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Effects of inter and intra row spacing on seed yield and yield components of sunflower (*Helianthus annuus*) at northwestern Gondar of Ethiopia

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ABSTRACT

An experiment was conducted to *determine* the optimum inter- and intra-row spacing for maximizing sunflower seed yield in the lowland areas of Metema and West Armachiho districts during the 2022/23 and 2023/24 main rainy seasons. The study employed a factorial combination of four inter-row spacings (55, 75, 95, and 115 cm) and three intra-row spacings (20, 30, and 40 cm), arranged in a randomized complete block design with three replications. Data were collected on phenological, growth, and yield-related traits, including days to flowering and maturity, plant height, head diameter, head weight, number of seeds per head, thousand seed weight, and grain yield. The analysis of variance (ANOVA) revealed that the main effects of inter- and intra-row spacing significantly ($p < 0.01$) influenced most parameters. The interaction effect significantly affected head weight and grain yield. The highest grain yield (2,375.2 kg ha^{-1}) and net benefit (89,671.4 ETB) were achieved with a spacing of 75 cm between rows and 30 cm within rows. Conversely, the lowest yield (1,704.3 kg ha^{-1}) was recorded at 115 cm × 40 cm spacing. Therefore, a 75 cm inter-row and 30 cm intra-row spacing is recommended for optimizing sunflower seed yield and economic return in the lowlands of Gondar and similar agro-ecologies.

1. INTRODUCTION

In Ethiopia, total edible oil consumption in fiscal year 2020/21 is projected at 630,000 metric tons, of which 90 percent is imported (USDA, 2021). Most of the oil consumed is palm oil, followed by sunflower oil and locally produced Niger seed oil. Small amounts of soybean, linseed, groundnut, and cottonseed oils are also consumed (USDA, 2021). The rising population and economic growth are driving up edible oil imports annually (USDA, 2021). Due to rising demand, limited domestic production, and heavy reliance on imports, Ethiopia has experienced edible oil shortages, particularly in urban areas. Moreover, as dietary awareness grows, some consumers are increasingly seeking healthier alternatives to palm oil (USDA, 2021). There is an increasing preference towards alternative edible oils containing non-saturated oils and fats (USAD, 2021). Most Ethiopian consumers prefer sunflower, niger seed, and soybean oils as healthier alternatives, and due to these changes in consumer preferences, consumption of sunflower oil has almost tripled over the last couple of years and importing of palm oil has dropped considerably (USAD, 2021; Urugo *et al.,* 2021).

Sunflower is a widespread oilseed crop of the world, and it is grown in almost all continents. The major global sunflower producers include Russia, Ukraine, the European Union, Argentina, Kazakhstan, Turkey, South Africa, Serbia, China, and Moldova (USDA 2023). These countries account for 94.8% of the total global sunflower production (USDA 2023). Sunflower was cultivated in an area of 31.45 million hectares with annual production and productivity of 54 million metric tons and 1,717 kg ha^{-1}, respectively, in the world, in the year 2023(FAO, 2023). In Ethiopia, it was cultivated in an area of 4,749.96 hectares with annual production and productivity of 5,150.5 tons and 1084.33kg ha^{-1}, respectively, in the year 2021(CSA, 2022). Sunflower is one of the most important oil crops in the world because it offers advantages in crop rotation systems, such as high adoption capability, suitability to mechanization, and low labor needs (Ramos *et al*., 2014). The sunflower oil can be used as a salad and cooking oil or in making margarine. Sunflower has multiple uses beyond oil production. Its stems have been identified as a sustainable source of commercial fiber (Ataman and Şık, 2023), while the seeds are utilized in traditional medicine as a diuretic and for treating certain respiratory disorders. Additionally, the seed cake serves as a high-quality feed for cattle and poultry due to its rich protein content (Baleseng et al., 2023). El Naim and Ahmed (2010) reported that sunflower oil is healthier than most other food oils on the market. Sunflower oil is generally considered a premium oil because of its light color, high level of unsaturated fatty acids and lack of linolenic acid, bland flavor an high smoke points, the primary fatty acids in the oil are oleic and linolenic (Typically 90 % unsaturated fatty acids), with the remainder consisting of palmatic and stearic saturated fatty acids.

Even though the crop has a high potential to become a competent oil crop in the country, much progress has not been achieved in improving the agronomic practices (Alemaw and Gurmu, 2023). Inappropriate agronomic practices, especially inappropriate optimum plant population, greatly affect the productivity of sunflower (Crnobarac *et al.,* 2012). Adequate plant population is important for the highest yields (Viorel *et al.*, 2015). Sunflower will compensate for differences in plant populations and density through adjustments in head size. The number of plants per unit area is one of the most important agronomic practices affecting the yield in sunflower (Ahmad *et al.*, 2010). Plant population may vary according to environmental conditions; however, an optimal population allows sunflower plants to utilize essential resources—such as sunlight, water, and nutrients—more efficiently (Agegnehu *et al.,* 2023). Further increase in plant density may lead to reduced seed yield as affected by environmental factors (Ion *et al.*, 2015). The reported results on the highest yield and plant density from various regions around the world are inconsistent and often contradictory. The higher yields were obtained by 100 thousand plants ha^{-1} (Beg *et al.*, 2007). However, different densities have been reported in providing variable yields in different areas, ranging from 45 to 75 thousand ha^{-1}. The differences in plant density may cause significant variation in seed yield different ecological conditions. The aim of this study was to determine the appropriate inter and intra row spacings of sunflower to obtain the highest seed.

2. MATERIAL AND METHODS

2.1. Description of the Study Area

A field experiment was conducted in Metema and West-Armachiho districts of West Gondar zone in Amhara region. In 2023 and 2024, field trials were conducted at two sites in Metema district and four sites in the West Armachiho district. The two locations are situated in the West Gondar zone. Both districts are the major producers of sunflowers in the region. Sesame, sorghum, cotton, and soybean were the dominant crops. Metema district is located at 12°24'48'' to 13°09'71'' N Latitude and 36°15'19'' to 36°64'71'' E longitudes with an altitude ranging from 710 to 898 meters above sea level. It is characterized by rainfall of 700 to 1160 mm and temperature 12.6-36.1°c. West-Armachiho district is located at 13°10'09'' to 13°70'36'' N Latitude and 36°31'29'' to 36°77'16'' E longitudes with an altitude ranging from 570 to 860 meters above sea level. It is characterized by rainfall of 570 to 880 mm and temperature 14.6-38.1°c. The study areas are characterized by mono-modal type of rainfall distribution pattern in which the rainy season commences in early June to ends in September.

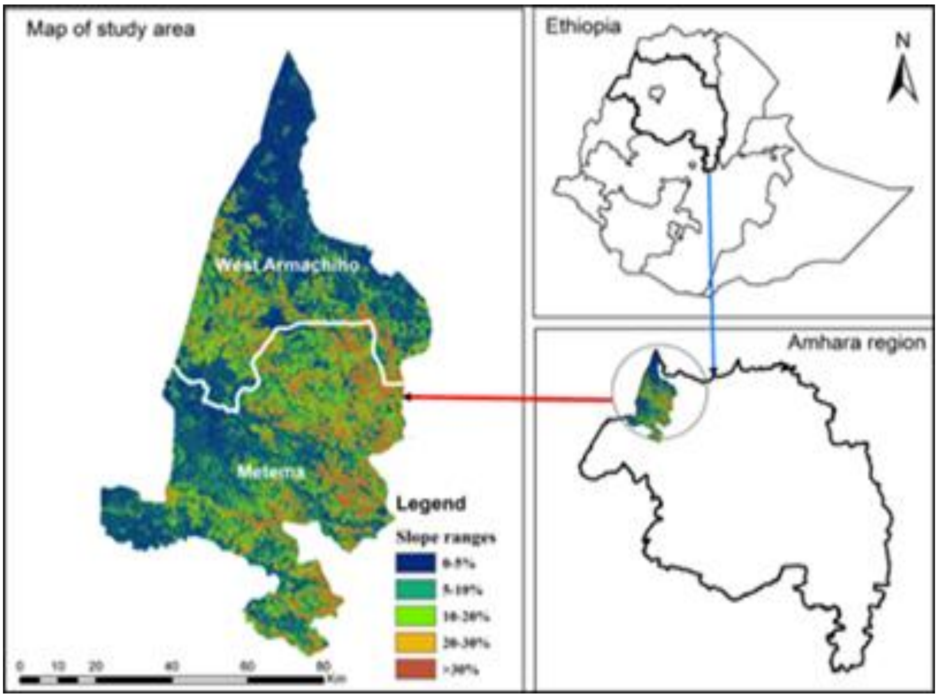


Figure 1. Study area map

2.2. Experimental Design and Treatments

A factorial combination of 4 inter row spacing (55, 75, 95, and 115 cm) and 3 intra row spacing (20, 30, and 40 cm) were laid out in a randomized complete block design (RCBD) with three replications. The spaces between plots and replications were maintained at 1m and 1.5m, respectively. The gross plot size was 4.5m x 4m (18m²). As per the treatments, there were 8, 6, 5, and 4 rows for 55, 75, 95, and 115 cm inter-row spacing, respectively. The number of plants in each row was 20, 13, and 10 for intra-row spacing of 20, 30, and 40cm, respectively. The harvestable plot areas were 13.2 m^2, 12 m^2, 11.4 $m^{2,}$ and 9.2 m^2 for the row spacing of 55 cm, 75 cm, 95 cm, and 115 cm, respectively. The outermost row on both sides of the row spacing served as border rows for all row spacing

2.3. Experimental Materials and Management

The improved variety Oissa was used as planting material. A basal application of 50 kg ha^{-1} NPS fertilizer was applied at sowing. Sowing was conducted in mid-June, placing two seeds per hole at a specific inter and intra row spacing at a depth of about 2.5 cm and covered by a 2.5 cm layer of soil for adequate emergence. Thinning was carried out one week after emergence to maintain a uniform plant population. Prior to sowing, the experimental fields were ploughed twice using oxen, then harrowed and leveled manually to achieve a fine tilt. All necessary agronomic management practices were done frequently throughout the growing period. Weeding was done appropriately three times. The first weeding was done 15 days after emergence, the second weeding on 25 days after the first weeding, and the third weeding on 30 days after the second weeding. Harvesting was done after physiological maturity (the back of the head turns yellow and the bract of the head turns brown) from the net plot at full ripening. The crop was harvested from the net plot area at full ripening. Harvested heads were sun-dried in sacks until thoroughly dried, after which manual threshing was performed.

2.4. Data Collection and Analysis:

Data on days to flowering and maturity were collected in plot-based and the remaining parameters were collected in single-plant-based. Ten randomly selected samples of plants in each plot from harvestable rows were taken to estimate plant height (PH), head diameter (HD), head weight (HW), and number of seeds per head (NSPH). Grain yield was collected from the net plot, and the number of seeds was counted. The grain yield and thousand-seed weight were then adjusted to a standard moisture content of 8% (on a wet basis) for uniformity and comparison purposes. Moisture content of the samples was determined using a moisture tester. To adjust the grain yield to 8% moisture content, the following equation was used. The data were statistically analyzed by using R statistical software version 4.4.0. (Kabacoff, R. 2022). Significant pairs of means were separated using the Least Significant Difference Test (LSD) at 5% level of significance and used for mean separation for all agronomic parameters.

$$Adjusted\ yield = Observed\ Yield \times \left(\frac{100 - Measured\ Moisture\ Content}{100 - 8}\right)$$

Where:

- Observed Yield: is the measured yield at the current moisture content,
- Measured Moisture Content: is the moisture content measured in the sample, and
- 8%: The target moisture content to which you want to adjust.

2.5. Partial Budget Analysis:

Partial budget analysis was performed to estimate the net profit from this cultural operation. The study employed methodologies outlined by CIMMYT (1988) to evaluate the economic viability of different spacing treatments of sunflower. Costs associated with seed, planting (row-making), and cultivation (weeding) were calculated on a per-hectare basis in Ethiopian birr (ETB). The partial budget analysis utilized mean grain yields from each treatment, adjusting the grain yield downward by 10%, reflecting the yield farmers might realistically expect. Gross benefit (GB) was derived by multiplying the adjusted grain yield (AGY) by the farm gate price (P), calculated as GB = AGY × P. The total variable costs (TVC) encompass all operational costs, including seed and labor for row-making and weeding. The net benefit (NB) was determined by subtracting the total variable costs from the gross benefit, expressed as NB = (AGY × P) - TVC. This formula highlights the relationship between yield, market price, and operational costs. Following this, the dominance analysis procedure, as per CIMMYT guidelines, was employed to identify potentially profitable treatments, categorizing them into dominated (D) and non-dominated (ND) groups.

3. RESULT AND DISCUSSION

The results of ANOVA on sunflower spacing across six environments in 2023 and 2024 on growth parameters and yield, and yield-related parameters are presented in Table 1. The result of ANOVA showed environment (years by locations) highly significantly (*P<0.01*) affected all recorded traits, and the combined main effects of inter-row and intra-row spacing also highly significantly (*P<0.01*) affected all recorded parameters listed in Table 1. However, their interaction significantly (*P<0.05*) affected only head weight (HW) and grain yield. The combined interaction effect of environment and inter-row spacing significantly (*P<0.01*) affected head weight (HW) and significantly (*P<0.05*) affected thousand seeds weight (THSW) and grain yield. The combined interaction effect of environment and intra-row spacing significantly (*P<0.05*) affected head weight (HW) and number of seeds per head (NSPH), and highly significantly (*P<0.01*) affected grain yield. The combined interaction effect of environment, inter-row, and intra-row spacing had no significant (*P>0.05*) effect on all recorded parameters listed in Table 1.

Table 1. The mean square analysis revealed significant effects of inter- and intra-row spacing on sunflower growth and seed yield across years and locations.

SOV	DoF	DF(days)	DM(days)	PH(cm)	HD(cm)	HW(gm)	NSPH	THSW(gm)	YIELD(kgh^{-1})
Env	5	125.1**	435**	866.1**	37.3**	61627.7**	412881**	656.9**	42967**
RS	3	289.1**	504.2**	5355.5**	146.8**	31271.3**	429389**	1558.7**	14361**
PS	2	223.7**	296.5**	1385.7**	305.8**	17855.1**	768504**	822.3**	3195**
RS*PS	6	4.7^{ns}	1.2^{ns}	20.7^{ns}	2.6^{ns}	375.1**	4003^{ns}	0.82^{ns}	183507*
Env*Rs	15	2.8^{ns}	3.4^{ns}	46.9^{ns}	0.61^{ns}	762.6**	5020^{ns}	23.7*	179534*
Env*Ps	10	5.9^{ns}	14.9^{ns}	55.2^{ns}	7.9^{ns}	583.3*	27658*	7.1^{ns}	34492**
Env*Rs*Ps	30	0.7^{ns}	4.2^{ns}	11.4^{ns}	0.72^{ns}	66.4^{ns}	1206^{ns}	9.7^{ns}	61766^{ns}

NB; DoF= Degree of freedom; DF=Days to flowering; MD=Days to Maturity; PH=Plant height; HD=head diameter, HW= Head weight; NSPH=Number of seed per head; THSW= Thousand seed weight and Yield= yield per hectare

Effect of inter and intra row spacing on growth parameters, yield, and yield components of sunflower

Days to 50% flowering and maturity: The combined main effect of inter and intra row spacing were highly significant (*P<0.01*) on days to 50% flowering and to maturity on both locations. However, non-significantly (*P>0.05*) difference by the interaction effect of inter and intra row spacing (Table 1).The maximum number of days to 50% flowering (68) and (67) were recorded from 115cm inter and 40cm intra-row spacing, respectively while the minimum number of days to 50% flowering (62) and (63) were recorded from 55cm inter and 20cm intra-row spacing, respectively. This showed that in narrower inter- and intra-row spacing, competition for nutrients, moisture, and space accelerated days to flowering. This result is in line with Demir (*2020*), who reported that narrowing inter- and intra-row spacing increased plant height, caused early flowering, and harvest maturity.
The longest number of days maturity (108) and (106) were recorded from 115 cm inter and 40 cm intra-row spacing, respectively, while the shortest number of days to maturity

(101) and (102) were recorded from 55 cm inter and 20 cm intra-row spacing, respectively (Table 2). This showed that in narrower inter- and intra-row spacing, competition for nutrients, moisture, and space accelerated crop maturity. This result is in line with Demir *(2020)*, who reported that narrowing inter- and intra-row spacing increased plant height, caused early flowering, and harvest maturity.

Regarding plant height (PH), the main effect of inter- and intra-row spacing showed a highly significant ($P<0.01$) effect on plant height in combined over locations. However, it was non-significant ($P>0.05$) to the interaction effect of inter and intra row spacing (Table 1). The tallest (191.5 cm) and (182.8 cm) plant heights were recorded from the plant growth with 55cm inter and 20cm intra-row spacing, respectively. The shortest (167.8cm) and (174.4cm) plant heights were recorded with 115cm inter and 40cm intra-row spacing, respectively (Table 2). This might be due to the spacing between plants decreased the interplant competition for light and nutrients increased while sparsely populated plants intercepted sufficient sunlight, which enhanced the lateral growth. This result is in line with Awais *et al.* (2015), who reported that plant height increased under higher plant density per unit area due to the competition of plants for light.

Head diameter (HD): head diameter is significantly affected by the main effect of spacing. The largest head diameter (18.3 cm) and (18.6 cm) were recorded from 115 cm inter and 40 cm intra-row spacing, respectively. The lowest head diameters (14.4 cm and 14.5 cm) were recorded from the plant growth with 55 cm inter and 20 cm intra-row spacing, respectively (Table 2). Increased plant spacing increased the head diameter of the sunflower, and the smaller head diameter of closer spacing may be due to the competition of plants for nutrients, moisture, and light. This result is in agreement with Babkir A Ibrahim *et al*. (2023), who reported that an increase in plant densities led to decreased head diameter. The result is also in line with El Naim and Ahmed (2010), who reported that an increase in plant densities led to decreased head diameter

Number of seeds per head (NSPH): The combined analysis of variance indicated that the average number of seeds per head was highly significantly ($P<0.01$) influenced by the main effect of inter and intra row spacing, but not for the interaction effects (Table 1). The highest (1068) and (1049) seeds per head were recorded from the plant growth with 115cm inter and 40cm intra-row spacing, respectively (Table 2). The lowest (854) and (848) average number of seeds per head were recorded from the plant growth with 55cm inter and 20cm intra-row spacing, respectively. This was due to larger heads at wider spacing. This result is in agreement with Hamed Modanlo *et al.* (2021, plant height, head diameter, 100-grain weight, and grain yield/plant all decreased with increasing plant density.

Thousand seeds weight (THSW): The combined main effects of inter and intra row spacing of sunflower had a highly significant ($P<0.01$) effect on thousand seed weight, whereas their interaction effect had a non-significant ($P>0.05$) effect (Table 2). The heaviest (62.3 gm) and (58.8 gm) thousand seed weight were recorded from 115 cm inter and 40 cm intra-row spacing, respectively and the lowest (49.3 cm) and (52 cm) thousand seed weight were recorded from 55 cm inter and 20 cm intra-row spacing, respectively (Table 2). Decreasing inter- and intra-row spacing might have increased the number of plants and increased interspecific competition, which eventually caused a reduction in the weight of seeds. This finding aligns with Pereira and Hall (2019), who demonstrated that increasing plant density per unit area results in a reduction of both seed number per head and thousand-seed weight.

Table 2. Main effect of inter and intra row spacing on growth parameters and yield-related parameters of sunflower in a combined over location

Treatment	DF	DM	PH(cm)	HD(cm)	NSPH	THSW (gm)
Row spacing(cm)						
55	62[d]	101[d]	191.5[a]	14.4[d]	853.5[d]	49.3[d]
75	64[c]	103[c]	181.9[b]	16.2[c]	943.8[c]	54.4[c]
95	66[b]	105[b]	175.9[c]	17[b]	986.7[b]	56.7[b]
115	68[a]	108[a]	167.8[d]	18.3[a]	1067.6[a]	62.3[a]
LSD (5%)	0.98	1.2	3.64	0.52	32.2	1.2
Plant spacing(cm)						
20	63[c]	102[c]	182.8[a]	14.5[c]	848.2[c]	52[c]
30	65[b]	104[b]	180.7[a]	16.2[b]	991.8[b]	56.2[b]
40	67[a]	106[a]	174.4[b]	18.6[a]	1048.6[a]	58.8[a]
LSD (5%)	0.85	1.07	3.2	0.44	27.9	1.03
Mean	64.7	104.2	179.3	16.5	962.9	55.7
CV (%)	3.98	3.12	5.34	8.22	8.78	5.6

DF=Days to flowering; DM=Days to Maturity; PH=Plant height; HD=head diameter; NSPH=Number of seed per head; THSW= Thousand seed weight

Head weight (HW): The combined main and interaction effects of inter and intra-row spacing were highly significant (*P<0.01*) on head weight (Table 3). The highest (216.2) head weight (gm) was recorded from the plant growth with 115 cm inter by 40 cm intra-row spacing. The lowest (132.5) head weight (gm) was recorded from the plant growth with 55 cm inter by 20 cm intra-row spacing (Table 3). The smaller head weight of closer spacing may be due to the competition of plants for nutrients, moisture, and light. This result is in line with Demir *(*2020), who reported that the plant yield was increased by increased inter and intra row spacing, in which the number of plants per unit area decreased. This result is also in agreement with Mamoun and Ekhlas (2023), who reported that the highest head yield was recorded with the widest inter- and intra-row spacing, and the lowest head yield was recorded with the narrowest inter- and intra-row spacing.

Grain yield: The combined analysis of variance showed that the interaction effect of inter and intra row spacing of sunflower had a significant effect (*P<0.05*) on grain yield (Table 3). The highest grain yield (2375.2 kg ha^{-1}) was recorded from 75 cm inter by 30 cm intra-row spacing. The lowest grain yield (1704.3 kg/ha) was recorded from 115 cm inter by 40 cm intra-row spacing (Table 3). The possible reason could be that when inter and intra row spacing decreased, the number of plants per unit area increased, resulting in higher grain yield per area. However, this could be up to a certain level of inter-row spacing. As demonstrated by Ismail Demir (2020), higher seed yields were ultimately achieved under narrower spacing conditions, despite the improved individual plant performance observed with wider inter- and intra-row spacing. This suggests that while wider spacing reduces competition and can enhance the growth of individual plants, the overall yield per unit area is more effectively maximized by increasing plant density, emphasizing the importance of optimizing spacing to achieve the best balance between plant health and total productivity. The lowest grain yields from the widest inter-row and intra-row spacing might be due to the total yield per unit area, depending not only on the performance of individual plants but also on the number of plants per unit area. This finding aligns with Mamoun and Ekhlas (2023), who demonstrated that a narrower combination of intra-row and inter-row spacing significantly enhances seed yield across both growing seasons, while wider spacing results in lower yields.

Table 3. Interaction effect of inter and intra row spacing of on growth parameters and yield related parameters in combined over locations and years

Treatment	HW(gm.)			Yield (kgh^{-1})		
	Plant spacing					
Row spacing	20	30	40	20	30	40
55	132.5^{g}	140.7^{f}	154.9^{e}	1961.5^{bcd}	1945.3^{bcd}	1927.6^{bcd}
75	155.9^{e}	178.9^{d}	189.2^{c}	2059.3^{b}	2375.2^{a}	1975.1^{bc}
95	157.1^{e}	183.2^{cd}	197.1^{b}	1879.1^{cde}	1834.2^{cdef}	1826.4^{cdef}
115	186.3^{c}	200.7^{b}	216.2^{a}	1754.5^{ef}	1809.1^{def}	1704.3^{f}
MEAN		174.4			1921	
LSD (5%)		6.7			152.5	
CV (%)		5.8			12.05	

HW= Head weight

3.1. Partial budget analysis

The cost-benefit analysis revealed that the highest net benefit of 89671.4 Eth-Birr with MRR% of 1178.4 was obtained from the interaction of 75 cm inter and 30 cm intra-row spacing. The lowest net benefit, 60131 Eth-Birr, was obtained from the interaction of 55 cm inter and 40 cm intra-row spacing. Therefore, planting sunflowers with 75 cm inters and 30 cm intra-row spacing is economically advisable in the study area for better sunflower production, as the highest net benefit and the marginal rate of return were above the minimum level (100%). Thus, 1178.4 % MRR indicates that by investing 1 Birr a farmer can get an additional 117.8 Eth-birr (Table 4).

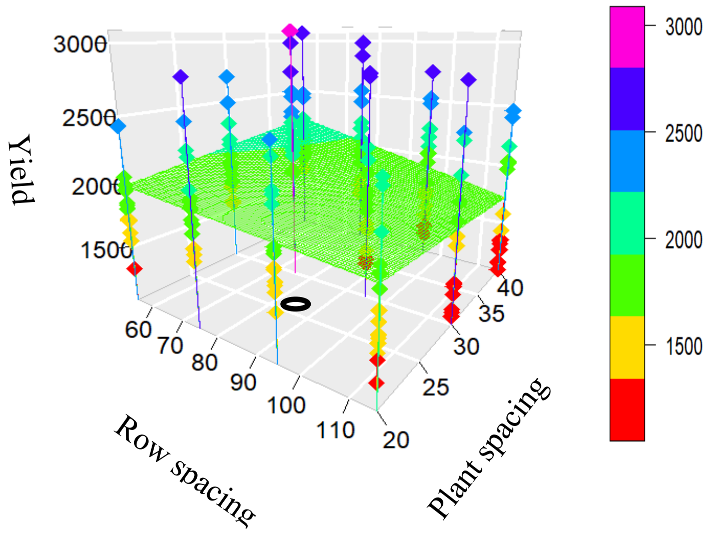
Table 4. Partial budget analysis for inter and intra row spacing effect on seed yield of sunflower

RS (cm)	PS (cm)	GY (kg h^{-1})	90% Adj .GY (kgh^{-1})	GB (Et. Birr)	TVC (Et. Birr)	NB (Et. Birr)	D	MRR (%)
115	20	1754.5	1579.05	94743	24689.7	70053.3		
115	40	1704.3	1533.87	92032.2	25849.7	66182.5	D	
115	30	1809.1	1628.19	97691.4	27387.7	70303.7		267.9
95	20	1879.1	1691.19	101471.4	29693.1	71778.3		63.9
95	40	1826.4	1643.76	98625.6	32003.1	66622.5	D	
95	30	1834.2	1650.78	99046.8	32183.1	66863.7		134
75	20	2059.3	1853.37	111202.2	34419.4	76782.8		443.5
75	40	1975.1	1777.59	106655.4	36899.4	69756	D	
75	30	2375.2	2137.68	128260.8	38589.4	89671.4		1178.4
55	20	1961.5	1765.35	105921	39973.4	65947.6	D	
55	30	1945.3	1750.77	105046.2	41949.4	63096.8	D	
55	40	1927.6	1734.84	104090.4	43959.4	60131	D	

Price birr/kg: sunflower seed = 60 Eth birr; seed cost of sunflower= 90 Eth birr; Louver cost= 400 Eth birr; RS=Row spacing (inter row spacing); PS=Plant spacing (intra row spacing); GY=Grain Yield; Adj.GY=Adjusted Grain Yield (90%); GB=Gross Benefit; TVC= Total Variable Cost; NB= Net Benefit; D= Dominance Analysis; MRR= Marginal Rate of Return

3.2. The Scatter Plot with Regression Plane

Regression analysis revealed that 78% (R2 = 0.78) of the total variation of the grain yield of sunflower was significantly explained by the regression equation. The scatter plot with regression plane showed the highest grain yield (2375.2 kg/ha) was obtained with the interaction effect of 75 cm inter and 30 cm intra row spacing Therefore, the inter row spacing 75 cm with intra row spacing 30 cm can be recommended to for sunflower growers in the low lands of Gondar and similar agro ecology.



$Z=-5.3X + 3.1Y + 2298.1$

$R2=0.78$

	P Value
Intercept	<2e-16***
X (row spacing)	0.000199***
Y (plant spacing)	0.4222476

Figure 2. Grain yield response of sunflower to different inter-and intra-row spacing of sunflower

4. CONCLUSION AND RECOMMENDATION

In conclusion, the study demonstrated a significant impact of inter- and intra-row spacing on the growth and yield of sunflower. The optimal combination of 75 cm inter row spacing and 30 cm intra row spacing yielded the highest grain production of 2375.2 kg ha^{-1} and a remarkable net benefit of 89671.4 Eth-Birr, underscored by a marginal rate of return of 1178.4%. Based on these findings, it is recommended that sunflower growers in the lowlands of Gondar and similar agro-ecological zones adopt this spacing configuration to maximize yield and profitability. Future research could explore the long-term effects of these spacing strategies on soil health and sustainability.

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