SOIL & CROP SCIENCES | RESEARCH ARTICLE

Optimum inter-row spacing and seeding rate of sesame for harnessing the maximum productivity potential in the dry land area of Abergelle District, Northeast Ethiopia

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Abstract: Field experiments have been conducted with the objective of identifying optimum inter-row spacing and seeding rate of sesame for harnessing the maximum productivity potential in the dry land area of Abergelle District, Northeast Ethiopia. The experiment was designed in factorial arrangement of three inter row spacing (40, 50 and 60 cm) and four seeding rates (2, 3.5, 5 and 6.5 kg ha\(^{-1}\)) in RCBD with three replications. The main effects of inter row spacing and seeding rate as well as the interaction had no significant effect on days to 50% emergence. The main effects of inter row spacing and seeding rate had significant effect on plant height and capsule length. On the other hand, the interaction effects of inter row spacing and seeding rate significantly influenced 50% flowering, 50% maturity, number of leaves, number of branches, number of capsules per plant and grain yield. The highest grain yield (758.32 kg ha\(^{-1}\)) was obtained from 3.5 kg ha\(^{-1}\) × 50 cm and (750.28 kg ha\(^{-1}\)) from 3.5 kg ha\(^{-1}\) × 40 cm seeding rate and inter row spacing. Based on partial budget analysis 3.5 kg ha\(^{-1}\) × 50 cm and 5 kg ha\(^{-1}\) × 40 cm seeding rate and inter row spacing combination can be also economical with high net benefit respectively. Thus, the

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PUBLIC INTEREST STATEMENT

In Ethiopia, sesame grows well in the lowlands either as sole crop or intercropped with millet or sorghum. Within the low lands of Ethiopia in particular Amhara region, Abergelle wereda is one of sesame producing area. Since sesame is widely utilized as oil crop by the people in world, its market price is much higher than all other crops. Despite the aforementioned importance of the crop, its current production is constrained by various problems in the country. An inappropriate agronomic practice is among the main problems associated with low productivity of sesame production in Ethiopia. Thus development of location specific agronomic practices like optimum plant population and inter-row spacing are necessary to enhance the productivity of sesame.
50 cm inter spacing × 3.5 kg ha\(^{-1}\) seeding rate and 40 cm inter spacing × 5 kg ha\(^{-1}\) seeding rate combination seems promising as 1\(^{st}\) and 2nd option for locally available sesame variety under the rain fed condition of Abergelle woreda.

**Subjects:** Agriculture & Environmental Sciences; Botany; Soil Sciences

**Keywords:** Dry land; grain yield; inter row spacing; seeding rate; sesame

1. Introduction

Sesame (Sesamum indicum L.) is an annual crop and one of the important oil crops of the world and belongs to the order Tubiflorae and family Pedaliaceae cultivated for seed (Raikwar & Srivastva, 2013). It was one of the first oil seeds from which oil was extracted by the ancient Hindus, which was used for certain ritual purposes (Arnon, 1972). Seegeler (1983) reported that it is an ancient oil seed, first recorded as a crop in Babylon and Assyria before 2050 BC.

Sesame has been cultivated in the hotter and drier parts of the Mediterranean region, Africa and India as well as in the Far East (Longham, Riney, Smith, & Wiemers, 2008). More specifically sesame is grown widely in countries such as India, Pakistan, Turkey, Iraq, Syria, Sudan and Egypt. India and China are the major world sesame producers; in Africa, Sudan is the largest and Ethiopia is the fourth largest sesame producers (Langham & Wiemers, 2002). Of the world’s sesame production, 60% is produced in Asia, but less than 2% of this total is exported. Africa too has large internal market, but supplies about 80% of the world exports (Seegeler, 1983). The principal African exporters in order of magnitude are the Sudan, Nigeria, and Ethiopia (Langham & Wiemers, 2002).

Sesame oil contains both insecticidal and anti-fungal properties. It is added to formulations to help coat plant surfaces and used as a surfactant; there is no published science on the use of this ingredient as a stand-alone fungicide (Calvert & Chalker-Scot, 2014). But, a mixture of sesame oil and Neem (Azadirachta indica L.) seed oil has been evaluated for their pesticide action in the suppression of dominant insect pests of sesame. pentatomid bugs, Dolycoris indicus (Stal), Nezara viridula, chrysomelid beetle, Aphthona nigrilabris (Duvivier), leaf sucking coleopteran beetle and Monolepta signata (Oliv.) (Ahmed et al., 2014).

In Ethiopia, sesame grows well in the lowlands either as sole crop or intercropped with millet or sorghum (Haile, Tesfaye, Tesfaye, & Mulat, 2004). Within the low lands of Amhara region, Abergelle is one of sesame producing woreda (BoA, 2013). Area allocated to sesame both at regional and national level increase from time to time. CSA (2014/15) reported that in Ethiopia area covered by sesame during 2009 to 2014 was increased from 185,000 ha to 216,988.58 ha. According to the Office of Agricultural Development (Oad et al.) of Abergelle wereda, area coverage of sesame increased from 6,118.16 ha to 10, 02.3 ha between 2009/14 (unpublished).

In Ethiopia and in particular in Abergelle wereda, the yield of sesame is very low. There is a wide gap between the national yield average 700 kg ha\(^{-1}\) (CSA, 2014/15) and the yield recorded under experimental stations in 2200 kg ha\(^{-1}\) (Omran, 1985) of sesame. According to OAD of Abergelle wereda, the average yield of sesame ranges from 450 kg ha\(^{-1}\) to 500 kg ha\(^{-1}\).

There are a number of constraints that limit the production of sesame. One of them is lack of optimum plant population and inter-row spacing recommendations. Farmers in the arid and semi-arid areas usually use high population and broadcast method for all crops grown for various reasons (Regasa, Tesfamichael, Alemu, & Admasu, 1995; Reddy & Giorgis, 1994). This practice mostly resulted in poor seedling growth and developments because of severe competition at the seedling stage that leads to lower yield (Reddy & Giorgis, 1994).
Yield responses to plant population and row spacing need to be known for practical purposes, as planting density is a major management variable used in matching crop requirements to the environmental offer of resources (Smith & Hamel, 2012). According to López-Bellido, López-Bellido, López-Bellido, and Castillo (2003) as plant density increases, competition between plants becomes more intense, affecting the growth, development and production of each plant. Sesame yield is dramatically decreased as the row spacing increased (Ngala, Dugje, & Yakubu, 2013).

Optimizing plant density and row spacing are also very important for improving grain yield in a particular environment. Maximum yield of sesame is achieved from the best spatial arrangement of plants for effective canopy development, water and nutrient utilization and pest control (Caliskan, Arslan, Arioglu, & Isler, 2004). These relationships are also important for optimal physiological function of the crop. In sesame, yield is a function of the number of plants per unit area, number of branches per plant, number of capsules per plant, and number of seeds per capsule and seed weight. Therefore, management practices should focus on obtaining the maximum number of yield component characteristics of the plant.

Though, more than 30% (10,002.3 ha) of the area is covered with sesame, there is no recommended seeding rate and inter row spacing in the study area. The currently used inter row spacing (40 cm) and seeding rate (5 kg ha\(^{-1}\)) are blanket recommendations for all sesame growing areas of Ethiopia, which does not consider the potential of the respective area.

2. Materials and methods

2.1. Description of the study area

The experiment was conducted from July to November 2016 at Abergelle wereda, Waghimra administrative zone of Amhara Regional State. The experimental site was located at an elevation of 1495 m.a.s.l, 13°20’ N latitude and longitude of 38°58’ E (Abeje et al., 2016). The climate of Abergelle is characterized as arid to semi arid agro ecology, where crop cultivation is the dominant sector in the woreda. The Rainfall pattern is characterized as unimodal.
The main rainy season (kiremt) extends from June to September. The mean maximum and minimum annual temperatures are 42 and 35°C, respectively. The mean annual rainfall of the area ranges from 250 to 650 mm. The textural class of the soil of study area is sandy loam; which accounts 71% sand, 13% silt and 16% clay (Abeje et al., 2016). Soil color of the area is 55% brown, 30% red, and 15% light reddish gray. Regarding some chemical properties of the soil, the pH is 7.5 with total nitrogen 0.012%, available phosphorous 7mg kg\(^{-1}\), available potassium 78ppm and 0.89% organic matter (Figure 1).

2.2. Treatments and experimental design
In this experiment, locally available sesame variety was used as planting material. The treatments were consisted of three inter row spacing (40, 50 and 60 cm), and four seeding rates (2, 3.5, 5 and 6.5kg ha\(^{-1}\)). The three inter row spacing and the four seeding rates were arranged in 3 × 4 factorials in Randomized Complete Block Design (RCBD) with 3 replication. The gross plot size was 9m\(^2\) with 3m width and 3m length. The net plot areas are (5 × 0.4 × 3 = 6.0m\(^2\)), (4 × 0.5 × 3 = 6.0m\(^2\)) and (3 × 0.6 × 3 = 5.4m\(^2\)) for 40 cm, 50 cm and 60 cm inter row spacing respectively. Spacing between plot and between replications were 0.5m and 1.0m, respectively. Treatments were assigned to each plot randomly. Five, six, and seven rows were planted per plot for 60, 50 and 40 cm inter row spacing respectively. The central three, four and five rows in the net plot areas were used for data collection for the 60, 50 and 40 cm inter row spacing, respectively.

2.3. Experimental procedure
The land was prepared by oxen/animal drawn plowing and hand tools, after that leveled and smoothed by human labor using hand tools. The seeds were drilled at a depth of about 2.5 cm to ensure adequate emergence. Fertilizer application was based on the recommendation of the area (38 and 29 kg ha\(^{-1}\) N and P\(_2\)O\(_5\) fertilizers respectively). Hence, 58kg ha\(^{-1}\) Urea (46% N) and 63kg ha\(^{-1}\) DAP (18% N and 46% P\(_2\)O\(_5\)) was used as sources of N and P nutrient at planting time. Weeding and other crop management practices were carried out uniformly for each plot as per the recommendation for the crop. Harvesting was done at physiological maturity when 50% of the plants got yellow and when the bottom of the sesame capsule started to open. Drying was done by setting the bundles upright until all capsules opened. Threshing was done by shaking properly the inverted bundles until all seeds dropped from the capsules.

2.4. Data collected

2.4.1. Phenological data
- Days to 50% emergence was recorded when half of the seedlings per net plot area emerged.
- Days to 50% flowering was also taken when half of the plant population on the net plot area started to flower.
- Days to 50% maturity was recorded when 90% of the population turned their leaves yellow and the lower most capsules started to open. Each phenological stage was determined from visual observation.

2.4.2. Growth parameters
- The number of leaves was recorded on the main stem as well as on the branches for ten randomly selected and tagged plants from net plot at 50% flowering stage of the plants.
- Number of branches per plant was counted from ten randomly selected plants per net plot area at physiological maturity.
- Plant height of the main stem was measured from the ground surface to the tip of the apex at physiological maturity.

2.4.3. Yield and yield related traits
- Number of capsules per plant was counted from ten randomly selected and pre tagged plants per net plot area at physiological maturity of the crop.
Capsule length was also measured on three capsules (lower, middle and upper positions) from each of the tagged plants and the average was taken.

Thousand seed weight was determined after harvest, 1000 seeds were taken randomly from the seed lots of each net plot and weighed after sun-drying.

Seed yield of each plot was weighed in grams and converted to area basis to determine the yield per hectare in kg ha\(^{-1}\). On the other hand, since a serious follow up was made during the maturity of the crop, there was no shattered crop and hence data on shattering was not analyzed. Moreover, there was no problem of lodging as well as disease or insect infestation and, therefore, data was not analyzed on lodging %, disease and insect infestation.

2.5. Statistical data analysis

Data was subjected to analysis of variance (ANOVA) using SAS software (9.0). All significant pairs of treatment means was compared using the Least Significant Difference test (LSD) at 5% and 1% level of significance. The economic analysis was carried out using CIMMYT partial budget analysis methodology (CIMMYT, 1988).

3. Results and discussion

3.1. Crop phenology

3.1.1. Days to 50% emergence

The analysis of variance showed that, the main effect of seeding rate, inter row spacing and the interaction had no significant effect on days to 50% emergence at (P < 0.05). The present finding is in agreement with the finding of Amato, Cibella, Giambalvo, and Gristina (1992) who reported that seed germination and establishment is not affected by increasing seeding rate. For this study result the other supporting evidences were reported by Tadesse, Ayalew, Getu, and Tefera (2006) who reported that germination of non inactive sesame seeds is first and foremost influenced by moisture and temperature no significant effect of the inter row spacing on the days to 50% emergence.

3.1.2. Days to 50% flowering

There was significant difference in the number of days taken to 50% of the plants to flower in a plot (P < 0.01) affected by the inter row spacing, seed rate as well as their interaction of inter row spacing and seed rate. The longest days of flowering was recorded in 60 cm inter row spacing (38.79) and in 2 kg seeding rate (38.95). Likewise significantly the highest days to 50% flowering of (43.66) was recorded for the interaction of widest inter row spacing and low seeding rate of 60 cm x 2 kg (Table 1). This might be attributed to that closely spaced plants use resources faster and growth rate hastened as described by Langham (2007) where at the same moisture and fertility,

Table 1. Interaction effect of inter row spacing and seeding rate on days to 50% flowering of sesame

| Inter row spacing (cm) | Seeding rate (Kg) | 2.0       | 3.5      | 5        | 6.5        |
|-----------------------|-------------------|-----------|----------|----------|------------|
| 40                    |                   | 36.70c    | 34.80def | 33.80f   | 32.83g     |
| 50                    |                   | 36.50cd   | 35.36cde | 34.40df  | 33.00g     |
| 60                    |                   | 43.66a    | 40.83b   | 34.83de  | 35.83cde   |
| LSD                   | **                |           |          |          |            |
| SE±                   |                   | 0.31      |          |          |            |
| CV%                   |                   | 12.82     |          |          |            |

LSD = Least significance difference, SE± = standard error, CV (%) = Coefficient of variation; Means in column and row by the same letters are not significantly different at 5% level of significance.
high populations will use up the resources sooner and will go through the whole development faster from the mid bloom to the late dry down stage. The result of this study was in agreement with Alessi, Power, and Zimmerman (1977) who reported significantly delayed flowering of sunflower planted at wider spacing than the denser planting. Similarly, Ahmad, Mahmood, Saleem, and Ahmad (2002) also reported that sesame row spacing had significant effect on number of days to flower and maximum days (56) was taken to flower at 60 cm row spacing, while crop sown at 30 cm rows took minimum days (52) to flowering and this might be attributed to more nutritional area available in wider spacing, which caused more vegetative growth. Turk, Tawaha, and El-Shatnawi (2003) worked on lentil, also reported that high plant density promotes phenomenological development; with flowering occurring 14 days earlier in the high plant density. The other supporting result also Al-Rifaee, Turk, and Tawaha (2004) found that plants from lower densities flowered significantly later than those from higher densities.

3.1.3. Days to 50% physiological maturity
The number of days to 50% physiological maturity of the plants in a plot was highly and significantly (P < 0.01) affected by the main effect of inter row spacing and seeding rate as well as the interaction of inter row spacing and seeding rate. Significantly longer days of physiological maturity (95.90) was recorded in 60 cm inter row spacing and 2kg ha$^{-1}$ seeding rate (101.38) respectively (Table 2). Likewise longer date of physiological maturity (107.56) were recorded at inter row spacing 60 cm and seeding rate of 2kg ha$^{-1}$ interaction while inter row spacing 40 cm and seeding rate of 6.5kg ha$^{-1}$ interaction exhibited the shortest days (81.66) to physiological maturity. This result was agreed with that of Langham (2007) who noted that the plant spacing affects the phenotype and the length of time of the phases and stages as plants compete for light at high population densities plants to grow taller and faster than low population density.

Moreover, Poulain, Keller, and Guen (1986) noted that high densities increase photosynthesis, reducing respiration and photorespiration, and accelerated maturity of safflower. In contrast, Oad, Samo, Qayyum, and Oad (2002) reported that closer inter row spacing of safflower increased maturity days; wider inter row spacing recorded early days to crop maturity. In addition, they reported that the interaction between closer distance between rows and low seed rate recorded maximum days to maturity, whereas, the wider plant spacing displayed early maturity.

3.2. Plant growth parameters

3.2.1. Number of leaves per plant
The analysis of variance showed that inter row spacing and seeding rate as well as their interaction had a highly significant (P < 0.01) effect on the number of leaves. The highest number of leaves (41.36) was recorded in 60 cm inter row spacing on the other hand (44.87) was recorded in

| Table 2. Interaction effect of inter row spacing and seeding rate on days to 50% physiological maturity of sesame |
|---------------------------------------------------------------|
| Inter row spacing (cm) | Seeding rate (Kg) | 2.0  | 3.5  | 5    | 6.5  |
|------------------------|-------------------|------|------|------|------|
| 40                     |                   | 96.13c | 90.06dc | 84.33gh | 81.66h |
| 50                     |                   | 100.40b | 92.83cd | 88.33ef | 83.33gh |
| 60                     |                   | 107.56a | 100.70b | 89.00f  | 86.33fg |
| LSD                    | **                | 96.13c | 90.06dc | 84.33gh | 81.66h |
| SE±                    |                   | 0.62  |      |      |      |
| CV%                    |                   | 12.16 |      |      |      |

**LSD = Least significance difference, SE± = standard error, CV (%) = Coefficient of variation; Means in column and row by the same letters are not significantly different at 5% level of significance**
2 kg ha\(^{-1}\) seeding rate (Table 3). The highest number of leaves per plant (49.83) was recorded at 60 cm inter row spacing and 2 kg ha\(^{-1}\) seeding rate, while the lowest number of leaves per plant (31.40) was recorded at 40 cm inter row spacing and 6.5 kg ha\(^{-1}\) seeding rate interaction. These may be due to as the plant population increased and row spacing decreased, competition between plants for limited resources increased and less vegetative growth and low number of branches per plant leads to low number of leaves, in reverse as the plant population decreased and as the row spacing increased vegetative growth and development of branches per plant increased as a result more number of leaves per plant. Supporting evidences were reported by López-Bellido et al. (2003) described that as plant density increases competition between plants becomes more intense, affecting the growth, development and production of each plant and Blackshaw (1993), Leitch and Sahi (1999), and Turk et al. (2003) conducted research on the effect of spacing on the growth characteristics of safflower, linseed and lentil, respectively, and they all pointed out that both maximum and final numbers of tillers per plant, total leaf numbers and arrangement, plant height, leaf length and maximum leaf area per plant increased consistently as plant spacing increased and as seed rate decreased.

3.2.2. Plant height

In the present study, main effects of inter row spacing and seeding rate exerts highly and significantly (\(P < 0.01\)) effect on plant height at maturity. The highest plant height (117.77) was obtained from the plants grown at 2 kg ha\(^{-1}\) seeding rate and (109.11 cm) with the widest inter row spacing (60 cm) respectively. While the lowest plant height (97.04 cm) was recorded from 6.5 kg ha\(^{-1}\) seeding rate and (102.90 cm) was recorded from plants grown at 40 cm inter row spacing (Table 4). On the other hand longest plant height was recorded in 2 kg ha\(^{-1}\) \(\times\) 60 cm and lowest in 6.5 kg ha\(^{-1}\) \(\times\) 40 cm seeding rate and inter row spacing interaction respectively. Supporting evidences were reported by Weiss (1983), where increase in plant height was obtained with decreased seeding rate and inter row spacing. However, this result was in contrast to Osman (1993) on Sesamum indicum indicated that in narrow spacing plants compete more for available resources especially for light and result in more height than widely spaced plants. Moreover, Singh and Singh (2002) described that, high plant density bring out certain modifications in the growth of plants. example, increase in plant height, reduction in leaf thickness, alternation in leaf orientation, and leaves become erect, narrow and are arranged at longer vertical intervals to intercept more sun light. The other supporting result was obtained by Levy, Palevitch, and Kleifeld (1985) plant density has shown to affect plant height and number of branches per plant. They reported that taller and more branched plants were obtained at the lower densities.

In contrast Jadhav, Chavan, and Gunagarde (1992) and Aydoğdu and Açıkgöz (1995) explained that closer inter row spacing increased plant height. On the other hand Osei Bonsu (1975) noted
that increase in plant population did not increase plant height and final seed yield but reduced the number of branches. This contrasting result from the above results could be due to the ample amount of sunlight at the study site as result plants did not compete for it.

3.2.3. Number of branches per plant
Number of branches is an important growth parameter which has considerable influence on yield. In the present study the analysis of variance showed that number of branches per plant was highly significantly ($P < 0.01$) affected by the main effects of inter row spacing and seeding rate as well as their interaction effect. More number of branches per plant (2.86) and (3.35) was recorded in 60 cm inter row spacing and 2 kg ha$^{-1}$ seeding rate respectively (Table 5). Likewise the highest mean number of branches per plant (4.46) was recorded for plants grown at 60 × 2 kg ha$^{-1}$ cm inter row spacing and seeding rate, whereas the lowest number of branches per plant (1.33) was obtained from plants grown at 40 cm x 6.5 kg ha$^{-1}$ inter row spacing and seeding rate interactions respectively. In general, in most cases as the inter row spacing increased and seeding rate

| Treatments | Plant height (cm) |
|------------|------------------|
| Seeding rate (kg) | |
| 2.0 | 117.77a |
| 3.5 | 111.77b |
| 5.0 | 98.15c |
| 6.5 | 97.04c |
| LSD | ** |
| SE± | 1.15 |

Inter row spacing(cm)

| Inter row spacing (cm) | 40 | 50 | 60 |
|------------------------|----|----|----|
| 2.0 | 102.90c | 106.10b | 109.11a |
| 3.5 | 102.90c | 106.10b | 109.11a |
| 5.0 | 102.90c | 106.10b | 109.11a |
| 6.5 | 102.90c | 106.10b | 109.11a |
| LSD | ** | ** | ** |
| SE± | 1.00 | 1.00 | 1.00 |
| CV (%) | 5.27 | 5.27 | 5.27 |

LSD = Least significance difference, SE± = standard error, CV (%) = Coefficient of variation; Means in column and row by the same letters are not significantly different at 5% level of significance

Table 5. Main effect of inter row spacing and seeding rate on plant number of branches per plant of sesame at physiological maturity

| Seeding rate (kg) | Inter row spacing (cm) |
|-------------------|------------------------|
| 2.0 | 3.5 | 5.0 | 6.5 |
| 40 | 2.60b | 1.76def | 1.53ef | 1.33f |
| 50 | 3.00b | 2.06cde | 1.66def | 2.20cd |
| 60 | 4.46b | 4.06a | 1.60def | 1.46ef |
| LSD | ** | ** | ** | ** |
| SE± | 0.12 | 0.12 | 0.12 | 0.12 |
| CV (%) | 16.90 | 16.90 | 16.90 | 16.90 |

LSD = Least significance difference, SE± = standard error, CV (%) = Coefficient of variation; Means in column and row by the same letters are not significantly different at 5% level of significance
decreased the number of branches per plant increased indicating the importance of inter row spacing and seeding rate in determining the number of branches per plant. The result of this study was in agreement with that of Caliskan et al. (2004) who reported more branched plants at the lower plant densities of sesame. On the other hand Levy et al. (1985) reported that taller and more branched plants were obtained at the lower densities. Likewise Osei Bonsu (1975) noted that increase in plant population did not increase plant height and final grain yield but reduced the number of branches.

3.3. Yield and yield components

3.3.1. Number of capsules per plant

The analysis of variance indicated that inter row spacing, seeding rate and the interaction had highly significant (P < 0.01) effect on number of capsules per plant. More number of capsules per plant (40.12) and (44.22) was recorded in 60 cm inter row and 2 kg ha\(^{-1}\) seeding rate respectively (Table 6). Likewise highest mean number of capsules per plant (57.33) was recorded for the interaction 60 cm x 2 kg ha\(^{-1}\) inter row spacing and seeding rate, while the lowest number of capsules per plant (27.33) was recorded for 50 cm x 5 kg ha\(^{-1}\) inter row spacing and seeding rate, respectively. Like the effect on number of branches, as the inter row spacing increased and seeding rate decreased, the number of capsules per plant increasing was indicating the importance the inter row spacing and seeding rate in determining the number of capsules per plant. This result was in agreement with the earlier studies on sesame by Osei Bonsu (1975) who reported that the number of capsules per plant of sesame decreased with close planting. Similarly, Caliskan et al. (2004) on their work on the effect of planting method and plant population on the yield performance of sesame under Mediterranean condition reported that the highest numbers of capsules were obtained from the lowest plant population or seed rate. On the other hand, Ahmad et al. (2002) reported that sesame plant grown at 60 cm inter rows produced significantly more number of capsules per plant than 40 and 30 cm inter rows spacings. Contrasting finding was obtained by Imoloame (2004) number of seeds per capsule, number of capsules per plant, and dry matter production increased when the seed rate increased.

3.3.2. Capsule length

The analysis of variance showed a highly significant (P < 0.01) effect of seeding rate and inter row spacing on capsule length, but their interaction did not significantly affect this character. The highest capsule length (2.84 mm) was recorded for 2 kg ha\(^{-1}\) seeding rate and (2.59mm) for 60 cm inter row spacing. Then it showed increasing trend as the inter row spacing increased and the lowest capsule length (2.28 mm) was recorded at 40 cm inter row spacing (Table 4.7). On the other hand, seeding rate of 2 kg ha\(^{-1}\) gave the highest capsule length of 2.84 mm which was showed

| Seeding rate (kg) | 2.0 | 3.5 | 5.0 | 6.5 |
|------------------|-----|-----|-----|-----|
| Inter row spacing (cm) |     |     |     |     |
| 40               | 34.26d | 28.33ef | 29.33ef | 28.40ef |
| 50               | 41.06c | 31.96de | 27.33f | 32.16d |
| 60               | 57.33a | 45.66b | 29.83ef | 27.66f |
| LSD             | **   |     |     |     |
| SE±             | 0.78 |     |     |     |
| CV (%)          | 7.24 |     |     |     |

LSD = Least significance difference, SE± = standard error, CV (%) = Coefficient of variation; Means in column and row by the same letters are not significantly different at 5% level of significance.
that increasing trend as the seeding rate decreased and the lowest capsule length (2.05 mm) was recorded at 6.5 kg seeding rate (Table 7). Likewise the highest capsule length (2.23 mm) and lowest capsule length (1.93 mm) was recorded by the interaction of 2 kg ha\(^{-1}\) x 60 cm and 5 kg ha\(^{-1}\) x 40 cm seeding rate and inter row spacing respectively. The reduction on capsule length with closer spacing could be due to high inter specific competition for growth resources. This result agreed with that of Hadgu (2006) who reported higher mean capsule length when sesame was planted at 50 cm inter row spacing than that of 30 cm inter row spacing and the smallest seeding rate (2 kgha\(^{-1}\)) gave the highest mean capsule length as compared to the largest seed rate (5 kgha\(^{-1}\)). On the other hand Udom, Fagam, and Ekwere (2006) reported that the capsules length, number of capsules per plant and grain yield was significantly affected by seed rate. The capsules and grain yield of sesame increased significantly with decreasing seed rate.

### 3.3.4. Thousand seed weight

Thousand seed weight was highly significantly (P < 0.01) affected by both the main effect of inter row spacing, the seeding rate and the interaction. The highest thousand seed weight (2.92g) and (3.05) was recorded from the main effect of 40 cm inter row spacing and 3.5 kg ha\(^{-1}\) seeding rate respectively (Table 8). Likewise the highest thousand seed weight (3.56g) was recorded at inter-action of 40 cm inter row spacing and 3.5 kg ha\(^{-1}\) seeding rate while the lowest thousand seed weight (2.19g) was recorded at interaction of 50 cm inter row spacing and 2.0 kg ha\(^{-1}\) seeding rate. This might be due to better availability of nutrients and better translocation of photosynthates to the seeds at properly spaced plants of 3.5 seeding rate and 40 cm inter row spacing. The result of this study was in line with that of Caliskan et al. (2004) who reported gradual decrease in thousand seed weight as plant population increased. Further, Caliskan et al. (2004) reported that 1000 seed weight decreased from 3.7 g to 3.2 g with greater than ever plant populations. On the other hand a non significant variation in 1000 seed weight among various plant populations was also reported by (Ahmad et al., 2002).

### 3.4. Grain yield (kg ha\(^{-1}\))

The analysis of variance showed that grain yield was highly and significantly (P < 0.01) affected by inter row spacing and seeding rate and by the interaction of inter row spacing and seeding rate.
The highest grain yields (758.32 kg ha\(^{-1}\) and 750.28 kg ha\(^{-1}\)) were obtained from 3.5 kg ha\(^{-1}\) x 50 cm and 3.5 kg ha\(^{-1}\) x 40 inter row spacing and seeding rate interaction respectively, while the lowest grain yields (509.27 kg ha\(^{-1}\)) was recorded from (6.5 kg ha\(^{-1}\) x 40 cm) seeding rate and inter row spacing (Table 8). The decrease in grain yield at the narrow inter row (40 cm) and seeding rate (6.5 kg ha\(^{-1}\)) might be due to computation for resources per unit area. Studies showed that population density determine grain yield of sesame where the top grain yield was obtained from the peak plant population (Caliskan et al., 2004). Further, it is well known that grain yield was gradually decreases with rising plant population. This is endorsed to the drop in number of capsules and seeds per plant as the plant population increased. In conformity with the result of this study, Roy, Abdullah-Mamun, and Sarwar-Jahan (2009) reported that sparsely populated fields with wider spacing could lead to uneconomic utilization of space, profuse growth of weeds and pests and reduction of yield per unit area of sesame. Moreover, Jettner, Loss, Martin, and Siddique (1998) reported that decrease in the number of branches per plant as plant density increased, was advantageous for seed yield as the side branches contribute less than the main stem to grain yield.

Normally, as population increases yield also increases proportionally. After, it reached a certain level the yield declines. Population density is also dependant on the moisture availability and nutrient status of the soil. The spacing between stands is largely determined by the extent of the root and shoots systems of the crop plant in question. In the present result high seed rate was not showed significance difference this may be due to moisture stress in the study area.

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### Table 8. Main effect of seeding rate and inter row spacing on thousand seed weight of sesame

| Seeding rate (kg) | Inter row spacing (cm) | 2.0 | 3.5 | 5.0 | 6.5 |
|------------------|------------------------|-----|-----|-----|-----|
| 40               | 2.24efg                | 3.56a| 2.80cd | 3.06bc |
| 50               | 2.19g                  | 3.23b| 2.76cd | 2.53de |
| 60               | 2.20gf                 | 2.37efg | 2.52def | 2.40efg |
| LSD              | **                     |     |     |     |     |
| SE±              | 0.32                   |     |     |     |     |
| CV (%)           | 7.34                   |     |     |     |     |

LSD = Least significance difference, SE± = standard error, CV (%) = Coefficient of variation; Means in column and row by the same letters are not significantly different at 5% level of significance

### Table 9. Interaction effect of inter row spacing and seeding rate on grain yield (kg ha\(^{-1}\)) of sesame

| Seeding rate (kg) | Inter row spacing (cm) | 2.0 | 3.5 | 5.0 | 6.5 |
|------------------|------------------------|-----|-----|-----|-----|
| 40               | 642.57bcd              | 750.28a| 710.25ab | 509.27e |
| 50               | 552.03e                | 758.32a| 650.31bc | 568.39cde |
| 60               | 585.02cde              | 523.73e| 560.42de | 518.39e |
| LSD              | **                     |     |     |     |     |
| SE±              | 15.60                   |     |     |     |     |
| CV (%)           | 8.20                    |     |     |     |     |

LSD = Least significance difference, SE± = standard error, CV (%) = Coefficient of variation; Means in column and row by the same letters are not significantly different at 5% level of significance
In contrast, Udom et al. (2006) and Auwalu, Oseni, Okonkwo, Tenebe, and Pal (1995) reported that capsule length and grain yield of sesame were increased significantly with decreasing seed rate and conversely capsule number decreased with decreasing seeding rate. The same author also reported that the yield per hectare of sesame was increased significantly with decreasing inter-row spacing. On the other hand, Osman (1993) reported that a significant increase in the yield of sesame with increasing seeding rate.

3.4. Correlation of grain yield and yield related traits

Yield of sesame was significantly related to most of the yield components (Table 10). Grain yield per hectare was strongly correlated and highly significant with plant height ($r = 0.75^{**}$), number of capsules per plant ($r = 0.78^{**}$), capsule length ($r = 0.67^{**}$), number of branches per plant ($r = 0.88^{**}$) and thousand seed weight ($r = 0.93^{**}$). Similar finding was presented by Uzo, Adedzwa, and Onwukwe (1985) where positive and strongly significant correlation of with plant height, number of capsules per plant and number of branches per plant of sesame. This could be due to the nature of capsule development; in that, capsules are born at the leaf axils, and taller plants might have more leaf axils that bear more capsules and due to the development of more capsules as the number of branches for individual plant increased. Moreover, number of leaves per plant ($r = 0.36^{**}$) was correlated positively but weak to the grain yield of sesame per hectare.

The major factors that contributed to decrease in grain yield at high plant densities were rapid increase in plant height early in the season, hastening of period to flowering, and increase in dry stalk seed weights. These are major characteristics that indicate the possibility of plant competition in stressful environments where rainfall and nutrients are in short supply as in the present study. The scope for improving sesame yield may not be achieved simply by increasing plant density without improving the moisture and nutrient regimes in the system. This is because the study area had very low level of N and low average annual rainfall that contributed to the low yield realized in the present study.

3.5. Partial budget analysis

In the experiment, marginal analysis shows the economic effect of changing from one treatment to another. It involves calculation of marginal rates of return between treatments. The marginal rate of return (MRR) is a ratio of the change in net benefits to change in total variable input costs between treatments.

$$\text{MRR} = \frac{\Delta \text{Net Benefits}}{\Delta \text{Total Variable Costs}}$$

In the result of present study, the costs for the different seeding rates, labor cost for row making, drilling the seed and fertilizer application varied according to their rates and spacing requirements being other costs were constant for each treatment. In order to recommend the present result for the study area, it is necessary to estimate the minimum rate of return acceptable to producers in

| Table 10. Correlation of yield and some yield components of sesame |
|----------------------|------------------|----------------|------------------|----------------|-----------------|-----------------|----------------|
|                      | PH   | LNPP | NBPP | NCPP | CL   | TSW  | GY   |
| PH                   | 1.00 |      |      |      |      |      |      |
| LNPP                 | 0.85** | 1.00 |      |      |      |      |      |
| NBPP                 | 0.79** | 0.87** | 1.00 |      |      |      |      |
| NCPP                 | 0.78** | 0.87** | 0.89** | 1.00 |      |      |      |
| CL                   | 0.66* | 0.67* | 0.70** | 0.68** | 1.00 |      |      |
| TSW                  | -0.38* | -0.50** | -0.47** | -0.50** | -0.25* | 1.00 |      |
| GY                   | 0.75** | 0.36* | 0.88** | 0.78** | 0.67** | 0.93** | 1.00 |

*, ** Indicates significant at 5% and 1% probability level, respectively PH = plant height; NBPP = number of branches per plant; NCPP = number of capsules per plant, CL = capsule length, TSW = thousand seed weight, GY = grain yield.
the recommendation domain. Based on partial budget analysis, the highest net benefit (22,304.58 Birr ha\(^{-1}\)) was obtained from treatment combination of 3.5 kg ha\(^{-1}\) seeding rate with 50 cm inter-row spacing followed by (21,971.32 Birr ha\(^{-1}\)) and (20,657.88 Birr ha\(^{-1}\)) from 40 × 5 and 40 × 3.5 treatment combination respectively while the lowest net benefit (14,274.51 Birr ha\(^{-1}\)) was obtained from the combination of 2 kg ha\(^{-1}\) seeding rate with 60 cm inter-row spacing with only in one growing season (Tables 11 and 12).

According to CIMMYT (1988), the minimum acceptable marginal rate of return (MRR %) should be 100%. The highest 23,744.36 value was obtained from the use of 3.5 kg ha\(^{-1}\) seeding rate and 40 cm inter row spacing combination followed by 22,137.42 and 21,356.69 value of MRR which were recorded from seeding rate of 3.5 and 5 kg ha\(^{-1}\) with 50 and 40 cm inter row spacing respectively (Tables 11 and 12). Therefore, the most attractive rates for small-scale farmers of the study area with low cost of production and higher benefits in this case were 3.5 kg ha\(^{-1}\) seeding rate and 50 cm inter-row spacing combination. However, 5 and 3.5 kg ha\(^{-1}\) seeding rate with 40 and 40 cm inter-row spacing combination was also profitable with the highest net benefit respectively.

4. Conclusion

Ten phenological and yield related traits were examined against the plant spacing and seeding rate combinations. Namely, days to emergence, days to flowering, days to maturity, number of branches, number of capsules, number of leaves, plant height at physiological maturity, grain yield per hectare; 1000 seed weight.

Days to 50% flowering and 50% maturity; number of leaves per plant, number of branches per plant, number of capsules per plant, plant height, capsule length, 1000 seed weight and grain yield were affected by plant spacing and seeding rate and their interaction. Significant variations due to spacing and seeding rate were recorded in 50% flowering and 90% maturity. Likewise both the main effects of seeding rate and inter row spacing as well as the interaction had significant effect on number of leaves per plant and number of branches per plant.

| RSxSR     | UAGY  | AGY   | TVC      | GB      | NB     | D     | MRR%   |
|-----------|-------|-------|----------|---------|--------|-------|--------|
| 60x2      | 585.02| 526.52| 1450.00  | 16,042.01| 14,274.51|       |        |
| 60x3.5    | 523.73| 471.36| 1502.50  | 16,497.50| 14,995.00| 1372.36|        |
| 50x2      | 552.03| 496.83| 1530.00  | 17,388.95| 15,858.95| 3141.64|        |
| 50x5      | 650.31| 585.28| 1555.00  | 20,484.77| 18,849.77| 11,963.28|        |
| 60x6.5    | 518.39| 466.55| 1582.50  | 16,329.29| 14,721.79|       | −15,010.84|
| 40x3.5    | 750.28| 675.25| 1607.50  | 22,372.88| 20,657.88| 23,744.36|        |
| 40x2      | 642.57| 578.31| 1610.00  | 20,240.96| 18,630.96|       | −81,076.80|
| 60x5      | 560.42| 504.38| 1635.00  | 17,653.23| 16,098.23|       | −10,130.92|
| 40x5      | 710.25| 639.23| 1662.50  | 23,633.82| 21,971.32|       | 21,356.69|
| 50x6.5    | 568.39| 511.55| 1687.50  | 17,904.29| 16,216.79|       | −23,018.12|
| 50x3.5    | 758.32| 682.49| 1715.00  | 23,887.08| 22,304.58|       | 22,137.42|
| 40x6.5    | 509.27| 458.34| 1767.50  | 18,428.13| 16,978.13|       | −10,145.62|

RSxSR = row spacing (Caliskan et al.) with seeding rates (kg ha\(^{-1}\)); UAGY = unadjusted grain yield (kg ha\(^{-1}\)); AGY = adjusted grain yield (kg ha\(^{-1}\)); TVC = total variable cost (Birr ha\(^{-1}\)); GB = gross benefit (Birr ha\(^{-1}\)); NB = net benefit (Birr ha\(^{-1}\)); D = dominated; MRR% = marginal rate of return in percentage; Cost of seed 35.00 Birr per kg; Sale price of sesame grain Birr 35.00 per kg; labor cost 50 birr per person per day and total man power needed to row making, drilling, weeding, harvesting were 31, 29 and 27 man days ha\(^{-1}\) for 40,50 and 60 cm inter row spacing respectively.
The main effects of inter row spacing and seeding rate significantly influenced on capsule length. On the other hand number of capsule per plant, thousand seed weight and yield per ha were significantly influenced by the main effects of seeding rate and inter row spacing and the interaction.

Results of this experiment indicated significant differences in grain yield per hectare. The present research finding showed that using of 3.5kg ha$^{-1}$ seeding rate and 50 cm inter row spacing combination gave better grain yield (758.32 kg ha$^{-1}$) of sesame and can be recommended tentatively for the study area as the first option. On the other hand based on partial budget analysis 3.5kg ha$^{-1}$ seeding rate with 50 cm inter row spacing combination can be also recommended as 1st option. However, to make reliable recommendation it is better to repeat this experiment across locations and over seasons.

### Table 12. Based on partial budget analysis as influenced by inter row spacing and seeding rate of sesame all acceptable values of RSxSR (> 100%)

| RSxSR | UAGY | AGY | TVC | GB | NB | D | MRR% |
|-------|------|-----|-----|----|----|---|------|
| 60x3.5 | 523.73 | 471.36 | 1502.50 | 16,497.50 | 14,995.00 | 1372.36 |
| 50x2 | 552.03 | 496.83 | 1530.00 | 17,388.95 | 15,858.95 | 3141.64 |
| 50x5 | 650.31 | 585.28 | 1607.50 | 20,484.77 | 18,849.77 | 11,963.28 |
| 40x3.5 | 750.28 | 675.25 | 1635.00 | 22,372.88 | 20,657.88 | 23,744.36 |
| 40x5 | 710.25 | 639.23 | 1662.50 | 23,633.82 | 21,971.32 | 21,356.69 |
| 50x3.5 | 758.32 | 682.49 | 1715.00 | 23,887.08 | 22,304.58 | 22,137.42 |

RSxSR = row spacing (Caliskan et al.) with seeding rates (kg ha$^{-1}$); UAGY = unadjusted grain yield (kg ha$^{-1}$); AGY = adjusted grain yield (kg ha$^{-1}$); TVC = total variable cost (Birr ha$^{-1}$); GB = gross benefit (Birr ha$^{-1}$); NB = net benefit (Birr ha$^{-1}$); MRR% = marginal rate of return in percentage.

Note: the highest net benefit which is recommended from all acceptable values of corresponding seeding row and inter row spacing is 22,304.58 from 50 × 3.5 interaction.
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