

Research Article

Determination of Optimum Plant Density for Sesame Productivity

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Abstract

Sesame is a vital cash crop and used for selling purpose for the livelihood of Ethiopian people. Nevertheless, the seed yield is low because of a number of production factors like the lack of optimum plant density and row spacing for sesame productivity. A fieldwork did to determine the appropriate row and plant spacings for Sesame productivity and profitability at Metema and Tach Armachiho districts. Treatments were arranged to five rows (40, 50, 60, 70 and 80 cm) with three plant spacing (10, 20 and 30 cm) spacings comparing with the blanket recommendation (40cm x 10cm) and arranged in randomized complete block design with three replications. The plant height, pods plant⁻¹, pod-bearing zone, seed and oil yield were highly significant and influenced by the interaction effects of row and plant spacings. The highest yield (1080 kg/ha⁻¹), oil content (53.8%) and net benefit (70,767 ETB) obtained from the 70 cm row spacing with the 20 cm plant spacing. However, the minimum yield (840 kg/ha), oil content (51.1%) and net benefit (25,973.2 ETB) were obtained from the blanket recommendation (40cm x 10cm) spacing. Therefore, the inter row 70 cm with intra row 20cm spacings are the most suitable plant densities and suggested to be promoted for sesame production on the tested locations in the lowlands of northwestern Gondar, Ethiopia.

Keywords

Abasena, Competition, Humera⁻¹, Interaction, Lowland Areas, Row

1. Introduction

Sesame (*Sesamum indicum* L.) is an important crop in world. Recognized as significant oil crops cultivated at warm regions across Asia, Africa and South America [1]. The Origin of sesame has been a matter of discussion for a long period. [2] Stated that it is believed to have originated from Ethiopia and India and presently the opinions are more in favour of Ethiopia because its wild relatives are found in Ethiopia and it has been spread from there to other parts of Africa, India, China, Japan, and Europe in very early times. Sesame is an important source of high quality oil and protein [3]. The seeds have a protein level of 25% and an oil content

of 52–57%. [4]. The oil has excellent stability due to the presence of natural antioxidants (sesamol and sesamin) and these lignans protect from oxidative rancidity. The sesame is so called ‘Queen of oil seeds’ due to its high quality polyunsaturated stable fatty acid, which restrains oxidative rancidity [5]. A total of 2,211,339 tons of sesame grain sold with a monetary value of 3.4 trillion USD in the world [6]. Moreover, sub-Saharan African countries exported about 1,465,493 tons of unprocessed sesame with a cash value of 1.9 trillion USD [5].

Ethiopia is the popular sesame producers in the world and

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Received: 9 December 2024; Accepted: 24 December 2024; Published: 16 January 2025



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the seed produced in western, Ethiopia (Gondar type) is highly competent in the world market by its desirable qualities in terms of colour, taste and aroma [6]. Sesame is an important cash crop and plays significant role as source of rural employment and ensuring food-security for over three million Ethiopian [7]. Ethiopia's sesame export share was 8.96% of global exports, valuing 307 million USD [5]. The area allocated for sesame production in Ethiopia was 375,119.95 ha, 45.7% of the estimated area under oil crop production. There were 375,119.95 hectares, 2,626,541.89 quintals and 7.0 Qt ha⁻¹ of the total area, production and productivity of sesame, respectively [8]. Though Ethiopia is among the top sesame producer countries in the world, the benefit is below the optimum yield because of different production factors. like plant density, time of planting, type, time and rate of fertilizers, lack of agricultural inputs, yield loss during harvesting and threshing and partly affected by the farmers to adopt improved cultural practices and lack of access to those improved sesame seeds for use [9]. Optimizing plant density per unit area is a prerequisite for obtaining higher yield [10]. Among the agronomic management practices, row spacing and plant density are important factors for the final productivity of the crop.

In Ethiopia, the recommended row and plant spacings to sesame production were 40 cm and 10 cm [11]. Nevertheless, production factors like fertility status of the soil, moisture availability and cultural practices influence both row and plant spacings. However, it is very vital to find site-specific recommendation of row and plant spacings depending on the potential of the area in order to maximize productivity and profitability of sesame through conducting experiment. Therefore, keeping this point in mind, the experiment carried out to determine the optimum row and plant spacings for better yield and profitability of sesame.

2. Materials and Methods

2.1. Description of Study Areas

The study was carried out from June to September during the main cropping seasons (2019 and 2020) at Metema research sub-Centre station and Tacharmachiho on farmer's field of northwestern Gondar, Amhara region, Ethiopia. The two locations are situated and the representative of the major Sesame growing areas of low land areas of northwestern Gondar and are suitable for high quality and quantity Sesame production to the local and international market. Sorghum, Cotton and Soybean are dominant precursor crops for Sesame in that area. All sites represent vertisols areas. The geographical coordination of Metema district (rain fall 1030.2-1037.3mm, temperature 19.5- 35.9 °C, relative humidity 53.1-58.3, altitude 710 - 898 masl, latitude 12°24'48" to 13°09'71" N and longitude 36°15'19" to 36°64'71" E). Whereas, Tacharmachiho district (Rain fall 970.88-973.1mm, temperature 18.5-34.5 °C, relative humidity 51.2-59.39, alti-

tude 1022 m. a. s. l, latitude 13°88 and longitude 13°88) in the northwestern Gondar, Ethiopia. The areas are characterized with mono-modal rainfall distribution pattern and rainy season begins late May t-end of September.

2.2. Experimental Design, Treatments

Five levels of row spacings (40 cm, 50 cm, 60 cm, 70 cm and 80cm) with three plant spacings (10 cm, 20 cm and 30 cm). Randomized complete block design (RCBD) was used with three replications. The plot size was 5 m x 3m (15m²), however, the harvestable plot sizes were arranged differently depend on the width of inter row spacings. As per the treatments, there were 10, 8, 6, 5 and 4 the harvestable number of rows for 40, 50, 60, 70 and 80 cm -row spacings, respectively. The number of plants in each row were 28, 13 and 8 for intra row spacings of 10 20 and 30 cm, respectively. In addition, the spaces 1.5 m and 1 m between replications and plots were maintained, respectively.

2.3. Research Materials and Cultivation Activities

The study is conducted using Abasena variety with 4 kg ha⁻¹ of seed rate as a planting material and the recommended rate (65 kg ha⁻¹) of nitrogen fertilizer was applied two times, half (97.5 gram plot⁻¹) at the time of sowing and half (97.5 gram plot⁻¹) at 50% flowering time. The experimental sites were ploughed three times using oxen, all years at planting times, harrowed and levelled were done by human labours to fine tilt soils. The seeds were planted on June 20/2019 and June 18/2020 by drilling the seed on plant spacings. The crop is weeding three times at 10; 25; 45 days after emergence, respectively. All other necessary agronomic management practices were done frequently throughout growing period of the crop accordingly.

2.4. Data Collection and Analysis

Phenological data such as DF and DM taken from whole plot. Ten purposively and randomly selected plants used for sampling on each plot from central harvestable rows to measure different parameters; such as PH, NBPP, NPPP and NSPP. At harvest, the outer most one row and one plant on both sides of the row and plant spacings left to avoid border effects for all plots. Harvesting done 7 days after physiological maturity (90%) from harvestable plots at full ripening when the leaves and stems became 75% yellowish color but before shattering. Pods dried by sun and threshed. After threshing the seed yield cleaned and weighed with sensitive balance measurement in gram plot⁻¹ and changed to kg ha⁻¹. Thousand seeds counted and weighed after a moisture content of 8% on wet bases with a moisture tester. The statistical analysis of the generated data on individual character carried out on the mean values over three replications. The collected

data analyzed by statistical version 9.4. The 5% and 1% levels significance used for mean separation for all agronomic parameters.

2.5. Economic Analysis

It employed the methodologies outlined by [12] to evaluate the economic viability of different spacings treatments. Variable costs associated with seed, planting (row making) and cultivation (weeding) calculated by ETB per hectare. The sesame (100 ETB kg⁻¹) market price was determined by assessing farm gate price at harvest. The partial budget analysis utilized on mean seed yields from each treatment, the average yield adjusted by 10% to estimate the ASY to reflect the difference that farmers could expect from the same area. GFB was obtained by multiplying the ASY with the farm gate price, (GB = ASY × P). The TVC is a summation of all operational costs that vary with changes in scale of operation includes, seed cost and labor costs (for row making and weeding costs) for all treatments. The NB was determined by NB = (ASY × P) – TVC. This formula highlights the relationship between yield, market price and operational costs. Following this, the dominance analysis is categorizing into dominated (D) and non-dominated (ND) groups. $MRR = (NB_a - NB_b / TVC_a - TVC_b) \times 100$. The systematic approach

allowed for a clear identification of the most economically viable sesame cultivation strategies among tested spacings.

3. Results and Discussion

3.1. Sesame Response to Row and Plant Spacings

3.1.1. Days to 50% Flowering

Plant density affects the phenological traits of sesame. It flowered early at the narrowest inter and intra row spacings and late flowering on the widest row and plant spacings. That is, shortest day (57) and longest day (62) to 50% flowering recorded from the plants grown with 50 cm with 20 cm and 80 cm with 30 cm spacings, respectively (Table 1). This showed narrowest row and plant spacings because growth and development were fast that accelerates flowering period. Even though the maximum 50% flowering the crops grown on the widest spacings, the shortest flowering time is best, especially in the case of shortage of rain on the time of seed setting.

Table 1. The interaction effects of various row and plant spacings phenological parameters Sesame in combined over locations and years.

TRT	DF			DM		
	Plant spacings (cm)					
Row Spacings (cm)	10	20	30	10	20	30
40	59.1	59	61	99.5	100	100.7
50	59	57	61	100.3	100.2	101.5
60	58	60	59.5	99.8	102	101.3
70	59	61	60	100	101	101.7
80	61	58	62	101.8	100.6	101.2
Mean	59.8			100.9		
CV (%)	3.2			1.1		
LSD (0.05)	2*			1.2*		

3.1.2. Physiological Maturity

The longest (101.8) days and shortest (99.5) to 90%, physiological maturity were recorded the plants grown with the 80 cm row spacing with 10 cm plant spacing and the 40 cm row spacing with 10 cm plant spacing, respectively (Table 1). Light interception would be intercepted better in the narrow-

est inter row spacing as compared to widest inter row spacing but free air circulation in the canopy of the widest spaced rows could have its own contribution for longest days to [13]. Narrowest row spacing had its own advantages for fast seed setting and maturity in the case of shortage of rain and labours.

3.2. Sesame Response to Row and Plant Spacings Growth Parameters

3.2.1. Number of Branches per Plant

The maximum (6.2) and minimum (4.3) number of branches obtained from 80 cm x 20 cm and 40cm x 10cm spacings, respectively (Table 2). This showed that row and plant spacings increased, NBpP increased directly and visa-versa. Conformity by [14] the secondary branches (1.50 m) from 75 x 10 cm spacing. [15] Confirmed that the highest (3.9) obtained at the wider row and spacings (100 cm x 40 cm).

3.2.2. Plant Height

Plant density has indicated statistical variation on sesame (Table 2). The longest (1.565 m) and shortest (1.379m) plant heights obtained from the plants grown with 50 cm with 10 cm and 80cm with 30cm spacings, respectively (Table 2). This showed that when row spacing increased from 50cm to

80cm and plant spacings from 10 cm to 30cm spacings, the plant height decreased. [16] Conformity that when the number of plants in m⁻² increases, the competition for light also increases and plant grows taller to intercept maximum light. However, this result is contradicted with the findings of [17] showed that (129.7 cm) was obtained when the inter row and intra-row spacings of 100 cm x 40 cm.

3.2.3. Length of Pod Bearing Zone

The length of pod bearing zone at maturity affected by the interaction effect of row and plant spacings. The longest (58cm) and shortest (48cm) length of pod bearing zone recorded from the plants grown with 50 cm x 10 cm and 80cm x 30cm spacings, respectively (Table 2). These result showed that when row and plant spacings increased from 50 cm x 10 cm to 80cm x 30cm spacings, the length of pod bearing zone was decreased like that of plant height. Plants grew in the widest row and plant spacings length of pod bearing zone decreased and vise-versa.

Table 2. The interaction effects row and plant spacings on growth parameters in combined over locations and years.

TRT	NBpP			PH (cm)			LPBZ (cm)		
Row Spacings (cm)	Plant spacings (cm)								
	10	20	30	10	20	30	10	20	30
40	4.3	4.5	5.1	154.5	150	154.9	56	54	53
50	5.8	5.2	4.9	156.5	150	144.5	58	56	54
60	5.1	5.2	4.9	150.7	150	145	55	56	54
70	5.1	5.1	5.0	150.7	141.8	151.9	55	54	52
80	5.3	6.2	5.2	153.5	154	151.2	55	56	51
Mean	5.1			150.7			54		
CV (%)	16.7			6.8			10		
LSD (0.05)	1.1*			8.3**			2.5**		

3.3. Sesame Response to Row and Plant Spacings on Yield Contributed Traits

3.3.1. NPpP

The maximum (82.4) and minimum (53.6) NPpP recorded from row and plant of spacings 70 cm x 20 cm and 40cm x 10cm spacings, respectively (Table 3). This showed that less populated plants increase a number of branches per plant produced more number of pods per plant. [14] Conformity higher number of capsules per plant at wider spacing (75 cm). In addition [15] higher number of capsules per plant (75.6) at

wider inter-row spacing (100 cm).

3.3.2. NSpP

The highest (74.9) and lowest (68.4) NSpP obtained from the plants growing at 70cm x 20cm and 60cm x 20 cm row and plant spacings, respectively (Table 3). This result indicated that row spacing is vital for more number of seeds pod⁻¹. [14] Confirmed that the highest number of seeds per capsule (65.22) at wider spacing (75 cm). [15] Confirmed that the highest number of seeds per capsule (62.11 and 62.6) recorded at wider row spacing (100 cm) and plant spacing (40 cm).

3.3.3. 1000 Seeds Weights

The highest (2.91) and lowest (2.53) thousand seeds weight were obtained on 70 cm x 20 cm and 80 cm x 20 cm row and plant spacings (Table 3), respectively. That the 1000 seeds

weight was higher at medium row spacing compared to narrowest and widest row spacings but plant spacing has no effect on the 1000 seeds weight. [14] Confirmed that the highest thousand seed weight (3.28 g) affected by row spacing (75cm).

Table 3. The interaction effects of row and plant spacings on yield related traits over locations and years.

TRT	NPPP			NSPP			TSW (G)		
Row Spacings (cm)	Plant spacings (cm)								
	10	20	30	10	20	30	10	20	30
40	53.6	77.6	68.6	70.3	70.8	70.6	2.86	2.76	2.72
50	63.6	68.9	66.3	70.8	71.0	68.7	2.81	2.76	2.84
60	62.2	62.7	70.2	71.7	68.4	68.9	2.68	2.62	2.64
70	61.1	82.4	62.9	69.3	74.9	69.9	2.82	2.91	2.83
80	65.2	63.9	79.4	72.5	69.2	72.2	2.71	2.53	2.77
Mean	67.2			70.4			2.7		
CV (%)	15.3			10.8			11.1		
LSD (0.05)	13**			6*			0.24*		

3.4. Seed Yield

The seed yield of sesame was highly significant ($P < 0.01$) and affected by the interaction effects of row and plant spacings over locations and years. Average seed yield is from 1080 kg ha⁻¹ to 840 kg ha⁻¹. The maximum seed yield (1080 kg ha⁻¹) was noticed in 70 cm x 20 cm (70,000 plants ha⁻¹), and the minimum seed yield (840 kg ha⁻¹) obtained at 40 cm x 10 cm (260,000 plants ha⁻¹) row and plant spacings (Table 4). The blanket recommended spacings gave below the mean average yield (910 kg ha⁻¹). The significant difference among treatments for seed yield could be due to variation associated with yield parameters, such as NBpP, NPpP, NSpP and 1000 seed weight. Furthermore, plants grown at the lowest plant density could receive relatively high growth factors (light, moisture and nutrient) that cause for increment of seed yield. Controversially, high plant population resulting lower seed yield per hectare of crop to express its potential because of competition for such growth factors. Crop cultivation practices became easier and reduced cost of seed rate, row-making labours, weeding labours, etc at wider spacings. Even though, there were variations among treatments in seed yield of this experiment, the seed yield was high as compared to the national average (700 kg ha⁻¹) due to high plant densities. Over all, the 70 cm inter row and 20 cm intra row spacings recorded significantly highest seed yield over mean seed yield and

other inter and intra row spacings. The 70 cm x 20 cm gave 240 kg ha⁻¹ (22.23 %) seed yield advantage over that of blanket recommendations (40 cm x 10 cm). [17] Confirmed that the 75 cm row spacing recorded significantly higher yield than 50 cm spacing. [18] Concluded that the 75 cm x 20 cm spacings recorded the highest grain yield revealed that potential yields are probably as high as 2000 kg per hectare at wider spacing. However, [19] contradicted and reported that the highest seed yield (1135.3 kg ha⁻¹) obtained 30cm x 5 cm (666 666 plants ha⁻¹) and lowest seed yield (677.1 kg ha⁻¹) obtained 70cm x 30 cm (47 619 plants ha⁻¹) plant densities.

Table 4. The interaction effects of row and plant spacings over locations and years.

Treatment	Seed Yield (kg ha ⁻¹)		
	Plant spacings (cm)		
Row spacings (cm)	10	20	30
40	840	910	890
50	880	930	870
60	860	920	880
70	1000	1080	960

Treatment	Seed Yield (kg ha ⁻¹)		
	Plant spacings (cm)		
Row spacings (cm)	10	20	30
80	860	910	850
Mean		910	
CV (%)		10.6	
LSD (5%)		150**	

3.5. Response of Sesame to Row and Plant Spacings on Oil Yield

The highest (53.8%) and the lowest (51.1%) oil contents recorded from the plants grown with the row and plant spacings of 70 cm x 20 cm and 40 cm x 10 cm, respectively (Table 5). Under the optimum plant density, the crops utilized efficiently all the resources for accumulation of food ingredients as oil content. [20] Confirmed that the lower population density resulted in higher oil content while increased density reduced amount of oil content in seeds.

Table 5. The interaction effects of oil yield under row and plant spacings over locations and years.

Treatment	Oil Content Yield (%)		
	Plant spacings (cm)		
Row spacings (cm)	10	20	30
40	51.1	53.2	51.3
50	52.4	52.6	53.3
60	51.4	52.2	52.7
70	52.6	53.8	52.7
80	52.7	52.4	51.8
Mean		52.22	
CV (%)		2.5	
LSD (5%)		0.001***	

Table 6. Partial budget analysis of row and plant spacings on seed yield of sesame.

Treatment (cm)	UASY (kg ha ⁻¹)	ASY (kg ha ⁻¹)	TVC (ETB ha ⁻¹)	GFB (ETB ha ⁻¹)	NB (ETB ha ⁻¹)	Dominance	MRR (%)
80×30	850	765	47600.5	76,500	28,899.5	ND	
80×20	910	819	47631.3	81,900	34,268.8	ND	17460.9
80×10	860	774	47723.5	77,400	29,676.5	D	
70×30	960	864	37034.2	86,400	49,365.8	ND	1717.9
70×20	1080	972	37070.0	97,200	60,130.0	ND	30004.9
70×10	1000	900	37177.7	90,000	52,822.4	D	
60×30	880	792	30375.4	79,200	48,824.6	D	
60×20	920	828	30416.4	82,800	52,383.6	D	
60×10	860	774	30539.4	77,400	46,860.6	D	
50×30	870	783	27333.3	78,300	50,966.7	D	
50×20	930	837	27384.6	83,700	56,315.5	D	
50×10	880	792	27519.1	79,200	51,680.9	D	
40×30	890	801	24541.6	80,100	55,558.4	D	
40×20	910	819	24608.2	81,900	57,291.8	D	
40×10	840	756	24808.1	75,600	50,792.0	D	

3.6. Partial Budget Analysis

It evaluated the economic performance of different row and plant spacings on sesame production. The result of partial budget analysis indicated that the use of row and plant spacings of 70 cm x 20 cm gave the highest net benefit (60,130 ETB ha⁻¹) (MRR=30004%) followed by 40 cm x 20 cm (57,292 ETBha⁻¹). However, the lowest net benefit (50,792 ETBha⁻¹), was obtained from the interaction of 40 cm inter and 10 cm intra row spacings. The spacings of 70 cm×20 cm showed a notable monetary advantage of 9,338 ETBha⁻¹ over that of the blanket recommendation (40 cm×10 cm) now what producers used technology. Furthermore, MRR utilized to evaluate the financial implications to adopt this new technology. This indicated that for every one birr invested, the farmers could anticipate a return of 300.049 ETB, providing a strong incentive to implement these spacings for greater profitability of sesame. Therefore, based on partial budget analysis planting sesame on 70 cm row with 20 cm plant spacings is economically advisable for farmers in the study area for better sesame production.

4. Conclusion and Recommendation

The study result indicated that various plant densities did affect the major agronomic parameters, yield components and grain yield of sesame. Ultimately, the findings of this study showed that the optimum plant density and uniform plant distribution could enhance the seed yield and profitability of crop. Most of the studied agronomic parameters influenced by row and plant spacings across locations and two years. The two-way interactions of row and plant spacings were highly significant on yield and yield related parameters. Generally, this research result confirmed that 70cm ×20cm s (70,000 plants ha⁻¹) are the best spacing for maximum yield and net benefit. Therefore, it can be concluded that for higher productivity and profitability of sesame, the 70 cm row spacing with 20 cm plant spacing is recommended and will be demonstrated for further applicability of sesame for studied areas and similar agro-ecologies.

Abbreviations

ASY	Adjusted Seed Yield
cm	Centi Meter
CV (%)	Coefficient of Variation
DF	Days to 50% Flowering
DM	Days to 90% Physiological Maturity
D	Dominance
ETB	Ethiopian Birr
GFB	Gross Field Benefit
LSD (%)	Least Significant Difference
LPBZ	Length of Pod Bearing Zone
kg	Kilo Gram

ha	Hectare
PH	Plant Height
NBpP	Number of Branches per Plant
NPpP	Number of Pods per Plant
NSpP	Number of Seeds per Plant
ND	Non- Dominated
Ns	Non-Significant
MRR	Marginal Rate of Return
SY	Seed Yield
TVC	Total Variable Cost
TRT	Treatment
UASY	Unadjusted Seed Yield
%	Percentage
**	Highly Significant
*	Significant

Acknowledgments

The authors are thankful to all researchers and staff members of the Gondar agricultural research center and to Metema sub center for their assistance during the experimental research periods. Moreover, the authors acknowledge to Gondar agricultural research center and Amhara agricultural research institute for financial support (150,000.00ETB).

Additional Information

No additional information is available for this paper.

Author Contributions

Melaku Azanaw: original draft, proposal preparation, conceptualization, methodology, data collection, investigation data curation, formal analysis and writing

Getachew Asmare: data collection, data feeding and methodology

Conflicts of Interest

The authors declare no conflicts of interest.

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Research Field

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