaye K, Van Ittersum M K (2020). Reducing the maize yield gap in Ethiopia: Decomposition and policy simulation. Agricultural Systems 183:102828.

Wu I-P, Howell TA, Hiler EA (1979). Hydraulic design of drip irrigation systems.