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Comparative Performance Evaluation of Alternate and Convectional Furrow Irrigation under Different Water Application Level on Cabbage Water Use Efficiency and Economic Analysis

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Abstract: Suitable irrigation method with application level is essential for adaptation and adoption in the areas where water resources are limited. Therefore, a field experiment was conducted to test the performance of alternate furrow irrigation (AFI or FFI) and convectional furrow irrigation (CFI) with three water application level on crop, yield response, water use efficiency and cost benefit analysis of cabbage. The experiment had two factors, factorial design arranged in Randomized Complete Block Design (RCBD) with nine treatments of three replicate. The treatment namely three furrow Irrigation method alternative Furrow Irrigation (AFI), Fixed Furrow Irrigation (FFI) and Convectional Furrow Irrigation methods (CFI) and three application levels full (100%), three forth 75% and half 50% of full ETc (crop water requirement). The result shows CWUE, IWUE and EWP were highly significantly ($P<0.01$) affected by both IMs and ALs. The highest and the lowest mean crop and irrigation water use efficiency (CWUE and IWUE), and economic water productivity (EWP) were recorded by AFI and CFI irrigation. Whereas, under ALs the highest and the lowest mean CWUE, IWUE and EWP were recorded by 50% and 100% ETc Application depth. Maximum water saved resulted from AFI and FFI, with 50%, 75% and 100% ETc application depth was equally computed as 58.33%, 37.50% and 16.67% which could irrigate additional area of 0.20, 0.60 and 1.40 ha for each treatment respectively. Contrarily yield reduction was higher in FFI followed by AFI and CFI with the same ALs. NR (net return) produced per hectare was higher in CFI followed by AFI and FFI. In case of BCR, AFI with 75% and 50% ETc was higher than FFI followed and the smallest by CFI of 50% and 75% ETc deficit level. Hence yield reduction and NR incurred by alternate (AFI and FFI) were compensated from additional irrigable area by diverting the water and labour saved. Generally from over all investigation of CWUE, IWUE, EWP, NR and BCR alternative furrow irrigation method (AFI) was better than FFI and CFI for the water scarce area.

Keywords: Alternate Furrow Irrigation, Deficit Levels, Cabbage Crop, Water Use Efficiency, Economic Analysis

1. Introduction

Irrigated agriculture extends over 270 million hectares [1]. Although it represents only 17% of the world cultivated area, it provides 40% to 45% of the world food and fiber supply [2]. Irrigated agriculture is the major consumer of available fresh water worldwide and its consumption is estimated at ~70% of the existing freshwater supplies [2]. The competing uses for water (domestic, industrial, and environmental) and the increasing demand for food due to a rapidly growing world population require an urgent improvement of productivity per unit of water consumed in agriculture [3].

About 90% of the irrigated land of the world is irrigated using relatively inefficient surface irrigation methods [4].

Similarly in Easter Ethiopia traditional surface irrigation methods (basin, border and furrow) are widely used to irrigate crops, though acute water shortage. Now a day the modern, high-tech and efficient micro irrigation methods (drip, bubbler, sprinkler etc.) are advocated worldwide, however; in developing countries like Ethiopia is not affordable, because of high cost of installation, operation and maintenance, and required skilled manpower. Thus seeking for efficient irrigation methods that are economical, easy to install and operate, and which are readily acceptable to the farming community is demanding.

Furrow irrigation, reported to be one of the least efficient methods compared with other irrigation methods [5] is still one of the most widely used forms of surface irrigation. Despite its application efficiency remaining relatively low [6], not enough effort is being made to keep improving its management and efficiency. Because furrow irrigation is a well-known, simple and economical method of irrigation, farmers are likely to be ready to adopt new approaches that are practical improvements of their current practices and that result in improved water use efficiency.

The studies of [7, 8] have been suggested efficiency of conventional furrow irrigation (CFI) or every furrow irrigation, can be improved by converting it to alternate furrow irrigation (AFI). The AFI method is essentially the same as CFI, except that instead of irrigating every furrow, irrigation is applied to alternate furrows, while the in-between furrows remain dry. This means each ridge receives water from only one side, and the side receiving irrigation water could be changed with each irrigation event if the field set up is facilitating this change. Irrigating just one side of the ridge means there is significant potential to save irrigation water compared to CFI. However, there is potential in some cases for a reduction in crop yield [9].

Deficit irrigation has been used as a water saving method in agricultural production to increase benefit and water use efficiency [10 and11]. Deficit irrigation, under furrow irrigation, can be induced via different irrigation techniques such as fixed-furrow. Fixed furrow irrigation (FFI) is a way to save water and showed a small improvement over the alternate furrow irrigation [12]. For economic and environmental benefit of using every-other furrow irrigation method is higher than any other irrigation methods, because less water is applied and a greater economic return can be obtained [13]. Therefore; the aim of this study was to investigate the comparative performance of alternate and convectional furrow irrigation under different water application levels on cabbage relative yield response, water use efficiency and economic analysis.

2. Methods

The field experiment was conducted Eastern Ethiopia in Kombolcha ATEVT college farm site situated at 09° 25′ 50″ – 09° 28′ 20″ North latitude and 42° 04′ 10″ – 42° 08′ 20″ East longitude and at an altitude of 2160 m a. s. l. Site is 566 km from capital city and 1 km from meteorological station. The site receives a mean annual rainfall of 650 mm. It has erratic and uneven in distribution, with mean minimum and maximum temperatures of 10°C and 27.8°C, respectively. The sources of irrigation water are hand dug wells. The soil in the experimental site, being sandy clay loam, moderate infiltration and moderate organic matter content. Average field capacity and permanent wilting point in volume bases of the soil for the experimental plots were 34.88% and 20.8% respectively, in the upper 0 - 60 cm of the soil profile. The bulk average density for this soil was about 1.14 g cm^{-3}.

2.1. Treatments and Experimental Design

The experiment had two factors, factorial design arranged in Randomized Complete Block Design (RCBD) with three replications. The treatments considered for the experiments were two factors namely three furrow irrigation methods and three application levels. 1) Alternative Furrow Irrigation (AFI) with 100%, 75% and 50% of crop water requirement, 2) Fixed Furrow Irrigation (FFI) with 100%, 75% and 50% of crop water requirement and Convectional Furrow Irrigation methods (CFI) with 100%, 75% and 50% of crop water requirement. The experiment was conducted on individual plot size of 4 m x 3 m (12 m^2) with 27 number of such plot. The number of seedlings on each plot (bed) was 40. The number of seedlings in each row was 10 spaced at 40 cm and the numbers of row of seedlings on each bed was 4 spaced at 75 cm. Five weeks after germination seedlings were transplanted on December 10, 2015 to experimental plots and harvested after 120 DAP (days after planting).

2.2. Agronomic Practices

A common recommended fertilizer rate was applied manually in the experimental plots. All plots received the same amounts of fertilizer consisted of 150 kg ha^{-1} of urea and 100 kg ha^{-1} of P_2O_5 (DAP). The irrigation water used in the study was obtained from a well. Crop water requirements was estimated using the CROPWAT computer software program using climatic, soil and crop data as inputs. Soil samples were taken by a screw auger at planting, before and two days after each irrigation event, Samples were taken on the beds at three point and in the furrows at two depths: 0–30 and 30–60 cm from convectional furrow. The samples were used to measure the volumetric soil-water content in the root zone using the gravimetric method, based on the conventional oven-dry weight, and multiplied by the bulk density to determine irrigation water requirement.

2.3. Water Application and Irrigation Water Requirement

The total amount of water estimated using the CROPWAT model was diverted to the furrow with calibrated siphon of correction factor of (0.65) tubes having opening diameter of one and half inch at the sides of the ditch water supplied to each furrow was under controlled by the difference in depth between the water level in the feeder canal and free water level at the outlet at the furrow head. This was calculated as [14].

$$Q = 0.65 * 10^{-3} * a * \sqrt{2gH} \quad (1)$$

where; Q is discharge from siphon tube ($l\ s^{-1}$), a is area of cross section, inside of tube (cm^2), g is acceleration due to gravity (cm sec^{-1}, 981cm sec^{-2}) and H is effective head causing flow (cm).

The effective head was calibrated to be 12 cm and hence the resulting discharge out of the siphon tube was 1.15 liters per second. This discharge was selected in order to avoid erosion, in accordance effective height and allowable maximum non erosive discharge as possible recommended by [3].

The time required to deliver the desired depth of water in to each furrow was calculated using the equation recommended by [15]:

$$t = \frac{D_{ap} * w * l}{360 * q} \quad (2)$$

where; D_{ap} is depth of water applied (cm), t is application time (hr), l is flow length (m) q is flow rate ($l\ s^{-1}$) and w is furrow spacing (m).

2.4. Net and Gross Irrigation Water Requirement

Cabbage (*Brassica oleraceacapita L.*) can flourish under irrigation in the lower altitudes. Irrigation is a standard practice in vegetable crop like cabbage. Water needed per irrigation was determined as net depth of irrigation water that is required consumptively for crop production. It is the amount of irrigation water required to bring the soil moisture level in the effective root zone to field capacity. Thus it was the difference between the field capacity and the soil moisture content in the root zone before starting irrigation. This is obtained by the relation given below;

$$I_{net} = \frac{(\theta_{fc} - \theta_i)\rho_b * D_r}{100} \quad (3)$$

where; I_{net} is the net amount of water to be applied during irrigation (cm), θ_{fc} is the moisture content at field capacity in the root zone by volume (%), θ_i is field moisture content before irrigation in the root zone by volume (%) i.e. 0-30 and 30-60 cm depth, D_r is the depth of the root zone (cm) r= 60 cm and bulk density of the soil in the root zone (g cm^{-3}). Gross depth of irrigation water (I_{gr}) equals the net irrigation depth (I_n) divided by the application efficiency (E_a). The following equation was used to compute gross irrigation water requirement.

$$I_{gr} = \frac{I_n}{E_a} \quad (4)$$

The field water application efficiency for surface furrow irrigation is normally taken as 60%.

Water saving with AFI and FFI compared to CFI was calculated as:

$$WS(\%) = \frac{(W_{CFI} - W_{AFI/FFI})}{W_{CFI}} * 100 \quad (5)$$

where WS is water saved W_{CFI} is total water used (mm) with the CFI method and WA is total water used (mm) with the AFI and FFI method and amount of water applied for AFI and FFI was equal.

Percent of yield increase/decrease in yield (%) compared to the AFI or FFI method was computed as

$$Y_{I/D}(\%) = \frac{(Y_{CFI} - Y_{AFI/FFI})}{Y_{CFI}} * 100 \quad (6)$$

where $Y_{I/D}$ is percent yield increase or decrease, $Y_{AFI/FFI}$ and Y_{FIC} are yields ($kgha^{-1}$) obtained with the AFI/FFI and CFI methods, respectively.

2.5. Water Productivity

(1) Crop water use efficiency (CWUE): Crop water use efficiency (CWUE) or so-called in other references crop water productivity (CWP) was computed by dividing crop yield by consumptive water use (net irrigation).

$$CWUE = \frac{Y_a}{\text{Consumtive water applied to the field } (m^3)} \quad (7)$$

(2) Irrigation water use efficiency (IWUE): IWUE (kg m^{-3}) was determined by dividing the yield to seasonal evapotranspiration and total seasonal irrigation water applied, and calculated by the following equation:

$$IWUE = \frac{Y_a}{\text{Total water applied to the field } (m^3)} \quad (8)$$

where WUE is water use efficiency (kg m^{-3}), Ya is actual yield (kg), and total (gross irrigation) water applied to the field (m^3) was determine from ETc is seasonal crop evapotranspiration from the cropped area.

(3) Economical water productivity: (ETB m^{-3}) relates the economic benefits per unit of water used. It was calculated by:

$$EWP = \frac{\text{Output (value)}}{\text{Total amount of water consumed } (m^3)} \quad (9)$$

where; Wp is the economic water productivity in ETB m^{-3}, out-put is the product of marketable yield and market price in ETB, and water consumed in m^3. ETB is Ethiopian ETB

2.6. Cost Benefit Ratio and Net Return Analysis

The cost and benefit of each treatment was analyzed partially, yield and economic data were computed to compare the advantage of different furrow irrigation methods and application levels of each treatment. The total cost mainly includes operating and variable costs. Operating costs (labor, land preparation, seeds, and fertilizers and implement costs) were based on the planted area. Variable costs depended on the number of irrigation events, labour and water unit price. The indigenous farmers in the study area do not pay for irrigation water of their farms. Therefore assumption was made for the costs of water unit price which was estimated to be 12.5 ETB m^{-3}. The man-day labor cost was 50 ETB day^{-1} to irrigate field. Total water cost for season was calculated by multiplying the water unit price by the total amount of irrigation water required for cabbage crop. Gross revenue has been calculated by multiplying total yield in kg ha^{-1} of cabbage market price per kilogram. The farm-gate price for cabbage in this study was 2.5 ETB kg^{-1} (averaged local price). Net return (NR) and benefit-cost ratio (BCR) due to irrigation were calculated according to [16] as follows:

$$NR = \text{Gross revenue} - \text{Total cost} \quad (10)$$

The benefit cost ratio (BCR) in ETB or ETB measures the increase in net return (NR) which was generated by total cost expenditure (TC):

$$BCR = \frac{NR}{TC} \quad (11)$$

The amount of water saved (WS) per hectare of land was obtained by subtracting convectional furrow irrigation with 100% ETc application levels as control for each treatment. The net return for additional area (NRA) for harvested marketable yield was calculated as the difference between the sum of the cost of labor for interaction of irrigation methods and application levels, the cost of water that was saved from application levels, and the revenue lost due to yield decreases resulting from this factor protocol is given [17] as;

$$NRA = (G*LS + C*WS) - P*YL \quad (12)$$

where, NRA is Net returns of additional area (ETB), LS is Labor saved from irrigation system (man per day), WS is Volume of water saved (m^3 ha^{-1}), YL is Yield loss (kg ha^{-1}), C is Unit price per m^3 of water, P is Unit price per kilogram of cabbage yield and G is Unit cost of labor per irrigation per ha

The extra irrigable land area which could be served by the irrigation water saved per hectare was determined by dividing the total saved water per hectares of land to be irrigated, the extra land was obtained by multiplying the change in net income by the area saved [17].

2.7. Statistical Analysis

All measured variables were subjected to analysis of variance appropriate for RCBD. The data were analyzed using Genstat 15th edition statistical software. The mean separation was made using fisher protected list significant difference (LSD) method.

3. Result and Discussion

3.1. Water Productivity

3.1.1. Crop Water Use Efficiency (CWUE)

The outcome of statistical analysis indicates that CWUE varied highly significantly ($P<0.01$) influenced by both irrigation methods (IMs) and application levels (ALs). The highest value produced was 29.53 kg m^{-3} by AFI, and the lowest was recorded by CFI as 26.48 kg m^{-3}, but when compared AFI with FFI there were no significant difference between them. Application levels show that, CWUE significantly increased when irrigation amount or depth decreased. Similarly the result for ALs shows that, the highest value of crop water use efficiency of 35.93 kg m^{-3} was obtained by ALs of 50% ETc followed by 75% ETc as 26.90 kg m^{-3} and 22.07 kg m^{-3} at 100% ETc correspondingly (Table 1).

It is also evident that, at each irrigation methods, the CWUE increased with decreasing the water application level, comparatively, when goes from 100% ETc to 50% of ETc ALs the value observed as 13.86 kg m^{-3} difference (Table 1).

Table 1. *Effect of different furrow irrigation methods and application levels on crop water use efficiency.*

Irrigation method	CWUE	Application level	CWUE
AFI	29.53[a]	100 % ETc	22.07[c]
FFI	28.90[a]	75 % ETc	26.90[b]
CFI	26.48[b]	50 % ETc	35.93[a]
LSD (5%)	1.232		1.232

CWUE (kg m^{-3}): Crop water use efficiency, LSD: Least significance difference, Note: means followed by the same in column have not significant difference

3.1.2. Irrigation Water Use Efficiency (IWUE)

The analysis of variance, showed that IWUE were highly significantly ($P<0.01$) influenced by both IMs and ALs. The observation from Table 2 opined that irrigation water use efficiency was decreased significantly from 17.72 to 15.89 kg m^{-3}, for AFI and CFI respectively, but statistically mean of IWUE produced by AFI and FFI were not significantly different. IWUE was also affected by application levels, and the highest value was recorded as 21.56 kg m^{-3} by 50% ETc followed by 75% ETc (16.14 kg m^{-3}), whereas 13.24 kg m^{-3} at 100% ETc deficit levels in decreasing order.

This result indicates CWUE and IWUE related to the amount of water supplied has inverse relation with yield obtained as formulated previously in equation 7 and 8.

Table 2. *Effect of different furrow irrigation methods and application levels on irrigation water use efficiency.*

Irrigation method	IWUE	Application level	IWUE
AFI	17.72[a]	100 % ETc	13.24[c]
FFI	17.34[a]	75 % ETc	16.14[b]
CFI	15.89[b]	50 % ETc	21.56[a]
LSD (5%)	0.739		0.739

IWUE: (kg m^{-3}) Irrigation water use efficiency, ETc: Evapotranspiration of crop, LSD: Least significance difference, Note: means followed by the same in column are not significantly different

3.1.3. Economic Water Productivity (EWP)

The analysis of variance revealed that economic water productivity was highly significantly ($P<0.01$) influenced by both irrigation methods (IMs) and application levels (ALs). The result indicates that mean maximum economic water productivity value for AFI obtained as 64.26 ETB m^{-3}, which had no significant different from fixed furrow irrigation methods and the mean minimum EWP was recorded by CFI as 57.65 ETB m^{-3} (Table 3).

Table 3. *Effect of different furrow irrigation methods and application levels on economic water productivity.*

Irrigation method	EWP	Application level	EWP
AFI	64.26[a]	100 % ETc	48.34[c]
FFI	62.90[a]	75 % ETc	58.59[b]
CFI	57.65[b]	50 % ETc	77.88[a]
LSD (5%)	3.67		3.67

EWP: (ETB m^{-3}) Economic water productivity, LSD: Least significance difference, Note: means followed by the same in column are not significantly different.

Accordingly the maximum value logged by half (50% ETc) was 77.88 ETB m^{-3} followed by three forth (75% ETc) 58.59 ETB m^{-3} and lowest by full (100% ETc) 48.34 ETB m^{-3} in application levels (Table 3).

3.2. Significance of Irrigation Method and Application Levels on Cabbage Yield Optimization and Net Return

3.2.1. Combined Effect of Irrigation Methods and Application Levels on Relative Water Use Efficiency and Cabbage Yield

The result shown that maximum yield obtained 86866.7 kg ha^{-1} by CFI with 100% ETc which was not subjected to water stress, and minimum yield of cabbage (64277.8 kg ha^{-1}) was obtained under FFI with 50% ETc, this yield was obtained by stressed 50% of (4142.4 m^3 ha^{-1}) net volume of irrigation requirement of 2071.2 m^3 ha^{-1} (Table 4). More detailed the result was implicitly considered that the amount of water applied in treatment AFI and FFI only for two furrow in each irrigation event. Therefore amount of water applied was reduced by half and increased with application efficiency resulted in 1726.0 m^3 ha^{-1} for 50% deficit treatment. The study result was in line with that of others work such as [32] [33] [34].

Throughout growth season maximum volume of water saved from 50% application depth in volume was (2416.4 m^3 ha^{-1}) of net irrigation water requirement. The detail of water saved from each treatment of alternative and fixed furrow irrigation system and 75% and 50% deficit of CFI is described in Table 5.

Moreover further elaboration as per trial or based on different irrigation methods with respect to their application levels, considerable mean maximum yield achieved by CFI followed by FFI which is not significantly different from AFI with 100% ETc. Relative water use efficiency was decreased from 1.082, 1.076 and 1.0 as moving from FFI, AFI and CFI with 100% ETc respectively (Table 4). Accordingly at 75% ETc ALs, the result indicated that maximum mean yield recorded 80044.4 kg ha^{-1} by CFI and minimum was 69288.9 kg ha^{-1} by FFI with 75% ETc. However, Relative water use efficiency was lowered as moving from alternating (AFI) to convectional furrow irrigation (CFI) irrigation with 75% ETc of full ALs. Accordingly maximum relative water use efficiency as 1.80 was recorded by AFI followed by FFI of 1.78 and CFI with 50% ETc as 1.56 respectively (Table 4).

Yield reduction was calculated for all treatments, except control treatment (CFI with 100% ETc) which was not exposed to water stressed as described in Table 5. Hence the finding pursued to estimate water and labor saved from each treatment with modest yield reduction, which leads to increase cultivation land or otherwise compensating yield lost at an area of water scarce.

Table 4. *Effects of irrigation method and application levels on relative water use efficiencies of cabbage crop.*

Treatment combination	Yield kg ha^{-1}	I_n m^3 ha^{-1}	I_g (m^3 ha^{-1})	CWUE kg m^{-3}	IWUE kg m^{-3}	RCWUE
AFI 100% ETc	77904.4	3452.0	5753.3	22.6	13.5	1.076
AFI 75% ETc	72955.6	2589.0	4315.0	28.2	16.9	1.34
AFI 50% ETc	65300.0	1726.0	2876.7	37.8	22.7	1.80
FFI 100% ETc	78311.1	3452.0	5753.3	22.7	13.6	1.082
FFI 75% ETc	69288.9	2589.0	4315.0	26.8	16.1	1.28
FFI 50% ETc	64277.8	1726.0	2876.7	37.2	22.3	1.78
CFI 100% ETc	86866.7	4142.4	6904.0	21.0	12.6	1.00
CFI 75% ETc	80044.4	3106.8	5178.0	25.8	15.5	1.23
CFI 50% ETc	67755.6	2071.2	3452.0	32.7	19.6	1.56

Note: CWUE: Crop water use efficiency, IWUE: Irrigation water use efficiency, I_n: Net irrigation water applied, I_g: Gross irrigation water applied, RCWUE: Relative crop water use efficiencies

Since the planned ET deficit was imposed for specific irrigation methods and application levels. Then it could be possible to calculate the total irrigation water saved, since the total crop water applied is known. For all irrigation methods with 100% ETc ALs, actual evapotranspiration is assumed to be equal to maximum evapotranspiration [35]. Since $ET_a = ET_m$ therefore $Ya = Y_m$ (actual yield equals maximum yield). Therefore, it could possible to derive the relationship between relative yield reduction and relative evapotranspiration deficits or water application levels.

The observation reveals that yield reduction was maximum in treatment with 50% ETc levels of deficit. The maximum mean marketable yield reduction was observed in FFI of 18811.1 kg ha^{-1} followed by AFI as 17511.1 kg ha^{-1} and 15866.7 kg ha^{-1} by CFI with 50% ETc application depths, but water and labour saved was opposite (Table 5). Hence the yield reduced due to this deficit levels were compensated with additional production of water and labour saved from alternative and fixed furrow irrigation system and CFI with75% and 50% ETc.

3.2.2. Effect of Irrigation Methods and Application Levels on Water and Land Productivity

The result indicated that water saved from treatment combination of AFI and FFI with 100% ETc, 75% and 50% ETc levels were 16.67 %, 37.5% and 58.33% of total net volume of irrigation water applied. Whereas CFI with 75% and 50% application obtained 25% and 50% respectively.

CFI with 100% ETc application depth recorded maximum yield because this treatment received full crop water requirement, hence no yield reduction observed. Whereas AFI and FFI with 100% ETc yield reduction was less than 10%, which was indicated as 9.4 and 7.5%, respectively when compared with no water stressed (CFI with 100% ETc). However AFI and FFI with 100% ALs were saved 16.67% water from each treatment (Table 5), which could irrigate about 0.2 ha (Table 6).

But under plot of 75% ETc application depth or 25% stressed treatment of AFI, FFI and CFI were indicated that significant yield reduction as 16.3%, 21.2% and 9.7% respectively. As presented in Table 5 total amount of net volume of irrigation water as 37.5% (1553.40 m^3) from AFI, FFI of each treatment and 25% (1035.60 m^3) from CFI was saved. Hence water saved from AFI, FFI and CFI with 75% ALs could irrigate 27% (1.53 ha) of total additional area (Table 6). The result indicates cabbage performance under this deficit level was better in convectional furrow irrigation (CFI) followed by AFI and FFI with 75% ALs correspondingly.

Accordingly for treatments with 50% ETc application level, yield reduction was higher when compared to 75% ETc as presented in (Table 5). The yield reduction in accordance to application level was increased as 22.0, 24.3 and 26.1% by CFI, AFI and FFI with 50% ETc respectively. This is because the cabbage stressed by half (50%) net crop water requirement which resulted in maximum yield reduction compared to normal or full water application. However 66 % of water saved could irrigate a total additional area of 3.8 ha. This clearly shows that yield reduction resulted from both irrigation methods and application levels could be compensated by additional irrigable area to be cultivated. From economic point of view yield obtained from total additional irrigable area (5.73 ha) could produce 325.9 tons of marketable cabbage yield (Table 6).

Table 5*. Relative yield reduction of cabbage and water saving with respect irrigation methods and application levels.*

Treatment combination	Marketable yield (kg ha^{-1})	Yield reduction (kg ha^{-1})	Yield eduction (%)	I_n (m^3 ha^{-1})	Water saved from I_n (m^3 ha^{-1})	Water save in (%)
AFI 100% ETc	65304.4	6762.2	9.4	3452.0	690.40	16.67
AFI 75% ETc	60333.3	11733.3	16.3	2589.0	1553.40	37.50
AFI 50% ETc	54555.6	17511.1	24.3	1726.0	2416.40	58.33
FFI 100% ETc	66655.6	5411.1	7.5	3452.0	690.40	16.67
FFI 75% ETc	56811.1	15255.6	21.2	2589.0	1553.40	37.50
FFI 50% ETc	53255.6	18811.1	26.1	1726.0	2416.40	58.33
CFI 100% ETc	72066.7	0.0	0.0	4142.4	0.00	0.00
CFI 75% ETc	66377.8	5688.9	7.9	3106.8	1035.60	25.00
CFI 50% ETc	56200.0	15866.7	22.0	2071.2	2071.20	50.00

3.3. Cost Benefit and Economic Analysis

Net Return from Additional Irrigable Area

Net return from additional irrigable area due to water saved from irrigation methods and application levels of cabbage production estimated according to water applied for each treatment. Table 6 indicates that the net return (NR) computed from the water and labor saved of each treatment and detail calculation of net income or return gained from additional irrigable area of each treatment are presented. The result indicates that the highest net return observed in alternative irrigation method with 50% ETc application level and the lowest net return was obtained from CFI with 75% ETc application level. With the same vein, CFI with 75% ETc application level resulted in lowest water saved and irrigable area compared to AFI and FFI of the same ALs. It clearly seen that the value of net return generated was influenced not only by water applied but also furrow irrigation methods.

On the other hand, CFI with 100% ETc was used as control for all treatment. The result shows the water saved from AFI and FFI with 100% ETc or with full irrigation only found out from the two other furrows remain dry until the next irrigation schedule for AFI and FFI with their application. Accordingly the additional area to be irrigated of each treatment was calculated based on the amount of water applied and the ratio of total water applied for non-stressed treatment (CFI with 100% ETc) to stressed treatments. Likewise, the total additional area obtained was converted to hectare from each treatment as about 5.73 ha, which could be irrigated by total water saved of 20712.02 m^3 per hectare with total labor saved show in Table 6.

Table 6. *Net return generated of each treatments per hectare from additional land of cabbage cultivated.*

Treatment	MHY *100	I_g (*100)	WS ($m^{3)}$ *100	A. A irrig. by WS	YG of A. A (*100)	G* LS (*100)	C*W S (*100)	TC(*100)	TR(*100)	NR due to AA *100
T_1	65.30	57.53	11.51	0.20	130.61	5.8	143.8	167.7	326.5	158.8
T_2	60.33	43.15	25.89	0.60	362.00	13.1	323.6	391.0	905.0	514.0
T_3	54.56	28.77	40.27	1.40	763.78	20.4	503.4	650.4	1909.4	1259.1
T_4	66.66	57.53	11.51	0.20	133.31	5.8	143.8	167.7	333.3	165.5
T_5	56.81	43.15	25.89	0.60	340.87	13.1	323.6	391.0	852.2	461.2
T_6	53.26	28.77	40.27	1.40	745.58	20.4	503.4	650.4	1863.9	1213.6

Treatment	MHY *100	I_g (*100)	WS (m^3) *100	A. A irrig. by WS	YG of A. A (*100)	G* LS (*100)	C*W S (*100)	TC(*100)	TR(*100)	NR due to AA *100
T_7	72.07	69.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T_8	66.38	51.78	17.26	0.33	221.26	8.7	215.8	254.6	553.1	298.5
T_9	56.20	34.52	34.52	1.00	562.00	17.5	431.5	539.4	1405.0	865.6
Total			207.12	5.73	3259.40	104.9	2589.0	3212.2	8148.5	4936.3

Note: I_g: Gross irrigation per ha in m^3, A.A: Additional area irrigated, MHY: Marketable head yield in ton ha^{-1}, LS: Labor saved from irrigation system, WS: Volume of water saved in m^3 per ha, YG: Yield gained from A.A in kg ha^{-1}, C: Unit price per m^3 of water (C=12.5 ETB) and P: Unit price per kg of cabbage head (P=2.5 ETB kg^{-1}), G: Labor per irrigation per ha (G=50 ETB day^{-1}), TR: Total return in ETB ha^{-1}, TC: Total cost in ETB ha^{-1} and NR: Net return in ETB per hectare of additional area. (Hint: all values are multiple of 100 except additional area to be irrigated)

Finally Table 7 indicated that BCR (benefit cost ratio) of cabbage was computed for each treatment combination as the ratio of yield earned to the cost expended. Accordingly, treatments FFI, AFI and CFI with 100% ETc water application level had the lowest BCR as 0.99, 0.9 and 0.82 respectively. Because those treatments cost of production higher as compared to yield obtained.

Moreover treatment combination of 75% ALs, the highest BCR was attained by AFI and the lowest was recorded under CFI, as presented in Table 7. The other remaining treatments were occupied in between largest and the smallest value of BCR. This implied that the water saved with incorporation of both combined factor of (IMs and ALs) had an indicator for analysis of BCR from additional land available.

Therefore the net reduction in benefit due to yield reduction of each treatment was compensated by net benefit gained from yield obtained by additional area cultivated with labour and water saved with the same criteria and condition determined. Among different irrigation treatments, alternate furrow irrigation (AFI with 75%) had the better yield and the optimum BCR when compared with FFI and CFI with the same application.

Table 7. *Benefit cost ratio per hectare of cabbage production.*

Treatment	Water applied m^3 ha^{-1}	Cost of labor and water (VC)	Operation cost (FC)	Total cost (TC) in ETB ha^{-1}	Marketable yield(kg ha^{-1})	Gross Revenues (GR) in ETB	Net Return (NR) in ETB	BCR
T_1	5753.3	74830.03	9040.0	83870.0	65304.44	163261.1	79391.1	0.94
T_2	4315.0	56122.52	9040.0	65162.5	60333.33	150833.3	85670.8	1.31
T_3	2876.7	37415.01	9040.0	46455.0	54555.56	136388.9	89933.9	1.94
T_4	5753.3	74830.03	9040.0	83870.0	66655.56	166638.9	82768.9	0.99
T_5	4315.0	56122.52	9040.0	65162.5	56811.11	142027.8	76865.3	1.18
T_6	2876.7	37415.01	9040.0	46455.0	53255.56	133138.9	86683.9	1.87
T_7	6904.0	89796.04	9040.0	98836.0	72066.67	180166.7	81330.6	0.82
T_8	5178.0	67347.03	9040.0	76387.0	66377.78	165944.4	89557.4	1.17
T_9	3452.0	44898.02	9040.0	53938.0	56200.00	140500	86562.0	1.60

BCR: Benefit cost ratio, VC: Variable cost (ETB ha^{-1}) and FC: Fixed cost (ETB ha^{-1}), T_1, T_2 and T_3 for application level of (AFI) with 100%, 75% and 50% ETc respectively, T4, T_5 and T_6 for application level of (FFI) with 100%, 75% and 50% ETc respectively: T_7, T_8 and T_9 for application level of (CFI) with 100%, 75% and 50 % ETc respectively, ETB: Ethiopian Birr (Hint the home currency up to the paper of completion is 1 ETB = 0.045 US $)

4. Discussion

4.1. Water Productivity

Crop water use efficiency (CWUE): Comparing the results of the three irrigation methods from the point of crop water use efficiency, it clearly confirmed that, alternate furrow irrigation followed by fixed furrow irrigation and conventional furrow irrigation had more beneficial use of water respectively. This result revealed that increasing water application decreases water use efficiency of crop. The results agree with [18] [19] who reported that CWUE values decreased with increasing water use. On the other hand, for all irrigation methods, as application levels increased the CWUE decreases, this prove that as depth of application increase water lose by Dee percolation, surface runoff and evaporation increase rather than water utilized by crop. Accordingly [20] reported, that crop water use efficiency for alternate furrow irrigation substantially increased as compared with conventional furrow irrigation for corn.

Irrigation water use efficiency (IWUE): The result reported by [21] under a controlled environment study with maize, partial root zone irrigation applied at the jointing stage reduced water consumption by 12% and enhanced WUE by 12%. Some author confirmed that significant improvements in IWUE have been associated with AFI [22] and [23]. Similarly [24] demonstrated that IWUE increased with a decrease in irrigation water. Moreover [25] for field grown potato showed that compared with FI (full irrigation), PRD (partial root drying) treatment saved 30% of water and increased water use efficiency. In contrast to this study [26] found that IWUE was highest in the full irrigated treatment. In general, differences between this study and above cited studies may be due to differences in the plant variety used, agro-climatic conditions of the region and cultivation periods.

Economic water productivity (EWP): The reason behind this result is that, economic water productivity relies on the ratio of yield converted to value (cash) of marketable yield obtained by the amount of water applied on volume basis. Thus 50% ETc had least water application depth and also relatively lower yield produced, this resulted in superior economic water productivity. The reviewed literature also confirmed the same idea of water productivity is considerably increased by using APRD (alternative partial root drying) on different crops [25] [27]. [28] also reported that PRD significantly reduced yield by 24%, while WP (water productivity) increased by 52% compared with the FI (full irrigation). [29] reported that WP under deficit irrigation ranged from a minimum of 16 kg m^{-3} in FI to a maximum of 21.5 kg m^{-3} in PRD with 50% application level treatments.

4.2. Significance of Irrigation Method and Application Levels on Cabbage Yield Optimization and Net Return

Significance of Results: This study presents explicitly investigated water productivity of cabbage under different furrow irrigation methods and application levels. Hence, this leads or advances to qualify best furrow irrigation systems, while providing a framework for assessing potential future transitions of furrow irrigation methods, as likely reducing water requirement in view of producing optimum yield to meet increasing in food demand at water scarce area especially for developing country. Generally, it has been assumed that economic and agronomic control or water managements by improving existing surface irrigation methods including optimum application levels with modest yield reduction can improve net returns from additional irrigable area.

From a sustainability perspective, the primary objective of this study whether furrow irrigation overdraft the reduction of irrigation water consumption to maximize cultivation land with little yield loses when compared with cultural or normal practice and optimize water productivity. Water saved through improved irrigation systems could allow for an expansion of cultivation land and increase crop production in water limited area. Farmers' decisions are often driven by maximizing their return and rarely by environmental concerns; if they pursue efforts to save water, do they often use it to expand their irrigated areas or shift to higher value crops, rather than losing water allocation [30] [31].

Cost benefit and Economic analysis: Hence by using of appropriate irrigation methods and application levels were better for higher yield and could be economically attractive to increase crop production and productivity at water scarce or limited water and drought susceptible areas. Summing up in terms of NR and BCR alternative furrow irrigation show better when compared with FFI and CFI with synonymous application level. The report agreed and shared with [36] [37] [38] whom recommend that amongst the RDI (regulated deficit irrigation) approaches, alternate partial root-zone irrigation has been found to be most effective and efficient in saving water and improving WUE while maintaining crop productivity.

5. Conclusion

This study advocates that the technique of alternate furrow irrigations were substantially saved water than convectional furrow irrigation method in field conditions under water application level. From the result water saved alternate furrow (AFI and FFI) irrigation with 50% ETc ALs could save 58.33% of total net volume of irrigation water applied. With respect to physical water use efficiency and economic water productivity, summarized as follow: Mean maximum and minimum CWUE, IWUE and EPW were recorded by AFI and CFI respectively. For ALs crop and irrigation water use efficiency and EWP were increasing from 100% ETc (full irrigation) to 50% ETc. In the case of net return (NR) and benefit cost ratio (BCR) interaction of (and CFI), under 100% ETc, the highest was produced by alternate furrow (AFI and FFI) irrigation higher than CFI, under all water application depth. Finally the finding indorses that farmers can practice either alternate furrow irrigation (AFI and FFI) with of 100% application level or CFI with 75% ETc as a best option, this was identified as negligible yield reduction of less than 10% as compared to every or convectional furrow irrigation with full water application. Another alternative option was observed AFI method indicates best BCR which preferentially selected at 100% and 75% deficit level over FFI with the same deficit level.

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