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Effectiveness of alternative furrow irrigation methods on cabbage yield and water productivity in Angacha District, Central Ethiopia Region

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Abstract

This study aimed at investigating the effectiveness of alternative furrow irrigation methods on the head yield of cabbage and water productivity at Guder Irrigation Scheme in Angacha district Kembata Zone Centeral Ethiopia Region. Three levels of treatment were replicated five times, in Randomized Complete Block Design (RCBD). Farmers were used as replication from farmers' research extension groups. The maximum head yield (52.8t/ha) was obtained from conventional furrow, following the second maximum head yield (49.07t/ha) at alternate furrow irrigation method. The minimum yield (38.112t/ha) was obtained from farmers' practice of irrigation method. Their yield advantages (26.8%) and (22.3%) were recorded from conventional furrow, and alternate furrow irrigation, respectively. The highest water productivity (22.23kg/m^3) was obtained from alternate furrow irrigation, following the second maximum water productivity form conventional furrow irrigation (11.96kg/m^3) and minimum water productivity (8.15kg/m^3). Farmers obtained a net income of (1,278,300 ETB/ha), (1,190,730 ETB/ha) and (909,903.3ETB/ha) from conventional furrow, alternate furrow, and farmers' practices, respectively. Highest benefit cost ratio (18.63) was recorded form alternative furrow irrigation method :(17.83) from every furrow and (14.15) from farmers' practice. This implies that alternative furrow irrigation saves half of irrigation water when assimilated with conventional furrow and doubles net income on the farm gate. Therefore alternative furrow irrigation method should be recommended as a best agricultural water management technology without limiting fresh head yield of cabbage, and water productivity. The technology should be scaled up in to other irrigation schemes with the same agro ecology.

Keywords: - Alternate Furrow Irrigation, Head Cabbage, Yield, Water Productivity, Farmer Practice, Fertilizer, Guder

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1. INTRODUCTION

The two most important critical factors affecting cabbage yield are water and fertilizer (Wang *et al*. 2014; Sui *et.al*. 2015; Mon *et.al*. 2016). Agricultural practice is traditionally dominated by small-scale farmers for centuries and its performance has long been adversely affected by shortage of rain and water that left many to sustain their lives on famine relief support (Abebe *et.al*, 2011). Of the total production, rain-fed agriculture accounts for about 97% of Ethiopia's food crops yield whereas irrigated agriculture explains the rest 3% (FAO, 2015). Ethiopia has an irrigation potential of 5.3 million ha (Mha) of which 3.7 Mha can be developed using surface water sources, whereas 1.6 Mha using groundwater and rainwater management (Shitu and Hymiro, 2022). The existing irrigation development in Ethiopia is not significant when compared to the potential of resources that the country has. In this case, the irrigation sub-sector is not contributing its fair share to the GDP. Wet soil conditions caused by over irrigation can damage crops, reduce yields, and contribute to ground water contamination. But adopting proper irrigation water management strategies can limit negative impacts of over irrigation (Nebraska, 2008).

Improving crop water productivity mainly depends upon choosing and adapting water-efficient crops, reducing unproductive water losses, and ensuring ideal agronomic conditions for crop production (Kijne *et.al*., 2003; Bouman, 2007). An important principle for crop water productivity is that water management should go hand in hand with nutrient management, soil management, and pest management (Bindraban *et.al.*, 1999). Conventional furrow irrigation method has a gap of water loss as compared to alternate furrow and fixed furrow irrigation methods. Conventional irrigation is 50 to 60% water efficient. That is to say, 50 to 40% of water released in a flood irrigation system is lost either by runoff or rapid soil infiltration. Efficiency of conventional furrow irrigation can be improved by converting it to alternate furrow irrigation (Jemal and Mukerem, 2017). Irrigation interval and number of irrigation frequency was not identified in the Guger irrigation scheme. As the need assessment result indicated there was a shortage of irrigation and high demand water in the scheme. Therefore, this study was conducted to evaluate and demonstrate alternative furrow irrigation method, refine the practices, and synthesize the lessons that increases water use efficiency.

2. MATERIALS AND METHODS

2.1 Description of study area

The study was conducted at Guder Irrigation Scheme in Adancho Ebala Kebele, Angacha District Kembata Tembaro Zone Southern Ethiopia. The scheme was constructed by Participatory Small Scale Irrigation Development Program (PASIDP-II), which covers 170.1 ha command area with a total beneficiaries of 300 HH. The study site was geographically located at latitude of 07.435°N, longitude of 037.908°E with elevation of 1903 m. a. m. s. l. The vegetable crop head cabbage was selected for the demonstration according to farmers' preference and possible suitability and practices. It was potentially cultivated in the area and used as the main income source for Angacha district.

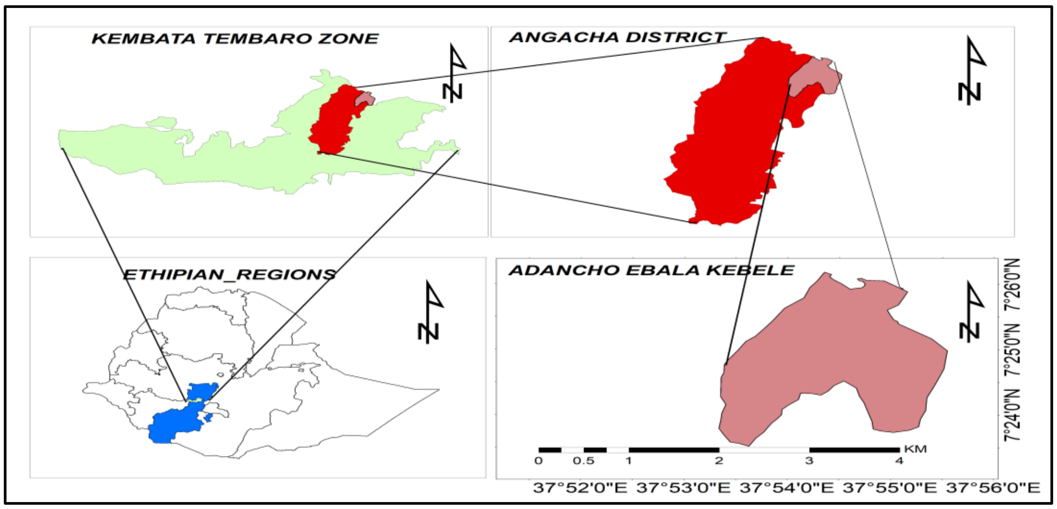

Figure 1. Location map of study area

2.2 Experimental design

The experiment was laid out in randomized complete block design with five replications across farmers. The treatments were conventional furrow irrigation (CFI), alternate furrow irrigation (AFI) and farmer practice (FP) with recommended fertilizer. In conventional furrow and farmer practice irrigation methods, all furrows obtain irrigation water at the same time on their assigned schedules. But in alternate furrow irrigation, odd furrows (1, 3, 5…) received water at first irrigation event and even furrows (2, 4, 6…..) at the next irrigation throughout the growing season with determined irrigation interval. Farmer practice was similar to conventional furrow irrigation method but furrows were made by farmer, not end closed. Furrow dimensions like furrow width, depth and ridge height were not properly constructed and was irrigated with community irrigation interval not crop water requirement based. The plot size was 10m*10m. The space between plants was 40cm while the rows were spaced 60cm apart. There were 25 plants in a single row and total of 400 plants per 100 square meters plot and 40,000 plants per hectare. The study used head cabbage Copenhagen market variety, ERO brand. The recommended fertilizer rate used was NPS (250 kg/ha) and Urea (330 kg/ha) with seed rate of 0.4kg/ha. Urea was applied in two splits at 30 days after transplanting and head initiation was applied for head cabbage production.

2.3 Data collection and analysis

Climate data, soil, water data, and crop data like scattered canopy, head length, head diameter, head weight and head weight were collected from secondary sources and fields. Some of the data collected were analyzed using an analysis of variance (ANOVA) to determine differences between treatments. Statistix 10.0 was used to run ANOVA and find out differences among the mean values and least significance differences (LSD) at 5% level of significance.

2.4 Climate data

The climatic data were collected from the nearby meteorological station situated at Angacha District. The mean annual rainfall of the area was 1,656 mm with a bimodal pattern that extended from February to September. The mean annual maximum temperature was 24 °C and monthly values ranged between 23°C and 24°C. The mean annual minimum temperature was 14 ^{0}C and monthly values ranged between 13°C and 14°C (Ayalew and Beyene, 2011).

2.5 Soil data

The textural class of the soil type was clay loam. That is to say, the soil has tiny particles with excellent water retention and high fertility as indicated in table 1 below. The maximum water holding capacity of the soil with one meter depth was (36.7%) which was below the threshold values of (40%) for clay soil (Datta *et.al.* 2017). The bulk density that restricts the root growth was (1.45g/cm^3) which was below the maximum limit of the value 1.58g/cm^3 for clay loam soil. 3.62% organic matter was obtained by multiplying organic carbon values with 1.724, conversion factor($OM\% = 1.724 * OC\%$). The pH value of the soil was 6.9 which was within the range of 5.5 - 7.5. This may not hinder the growth of most vegetables (Penas and Lindgen, 1990). The soil salinity was 1.24 d*S/*m which was below the salinity threshold values ≤2.5dS/m (Snapp *et.al.*, 1991) for the majority of vegetable crops.

Table 1: Physical and chemical property of the soil

Soil particle distribution				Bd (g/cm^3)	FC (%)	PWP (%)	SM (%)	OC (%)	pH	ECe (dS/m)
Sand	Silt	Clay	Textural class							
31	31	38	Clay Loam	1.45	36.7	23.3	19.86	2.10	6.9	1.24

where: - Bd-Bulk density, FC-Field capacity, PWP-Permanent wilting point, SM- Soil moisture, OC-Organic carbon, pH-Soil acidity, ECe-Electric conductivity of soil.

2.6 Crop water determination

Crop water requirement refers to the amount of water that needs to be supplied while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration (Allen *et.al*., 1998). The crop coefficient values varied at different stages: at initial stage 0.45 (28days), development stage 0.75(35days), mid stage 1.03(25days) and late stage 0.95(15days) with maximum allowable depletion (MAD) of 35% (Doorenbos and Kassam, 1986).The crop was transplanted in March 17/2021 and harvested in June 28/2021 within a total growing period of 103 days. CROPWAT 8.0 software was used to generate the climate data to determine irrigation schedule and seasonal crop water requirement. .

$$ETc = ETo \times Kc \quad (1)$$

Where-ETc stands for crop evapotranspiration; Kc -crop coefficient; and ETo -reference evapotranspiration.

Seasonal amount of crop water requirement for head cabbage (SCWR) determined by CWR 8.0 was 441.14 mm/ month.

Table 2: Seasonal crop water requirement for head cabbage

Months	Dev.t Stages	No. of days	Kc-Values	ETo (mm/day)	ETc (mm/day)	ETc (mm/Period)	ETc (mm/Month)
March	Initial	14	0.45	5.2	2.34	32.76	32.76
April		16	0.45	4.5	2.03	32.4	
April	Dev.t	14	0.75	4.5	3.38	47.25	79.65
May		31	0.75	4.4	3.3	102.3	102.3
June	Mid	30	1.03	4.3	4.43	132.87	
July		10	1.03	3.3	3.399	33.99	166.86
July	Late	19	0.95	3.3	3.135	59.57	59.57
Seasonal ETc(mm)							**441.14**

Irrigation water management: The total available water (TAW), stored in a unit volume of soil, was determined by the expression:

$$\mathrm{TAW} = \frac{(\mathrm{FC} - \mathrm{PWP}) * \mathrm{Bd} * \mathrm{Dz}}{100} \quad (2)$$

The irrigation schedule should be fixed based on the readily available soil water (RAW) for maximum crop production and was computed by the expression:

$$\mathrm{RAW} = (\mathrm{TAW} * \mathrm{p}) \quad (3)$$

Where RAW was in mm, and P (35%) was permissible soil moisture depletion

The depth of irrigation supplied at any time could be obtained by the equation: -

$$\mathrm{Inet(mm)} = (\mathrm{ETc_{mm}} - \mathrm{Peff_{mm}}) \quad (4)$$

Where Inet-Net irrigation, ETc-Crop evapotranspiration, P_{eff}- Effective rain fall, but effective rain fall could be calculated using dependable rain (FAO/AGLW) formulae: -

$Peff_{mm}$= 0.6*P_{mon}-10 for P_{mon} <70mm

$Peff_{mm}$= 0.8*P_{mon}-24 for P_{mon} >70mm

The gross irrigation requirement was obtained by the expression:

$$\mathrm{GI} = \frac{\mathrm{NI}}{\mathrm{Ea}} \quad (5)$$

Ea=application efficiency of the furrow for irrigation (60%)

The time required to deliver the desired depth of water into each furrow was calculated by the equation:

$$\mathrm{t} = \frac{\mathrm{l} * \mathrm{w} * \mathrm{dg}}{6\mathrm{Q}} \quad (6)$$

Where l was furrow length (m); w, stood for furrow spacing (m); dg, gross depth of water applied (cm); t, Application time (min); and Q, flow rate (discharge) (l/s). The amount of irrigation water applied at each irrigation application was measured using three-inch calibrated Parshall flume.

2.7 Water productivity

Water productivity plays a crucial role in modern agriculture as it increases yield production per unit of water used under rain fed and irrigated conditions. Water productivity with dimensions of kg/m^3 is defined as the ratio of mass of marketable yield (Y) to the volume of water consumed by the crop (Wa). Mathematically water productivity can be represented as follow in equation (Ali and Talukder, 2008).

$$WP = \frac{Y}{Wa} \tag{7}$$

WP stands for water productivity (Kg/m^3); Y, economic yield (kg); and Wa, total water applied (m^3).

2.8 Economic analysis

Analysis was carried out to compare the effects furrow irrigation methods, other inputs costs, and return to the producers among different treatments. Economic analysis was employed as suggested by CIMMTY (1988) to determine water application methods based on cost and benefits for head cabbage production.

3. Result and Discussion

3.1 Fresh head cabbage yield response for different furrow irrigation methods

The total head yield of cabbage was significantly affected by application of water through different furrow methods. The maximum total head yield recorded from conventional furrow irrigation was (52.8 t/ha) following the second maximum head yield from alternative furrow irrigation (49.072 t/ha). Yields obtained from furrow and alternate furrow irrigation methods were higher than those from conventional furrow (48.41 t/ha) and alternate furrow (43.84 t/ha) (Aregash *et.al*. 2023) and (42 t/ha) of head cabbage (Gurmu and Mano, 2016). Statistically the minimum total head cabbage yield obtained from farmers' practices was (38.11 t/ha). The yield obtained from all the treatments was better than other previous studies of head cabbage yield; (16.6 t/ha) from full irrigations 100%ETc (Zelalem *et.al*., 2022) and (40t/ha) (JICA and MoA, 2019).

Head diameter (cm)

The highest head diameter (40cm) was recorded at a conventional furrow treatment with application water level of (441.14mm). The next highest second head diameter of (37.37cm) was recoded at alternate furrow treatment method with seasonal amount of water (220.57mm). The lowest head diameter (32.28cm) was recorded at farmer practice with seasonal amount of irrigation water (467.61mm). In comparison to other studies, head diameter obtained from the three treatment levels (11.83cm) was greatest (Asfaw, 2023). Head diameter and head weight were strongly related with each other; hence, head diameter has a direct contribution to the weight of head yield.

Head length (cm)

Statistically the highest head length (22.72cm) and 21.36cm) were recorded at conventional and alternate furrow irrigation method respectively and the lowest head length (19.28cm) was recorded at farmer practices as shown in table 3 and its data collection process figure 2 below. Other agronomic parameters like scattered canopy, and unmarketable head yield were statistically not significant with each other in all treatments.

Table 3: Intermediate results of analyzed head cabbage yield data

Treatments	HL(cm)	SC	HD(cm)	MHY(t/ha)	UMHY(t/ha)	THY(t/ha)
CFI	22.720a	12.480	40.00a	44.56a	8.24	52.800a
AFI	21.360a	11.800	37.36a	42.32ab	6.75	49.07ab
FP	19.280 b	12.280	32.28b	32.16 b	5.95	38.11b
Mean	21.12	12.187	36.55	39.68	6.98	46.66
LSD(0.05)	0.72	NS	2.00	5.22	NS	5.94
CV	5.36	9.64	8.62	20.79	27.09	20.11

Where: - HL-Head Length, SC- Scattered Canopy, HD-Head Diameter, MHY- Marketable Head Yield, UMHY-Un Marketable Head Yield, THY-Total Head Yield

Figure 2. Field irrigating, its performance and data collections

Water productivity

The maximum water productivity values (22.23 kg/m^3) was obtained at the treatment level of alternate furrow irrigation following the second maximum values of (11.96 kg/m^3) at conventional furrow method as shown in table 4 below. The maximum value obtained was greater than other previous studies (17.1kg/m^3) on head cabbage productivity through alternate furrow (Aregash *et.al*. 2023). This indicates that alternate furrow irrigation method improves water productivity and yield of head cabbage in the area. The minimum water productivity value (8.15 kg/m^3) was obtained at farmers practices that implies huge amount of irrigation water applied for production of lower yield. Advantages of water productivity (63.34%) and (31.91%) was acquired from alternate and every furrow irrigation methods, respectively.

Table 4. Water productivity values of furrow irrigation methods

Treatments	WP(kg/m^3)
CFI	11.96b
AFI	22.23a
FP	8.15c
Mean	13.09
LSD(0.05)	1.58
CV	8.58

Different amount of water depth and advantages from farmers' practices

Amount of water depths applied were 441.14mm, 220.57mm and 467.61mm in conventional furrow, alternate furrow, and farmers practice, respectively. 26.8% and 22. 3% yield advantage was recorded from conventional and alternate furrow irrigation, respectively. Amount of irrigation water saved; (52.83%) acquired at alternate furrow and minimum values (11.43%) was obtained in conventional furrows over farmer practices. Managing field irrigation water loss through the technology was one of the main goals of the study in water scarce areas.

Table 5. Advantages alternate furrow over conventional furrow and farmers' practices

Treatments	Water depth (mm)	Advantages of water applied (%)	Yield (t/ha)	Advantages of yield (%)	WP (kg/m^3)	Advantages of Water Productivity (%)
CFI	441.14	11.43	52.8	27.8	11.97	31.91
AFI	220.57	52.83	49.07	22.3	22.25	63.34
FP	467.61	-	38.11	-	8.15	-

Economically farmers benefited from the seasonal market price in head cabbage production. Seasonal market price was (35-40ETB) per a single fresh head cabbage and weighs on average (1.32kg), with a price of (37.5ETB) per a single head. Partial budget analysis study indicates that the seasonal market price was (1,278,300 ETB/ha), (1,190,730.7 ETB/ha) and (909,904.4 ETB/ha) from the treatments of every furrow, alternate furrow, and farmers practices respectively as shown in table 6 below. The maximum benefit cost ratio (18.63) was incurred by alternate furrow irrigation method rather than every furrow (17.83) and formers' practice (14.15). The benefit cost ratio values obtained from all treatments were greater than 1.0, which means benefits outweigh the costs of production.

Table 6. Partial budget analysis of head cabbage on hectare base

Variables	Cost (ETB) Items	CFI	AFI	FP
	Seed	12800	12,800	12,800
	Land preparation	4800	4800	4800
	Fertilizer	9900	9900	9900
	Pesticide chemicals	5000	5000	2000
	Watering	15600	7800	15600
	Harvesting	3600	3600	3600
	Transporting	20000	20000	20000
Total Cost (ETB)		71,700	63,900	64,500
Yield(kg/ha)		52,800	49,070	38,110
10% Adjusted yield(kg/ha)		47,520	44,163	34,299
Gross revenue (ETB/ha)		1,350,000	1,254,630.7	974,403.4
Net Benefit (ETB/ha)		**1,278,300**	**1,190,730.7**	**909,903.4**
Benefit Cost Ratio(BCR)		17.83	18.63	14.15

Conclusion and Recommendations

The Ethiopian people live in areas of high-water stress that threaten the country's sustainable development goal. Regular watering through irrigation scheduling technology ensures uniform head formation, prevents head scattering, and increases the diameter of the head. Alternate furrow irrigation is considered to be one of the most effective tools to minimize applied water irrigation costs and produce a higher head yield. It is a way to save irrigation water and time, improve water productivity, increase cabbage yield and economic income benefits as compared to conventional furrow and farmer practice irrigation methods with recommended fertilizers. The saved irrigation water through alternate furrow method doubles the irrigable land, yield, and income of famers as compared to conventional furrow method. The district farmers under the scheme learned the lesson through field trainings and practiced the technology as a best water saving practice. Therefore, the technology should be scaled up to the other irrigation schemes with the same agro-ecology for transferring knowledge, and skill on irrigation water management technologies.

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