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EVALUATION OF ALTERNATIVE AND CONVECTIONAL FURROW IRRIGATION SYSTEM ON TOMATO (SOLANUM LYCOPERSICUM L.) YIELD AND WATER USE EFFICIENCY AT WONDOGENET WOREDA, ETHIOPIA

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Abstract

The scarcity of water, lack of irrigation water management and erratic rainfall distribution is the major problem in the study areas. To handle scarce supplies, deficit irrigation is an important tool to achieve the goal of reducing irrigation water use and increase water use efficiency (WUE) under scarce water resources. A field experiment was designed as two factors factorial in RCBD; with three-time replicates. The two factors of the experiment were irrigation systems and water application levels. Irrigation depth was monitored using a Parshall Flume of an opening diameter of 3 inches with the discharge of 1.705l/s ahead of 5cm. The interaction effects of irrigation systems and water application levels showed that there is significant yield differences among the two irrigation systems and Maximum yield was obtained from the CFI system with 100% ETC. However, from economic analysis results, the AFI system with 75% ETc water application level had a better marginal rate of return (387.02%). The water saved by alternative furrow irrigation with (75% ETc) may be used to irrigate additional area that would provide additional crop production. Those based on the results, the AFI system with 75%ETC is taken as favorable for conservation of water (2106.75m3/ha)and labor saving with a minimum reduction of yield.

Keywords: Deficit Irrigation, RBCD, Water Use Efficiency and Irrigation method.

1. Introduction

Improved agricultural production has become a vital requirement of the increasing world population (Howell, 2001; Chen et al. 2011). However, there has been a continued decline in available freshwater that can be used by agricultural production (Cai and Rosegrant, 2003). Due to this, the sustainable use of water in agriculture has become the main concern and the adoption of plans for saving irrigation water and sustaining suitable yields can contribute to the conservation of this ever more limited resource (Topcu et al., 2007). Deficit irrigation is a water-saving strategy under which crops are showing a certain level of water stress either during a particular developmental stage or throughout the whole growing season (Pereira et al., 2002).

Tolerance crop to deficit irrigation during the growing season changes with the phonological stage (Istanbulluoglu, 2009). On the other hand, the effects of deficit irrigation on yield or harvest quality are crop-specific (Costa et al., 2007). It has described by FAO (2001) that 97.8% of irrigation in Ethiopia is done by surface irrigation methods, mainly by furrow system in farmer’s fields and the majority of the commercial farms. Furrows are particularly suitable for irrigating row crops such as vegetables, sugar beet, cotton, maize, potatoes, and tomatoes planted on raised beds, which are subject to damage if water shelters the crown or stems of the plants (Michael, 2008). The furrow irrigation systems contained conventional furrow irrigation (CFI), fixed furrow irrigation (FFI), and alternative furrow irrigation (AFI). CFI is the types of furrow irrigation systems where every furrow is irrigated during consecutive watering, is known to be less effective particularly in areas where there is a shortage of irrigation water. It is frequently causing too much deep percolation at the upper part of the furrow, insufficient irrigation at the lower part, and considerable runoff, resulting in small application efficiencies and distribution uniformities. The development towards optimal utilization of irrigation is to irrigate alternate furrows during each irrigation time (Zhang et al., 2000). By irrigating alternative furrows, half of the root is exposed to wet soil conditions, and the other half is exposed to dry soil conditions. According to Hodges et al., 1989 and Graterol et al., 1993, fixed furrow irrigation is a means of selecting some furrows for irrigation while other adjacent furrows were not irrigated for the whole season that is from sowing to harvesting.

Proper furrow irrigation system practices can reduce water application and irrigation costs, save water, control soil salinity build-up, and result in higher crop yields (Booher, 1974).

Tomato (Solanum Lycopersicon L.) is a very important vegetable crop and it is one of the most demanding in terms of water use (Peet, 2005). The application of deficit irrigation strategies to this crop may significantly lead to saving irrigation water (Costa et al., 2007). Furthermore, studies have shown that water deficit occurs for the period of certain stages of the growing season improves fruit quality, although water restrictions may determine fruit yield losses (Patane and Cosentino, 2010). According to Patane et al. (2011), the adoption of deficit irrigation strategies in which a 50% reduction in ETc was applied for the whole or partial growing season to save water-assisted to minimize fruit losses and maintain high fruit quality. Pulupol et al (1996) observed a significant decrease in dry mass yield for a glasshouse tomato cultivar by deficit irrigation, while Zegbe-Domínguez et al. (2006) cannot find a decline in tomato fruits yield of field-grown processing cultivar. Practicing deficit irrigation and water-saving methods of furrow irrigation systems could help to increase agricultural production by increasing irrigable land with a given limited amount of water (Teklu 2017). Therefore, this study aims at evaluating the effect of irrigation methods and deficit levels on the yield of tomatoes and water use efficiency.

2. MATERIALS AND METHODS

2.1 Study Area Description

The experiment site is located in Sidama at Wondo Genet Wereda. The area is located 265 km away from Addis Ababa, the capital city of Ethiopia. Wondo Genet Woreda geographically located a range of 6°56′40″N to 7°7′30″N latitude and 38°30′50″E to 38°43′20″E longitude and the elevation ranges from 1680 to 3960 a.m.s.l.

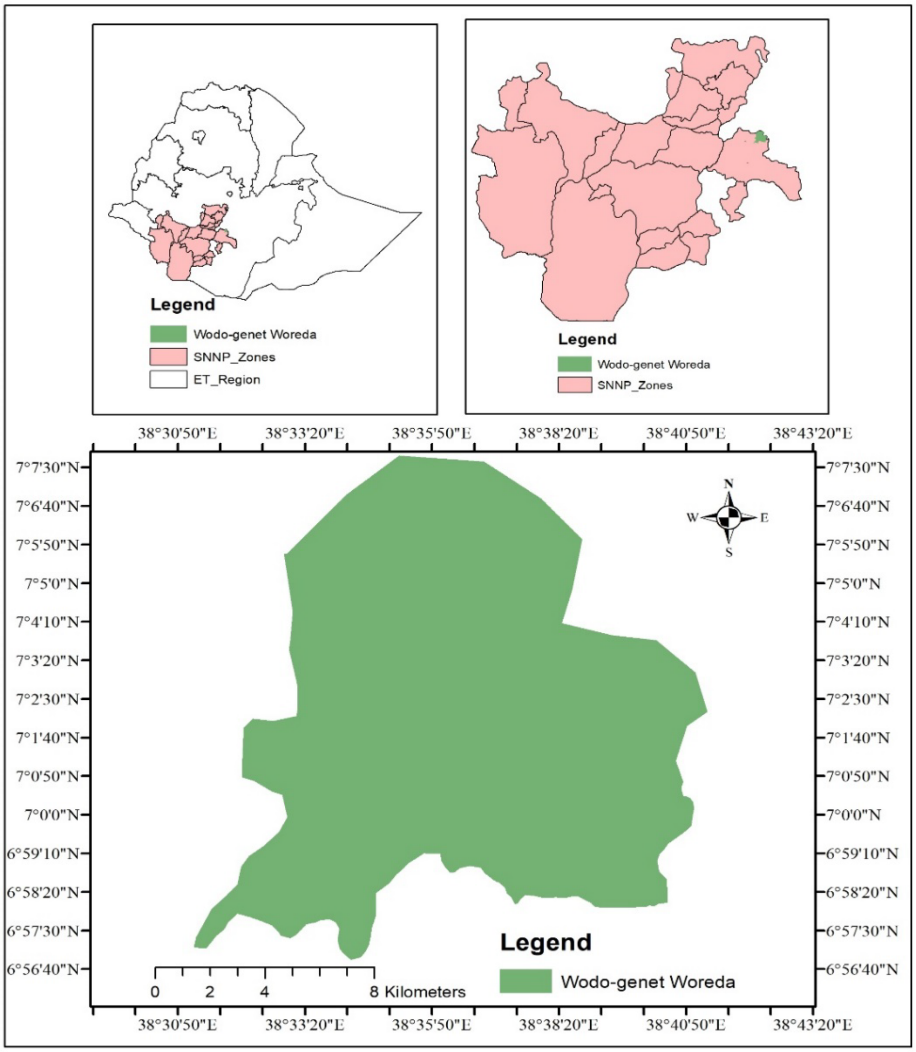

Fig.1. Location map of the study area

2.2 Experimental Design and Treatment

The experiment was applied in two factorial arrangement that is, two irrigation systems and three irrigation water levels (Table1). The treatments combinations were arranged as completely randomized blocks design with three-time replications. The depth of applied water to each treatment was measured by Parshall Flume of 3inch throat diameter.

The effective head of 5cm was calibrated and hence the resulting discharge out of the Parshall Flume was 1.705liters per second. Each treatment has a 4 m × 5 m plot size with 1m free space between plots and 1.5m wide spacing between blocks. The required crop water was calculated by using the CROPWAT version_8 computer program considering the soil and climatic properties of the study area (Allen et al., 1998). Improved tomato variety (Roma VF) having a total growing period of 45 days after transplanting was grown in seedbeds and transplanted on an experimental plot. This crop variety was selected for its good adaptability, disease resistance, and is most useful in the study area.

Table.1. Treatment used for the experiment

T1=100%ETc with alternate furrow irrigation

T2=100%ETc with conventional furrow irrigation

T3=75%ETc with alternate furrow irrigation

T4=75%ETc with conventional furrow irrigation

T5=50%ETc with alternate furrow irrigation

T6=50%ETc with conventional furrow irrigation

Where: AFI100% ETc and CFI100% ETc were alternatives, and conventional furrow irrigation with full irrigation respectively, AFI 75% ETc and CFI 75% ETc were 75% of the full irrigation (25% deficit level and CFI 50% ETc AFI and 50% ETc, were 50% of full irrigation (50% deficit).

2.3. Soil Sample Collection and Analysis methods

The disturbed and Undisturbed composite soil sample before planting from each treatment at a depth of 0-20cm, 20-40 cm, and 40-80cm were collected and analyzed for different soil physical properties such as bulk density, texture, field capacity, and permanent wilting point and also for chemical properties soil pH, at Hawassa Agricultural Research Center Soil Laboratory. Thus, the necessary analyzed soil data was used as input for the CROPWAT model.

2.4. Soil Physical and Chemical Properties

Soil texture was determined using pipette method. This is done based on direct sample of the density of the solution. As per Stoke's law at a depth 'L' below the surface of the suspension and at time't', all particles whose terminal velocity 'v' is greater than that was passed below this level for instance silt passes through but clay remains. The soil PH was measured in 1:1 soil: water mixture by using a pH meter. The soil bulk density is well-defined as the oven dry weight of undisturbed soil over in a given volume, as it occurs in the field. It was determined by core sampler method. We can collect soil sample from the field and weight it the soil sample, then it was placed in an oven dry at 105^{o}c for 24 hours. After drying the sample, the soil was weighed for a second time for dry mass and the bulk density was calculated by using the following formula.

$$pb = \frac{Wd}{Vv} \ldots\ldots (2.1)$$

Where

ρb= soil bulk-density, (g/cm3)

Wd = weight of dry soil, (g)

Vc = volume of core sampler, (cm3)

The double ring infiltrometers were used in order to measure the infiltration rate of the soil. The experiments were done at seven randomly particular points in the experimental site and the average result was taken at constant intervals of time. The Water content of field capacity (FC) and permanent wilting point (PWP) was determined by using a pressure plate apparatus by applying a suction of 1/3 and 15 bars to a saturated soil sample and when water is no longer leaving the soil sample, the soil moisture was taken as FC and PWP respectively and the PH was measured in a 1:1 soil: water mixture by using a pH meter.

2.5. Crop Data

The effective root zone depth (RZD) of tomato was ranged between 0.7-1.5m and it has an allowable soil water depletion fraction (P) of 0.40(Andreas et al., 2002). Tomato average Kc would be taken after adjustments have been completed for the initial, mid, and late-season stage to be 0.6, 1.15, and 0.8, respectively (Allen et al., 1998).

2.5. Crop Water Determination

Crop water requirement refers to the amount of water that needs to be supplied, whereas crop evapotranspiration refers to the amount of water that is lost through evapotranspiration (Allen et al., 1998). On behalf of the determination of crop water requirement, the effect of climate on crop water requirement, which is the reference crop evapotranspiration (ETo), and the effect of crop characteristics (Kc) are very important (Doorenbos and Pruitt, 1977). The long period and daily climate data such as maximum and minimum air temperature, relative humidity, wind speed, sunshine hours, and rainfall data of the study area were collected in order to determine reference evapotranspiration, crop data like a growing season, crop coefficient, and development stage, effective root depth, critical depletion factor of tomato and maximum infiltration rate and the total available water of the soil was determined to calculate crop water requirement using cropwat model.

$ETc = ETo * Kc$-- (2.2)

Where, ETc = crop evapotranspiration, Kc = crop coefficient and

ETO = reference evapotranspiration

2.6. Irrigation Water Management

The total available water (TAW), stored in a unit volume of soil can be obtained from the equation:

$TEW = (FC - PWP) * BD * Dz)/100$…………………………………………… (2.3)

The depth of irrigation water supplied at any time was determined by the expression

$Inet\ (mm) = ETc(mm) - Peff(mm)$……………………………………………… (2.4)

The gross irrigation requirement will be found from the expression:

$Ig = In/Ea$………………………………………………………………………. (2.5)

Ea =application efficiency of the furrows (60%)

The time required to distribute the desired depth of water into each furrow will be calculated using the equation:

$t = (d * l * w)/(6 * Q)$…………………………………………………………….. (2.6)

Where: d= gross depth of water applied (cm), t= application time (min), l= furrow length in (m), w= furrow spacing in (m), and Q= flow rate (discharge) (l/s)

2.7. Data Collection

Soil moisture was determined by the gravimetrical method and the Amount of applied water per all irrigation events was measured using an adjusted Parshall flume. During harvesting, the weight of economical yield, fruit number, unmarketable fruit weight, and unmarketable fruit number was measured from the net harvested area of each plot.

Meteorological like: minimum and maximum temperature, relative humidity, wind speed, and daily sunshine hours were collected from the nearby weather stations to determine reference crop evapotranspiration (Table 3). Evapotranspiration was calculated by using the Modified FAO Penman-Monteith method (Allen et al., 1998**).**

Table.3. Mean monthly meteorological data and ETO value of the study area

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m²/day	ETo mm/day
January	4.1	28.5	62	112	8.3	20.3	4.08
February	6.8	28.5	60	112	8	21	4.32
March	8.6	26.2	65	130	7.3	20.7	4.2
April	10.2	26.9	75	112	7.5	21	4.11
May	8.9	27.3	77	112	7.2	19.9	3.96
June	9.2	25.5	80	138	6.3	18.1	3.56
July	9.5	24.9	80	112	4.7	15.9	3.17
August	9.1	25.8	77	104	4.8	16.5	3.36
September	9.4	24.9	81	78	6	18.6	3.48
October	8.3	25.9	71	69	7	19.6	3.67
November	6.9	25.7	70	86	8.6	20.9	3.8
December	4.7	26.7	58	95	8.3	19.9	3.8
Average	8	26.4	71	105	7	19.4	3.79

2.8. Economic Analysis

Economical evaluation of deficit irrigation is analyzing the cost spent during the growing season and the benefit gained from yield produced by the application of water. Marginal Rate of Return (MRR) was used for analysis by the CYMMYT method (CIMMYT, 1988). Economic water productivity was calculated based on the information acquired at the study site: the size of the irrigable area, the price of water applied, and the income gained from the sale of tomato yield in view of the local market price. Yield and economic data were collected in order to evaluate the benefits of the application of different levels of water in deficit irrigation treatments. Economic data includes input costs like a cost for water (water pricing), seeds, fertilizers, fuel, and labor. However, the cost of water pricing and yield sale price were the only cost that varies between treatments. The net income (NI) treatments were calculated by subtracting total cost (TC) from gross income (GI) and were computed as

$NI = (GI - TC$ ……………………………………………………….……….. (2.7)

The difference between the net income of treatment and its next higher variable cost treatment is termed as a change in net income (ΔNI). Higher net benefits may very much higher costs (CIMMYT, 1988). Therefore, it is required to calculate marginal costs with the extra marginal net income. The marginal rate of return (MRR) indicates the increase of the net income, which is produced by each additional unit of expenditures and it is computed as follows:

$MRR = (\frac{\Delta \mathrm{NI}}{\Delta \mathrm{VC}})$ ………………………………………………………………………… (2.8)

Where, MRR= marginal rate of return, ΔVC= change in variable cost and

ΔNI= change in net income

2.9. Statistical Analysis

The collected data were analyzed using Statistical Agricultural Software (SAS 9.0) and the least significant difference (LSD) was employed to see a mean difference between treatments and the data collected was statistically analyzed following the standard procedures applicable for RCBD with a factorial. The treatment means that were different at 5% levels of significance were separated using the LSD test.

3. Results and Discussion

3.1 Physical and Chemical properties of Soil

As indicated in Table 2 the average composition of sand, silt, and clay percentages were 50.75%, 33%, and 16.25%, respectively. Thus, according to the USDA soil textural classification, the percent particle size determination for the experimental site revealed that the soil texture could be classified as loam soil. The soil of the trial experimental site is classified as loam and study place soil has an average bulk density of 1.3g/cm3 and the pH of the site is 6.4.

The bulk density shows a slight decrease with depth. This could be because of a slight decrease of organic matter with depth and compaction due to the weight of the overlying soil layer (Brady and Weil, 2002).

Table.2. Input soil data for CROPWAT model

Soil property		Soil depth in (cm)				
		0-20	20-40	40-60	60-80	Average
Particle size Distribution	Sand (%)	47	45	55	56	50.75
	Silt (%)	31	32	34	35	33
	Clay (%)	22	23	11	9	16.25
Textural class		Loam	Loam	Sandy loam	Sandy loam	Loam
Bulk density (g/cm3)		1.30	1.27	1.24	1.19	1.3
FC (Vol %)		17	16	13	15	15.3
PWP (Vol %)		9	8	6	7	7.5
PH		6.35	6.4	6.45	6.5	6.4
TAW (mm/m)						

Where: FC, Bd, and PWP were field capacity, bulk density, and permanent wilting point, respectively.

The basic infiltration rate in this experiment was found to be 10 mm/hr. This means that a water layer of 10 mm on the soil surface will take one hour to infiltrate. In dry soil, water infiltrates rapidly and as more water replaces the air in the pores, the water from the soil surface infiltrates more slowly and eventually reaches a basic infiltration rate. Irrigation water applied to the experimental plot was done using 3-inch Parshall flume at 5 cm head. The gross amount of water applied to each one plot was gained by multiplying the net irrigation depth of water by application efficiency.

Tomato was planted on 01/01/2018/19 and the growth months were (Dec, Jan, Feb, and March). The amount of water required by tomatoes was increasing from the initial period to the mid-period. The maximum irrigation water (53.5mm) and (26.8) as required by conventional and alternate furrow irrigation methods in March of mid-stage. In this stage, the tomato was attained its maximum crop coefficient and there was high reference evapotranspiration. At the late period the water required was reduced due to the reduction of crop coefficient value.

Table 3: Furrow type and irrigation water requirement for tomato at seven days interval

Date	Stage	Kc	ETo (mm/period)	100% ETc (mm/period)		75%ETc (mm/period)		50%ETc (mm/period)	
				CFI	AFI	CFI	AFI	CFI	AFI
23-Dec	Init	0.6	15.2	9.1	4.6	4.6	6.8	3.4	4.6
30-Dec	Init	0.6	42.8	25.7	12.9	12.9	19.3	9.6	12.9
06-Jan	Init	0.6	39.8	23.9	12.0	12.0	17.9	9.0	12.0
13-Jan	Deve	0.6	41.0	25.4	12.7	12.7	19.1	9.5	12.7
20-Jan	Deve	0.8	45.5	34.6	17.3	17.3	26.0	13.0	17.3
27-Jan	Deve	0.9	42.6	38.3	19.2	19.2	28.7	14.4	19.2
03-Feb	Deve	1.1	43.0	45.1	22.6	22.6	33.8	16.9	22.6
10-Feb	Mid	1.2	34.1	39.6	19.8	19.8	29.7	14.9	19.8
17-Feb	Mid	1.2	42.2	49.4	24.7	24.7	37.1	18.5	24.7
24-Feb	Mid	1.2	41.9	49.0	24.5	24.5	36.8	18.4	24.5
03-Mar	Mid	1.2	45.7	53.5	26.8	26.8	40.1	20.1	26.8
10-Mar	Mid	1.2	41.3	48.3	24.2	24.2	36.2	18.1	24.2
17-Mar	Late	1.1	41.2	45.3	22.7	22.7	34.0	17.0	22.7
24-Mar	Late	1.0	40.7	39.9	20.0	20.0	29.9	15.0	20.0
31-Mar	Late	0.9	40.4	34.7	17.4	17.4	26.0	13.0	17.4

Where: AFI and CFI are alternative furrow irrigation and conventional furrow irrigation, respectively.

3.2 Effects of irrigation systems with deficit irrigation levels on tomato yield

The result indicated in Table 4 Marketable yield was significantly affected by the amount of water applied to the tomato. The result showed that the application of too low water reduced the yield of tomatoes, but applying zero deficits gives a better yield. Higher marketable yield was 36908.3kg/ha obtained from treatment 100%ETC CFI irrigated with full irrigation, while lower yield was 20825.0kg/ha for treatment irrigated with 50% of ETc AFI.

Unmarketable yield means that the fruits that were affected by pest attack, birds attack, rotten and undersize. The result revealed that deficit irrigation treatment had no significant effect on the unmarketable yield of tomatoes.

The total fruit yield showed that treatment with full irrigation has a better yield and significant difference from other treatments. Total yield in this treatment means both marketable and unmarketable. In the treatment with full irrigation 37742.5kg/ha, yield was obtained.

Table 4: Tomato yield performance

No	TRT	MY(kg/ha)	UMY (kg/ha)	TY (kg/ha)
1	100%ETC AFI	27522.2c	570.6	28110.3c
2	100%ETC CFI	36908.3a	817.6	37742.5a
3	75%ETC AFI	22513.9d	690.2	23221.5d
4	75%ETC CFI	30502.8b	695.4	31216.3b
5	50%ETC AFI	20825.0d	640.4	21485.6e
6	50%ETC CFI	25861.1c	842.3	26718.9c
	CV	8.5	15.8	6.0
	LSD	2204.0	NS	1607.3

MY=marketable yield, UMY=unmarketable yield, TY=total yield, Kg/ha = kilogram per hectare, NS = non-significant

3.2.1 Water Use Efficiency

The analysis of variance indicated that irrigation levels and irrigation methods have significantly ($p<0.05$) affected the irrigation water use efficiency of tomatoes. Table 6 shows that the highest mean value of irrigation water use efficiency was observed to be 33.8 kg/m3 on irrigation with 50% ETc AFI and minimum mean value (15.0 kg/m3) for treatments T1(100% ETc CFI).

Table 6: Water Use Efficiency

No	TRT	CWUE (kg/m^3)	IWUE (kg/m^3)
1	100%ETC AFI	9.8bc	22.3bc
2	100%ETC CFI	6.6d	15.0d
3	75%ETC AFI	10.7b	24.3b
4	75%ETC CFI	7.2d	16.5d
5	50%ETC AFI	14.8a	33.8a
6	50%ETC CFI	21.0c	21.0c
	CV	11.3	11.3
	LSD	1.0	2.4

TRT= Treatment, WUE= Water use efficiency, IWUE Irrigation water use efficiency

3.3. Economic analysis of the interaction effects of irrigation systems and water application levels

The cost-benefit ratio for each treatment was analyzed and income was computed based on the current local market price of tomato at Wando-genet Woreda. At the time of harvest, the market price of tomato was 17 birr per kg and the cost of irrigation water was 10 birr/m3 (by considering the cost of drink water as the cost of irrigation water). To evaluate by the producer of dominance analysis, the treatments were set in their sort of increasing variable cost, and their equivalent benefits were put aside. 50%ETC AFI and 100%ETC CFI showed the minimum and maximum variable costs respectively. Based on the current prices of tomato yield produced and input costs required for production, the economic analysis was carried out. The highest net income (273327 birrs/ha) was obtained at (100%ETC CFI) and the least net income (131222 birr/ha) was obtained at (50%ETC AFI. However, as is indicated in the table the largest MRR (387.02 %) was acquired at 75%ETC AFI.

Table 8: Economic analysis of deficit irrigation on tomato

No	TRT	AW (m3/ha)	OY (kg/ha)	GI (birr/ha)	FC (birr/ha)	VC (birr/ha)	TC (birr/ha)	NI (birr/ha)	MRR (%)
1	50%ETC AFI	1404.5	16841.7	168417	19400	17795	37195	131222	0
2	75%ETC AFI	2106.7	21175	211750	19400	26692.5	46092.5	165657	387.0
3	50%ETC CFI	2809	23383.3	233833	19400	35590	54990	178843	148.2
4	100%ETC AFI	2809	23966.7	239667	19400	35590	54990	184677	D
5	75%ETC CFI	4213.5	28408.3	284083	19400	53385	72785	211298	149.6
6	100%ETC CFI	5619	36391.7	363917	19400	71190	90590	273327	348.4

AW= Applied water, Ay = Adjusted yield, GI=Gross income, FC= Fixed cost, TRT= treatment, VC=Variable cost, TC=Total cost, NI=Net income, MRR=Marginal rate of return, D=Domination Therefore, the highest economic return was observed at T2 (75%ETC AFI of CWR through the growing season) with net income of 165657.5 birr/ha and MRR of 387.02 %. The MRR tells us that the amount of additional income obtained for every 1 birr spent. Hence, T2 (75%ETC AFI of CWR through the growing season) acquired an additional 38.7birr for every 1birr spent. The minimum acceptable marginal rate of return (MRR) should be between 50 and 100% (CIMMYT, 1988).

4. Conclusion and Recommendation

The conclusions drawn from this research are;

Results obtained from this study show that, the highest economic return with a net income of 165657.5 birr/ha was obtained under 75%ETC alternate furrow irrigation. From economic analysis results, 75%ETC AFI system is better in the marginal rate of return and is the best technology among the tested technologies to be recommended for the communities of the study area, because of its yield performance, time, labor, and irrigation cost saving. Us alternative, in areas where enough water is available, applying 100%ETC CFI through the growing season, and in water-scarce areas of Wondo-genet woreda applying 75%ETC CFI of crop water requirement is advisable with a minimum reduction of yield.

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