YIELD PERFORMANCE OF SESAME IN RESPONSE TO POPULATION DENSITY AND SOURCE-SINK MANIPULATION

MD. ABDUL ALIM

DEPARTMENT OF AGRONOMY

SHER-E-BANGLA AGRICULTURAL UNIVERSITY
DHAKA -1207

JUNE, 2009

THE YIELD PERFORMANCE OF SESAME IN RESPONSE TO POPULATION DENSITY AND SOURCE-SINK MANIPULATION

BY

MD. ABDUL ALIM

REGISTRATION NO. 03-01146

A Thesis
Submitted to the Faculty of Agriculture
Sher-e-Bangla Agricultural University, Dhaka,
in partial fulfilment of the requirements
for the degree of

MASTER OF SCIENCE
IN
AGRONOMY

SEMESTER: JANUARY – JUNE, 2009

Approved by:

Md. Sadrul Anam Sardar
Professor
Dept. of Agronomy
SAU, Dhaka
Supervisor

Dr. Md. Jafar Ullah
Professor
Dept. of Agronomy
SAU, Dhaka
Co-Supervisor

(Prof. Dr. Md. Fazlul Karim)
Chairman
Examination Committee

CERTIFICATE

*This is to certify that the thesis entitled, "**THE YIELD PERFORMANCE OF SESAME IN RESPONSE TO POPULATION DENSITY AND SOURCE-SINK MANIPULATION**" Submitted to the Department of Agronomy, Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE in AGRONOMY** embodies the result of a piece of bonafide research work carried out by **MD. ABDUL ALIM, Roll No. 01146, Registration No. 03-01146** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that such help or source of information, as has been availed of during the course of this investigation has been duly acknowledged by him.

Dated:
Dhaka, Bangladesh

Md. Sadrul Anam Sardar
Professor
Dept. of Agronomy
SAU, Dhaka
Supervisor

ACKNOWLEDGEMENTS

All praises are due to Almighty Allah Who enable me to complete this thesis.

I would like to express my heartfelt respect, deepest sense of gratitude, profound appreciation and ever indebtedness to my Supervisor **Md. Sadrul Anam Sardar**, professor, Department of Agronomy, Sher-e-Bangla Agricultural University, (SAU), Dhaka for his sincere guidance, scholastic supervision, constructive criticism, and constant inspiration throughout the course and in preparation of the manuscript of the thesis.

I express my sincere respect to my Co-supervisor, **Dr. Md. Jafar Ullah,** Associate professor, department of Agronomy, Sher-e-Bangla Agricultural University, (SAU), Dhaka for his utmost co-operation, constructive suggestion to conduct the research work as well as preparation of the manuscript of the thesis.

I would like to express my heartfelt indebtedness and profound appreciation to my respectable all of the teachers, Department of Agronomy, Sher-e-Bangla Agricultural University, Dhaka for his nice co-operation sincere guidance, constructive criticism and constant inspiration throughout the course and in preparation of the manuscript of the thesis.

I thank all of my close friends specially Enam, Parvez, Mosharraf, Tareq, Shohagh, Hasan and Kabir to cooperate and help me during taking data from the field and to take care of my experimental plot time to time. Special thanks to my friends and roommates.

Mere diction is not enough to express my profound gratitude and deepest appreciation to my parents for their ever ending prayer, encouragement, sacrifice and dedicated efforts to educate me to this level.

The Author

Title: The yield performance of sesame in response to population density and source-sink manipulation

ABSTRACT

An experiment was conducted at the Sher-e-Bangla Agricultural University Farm Dhaka 1207 (Tejgaon series under AEZ No.28) during Kharif-1 (March – June), 2008 to study the yield performance of sesame in response to population density and source-sink manipulation. Two factors (A) population density and (B) source-sink manipulation were initiated. Three population densities viz. (1) 30 plants m^{-2} (D_1), (2) 40 plants m^{-2} (D_2) and (3) 50 plants m^{-2} (D_3) and four source-sink manipulation viz. (1) no removal (M_0), (2) removal of lower empty leaves, lower empty branches and top of the inflorescence (M_1), (3) removal of all branches (M_2) and (4) removal of lower empty leaves and lower empty branches (M_3) were comprised for the experiment. The treatment combinations were (i) D_1M_0, (ii) D_1M_1, (iii) D_1M_2, (iv) D_1M_3, (v) D_2M_0, (vi) D_2M_1, (vii) D_2M_2, (viii) D_2M_3, (ix) D_3M_0, (x) D_3M_1, (xi) D_3M_2 and (xii) D_3M_3. Significant effect was observe on the basis of population density, source-sink manipulation and their combination on plant height (cm), number of branches plant^{-1}, leaf area index, dry weight plant^{-1}, dry weight m^{-2} (g), crop growth rate, number of capsules plant^{-1}, number of capsules m^{-2}, number of seeds capsule^{-1}, 1000 seed weight (g), yield plant^{-1} (g), total yield (kg ha^{-1}), stover yield (kg ha^{-1}) and harvest index. Results revealed that the highest number of capsules plant^{-1} (28.38), number of capsules m^{-2} (1135.20), number of seeds capsule^{-1} (70.66), 1000 seed weight (3.45 g), total yield (1725.45 kg ha^{-1}) and harvest index (40.72) were obtained with the combined effect of D_2M_1 **(**40 plants m^{-2} + removal of lower empty leaves, lower empty branches and top of the inflorescence**)**. But the lowest number of seeds capsule^{-1} (66.30) and total yield (1060.75 kg ha^{-1}) were obtained with the combined effect of D_3M_2 **(**50 plants m^{-2} + removal of all branches**)**. However, to obtain a specific result and recommendation, more research work on sesame should be done in different Agro-ecological zones of Bangladesh.

LIST OF CONTENTS

CHAPTER	TITLE		PAGE NO.
	ACKNOWLEDGEMENT		
	ABSTRACT		
	LIST OF CONTENTS		
	LIST OF TABLES		
	LIST OF FIGURES		
	LIST OF APPENDICES		
	LIST OF ABBRIVIATIONS		
I	**INTRODUCTION**		
II	**REVIEW OF LITERATURE**		
	2.1	Effect of population density	
	2.2	Effect of source-sink manipulation	
	2.3	Interaction effect of population density and source-sink manipulation	
III	**MATERIALS AND METHODS**		
	3.1	Experiment site and soil	
	3.2	Climate	
	3.3	Crop	
	3.4	Treatments	
	3.5	Land preparation	
	3.6	Experimental design	
	3.7	Layout of the experiment	
	3.8	Sowing	
	3.9	Cultural practices	
	3.10	Harvesting	
	3.11	Data collection and sampling procedure	
	3.11.1	Plant height	
	3.11.2	Leaf area index (LAI)	
	3.11.3	Crop growth rate (CGR)	
	3.12	Number of branches plant^{-1}	
	3.13	Number of capsules plant^{-1}	
	3.14	Number of seeds capsule^{-1}	
	3.15	Weight of 1000 grains (g)	
	3.16	Seed yield ha^{-1}	
	3.17	Harvest index (HI)	
	3.18	Statistical analysis	

LIST OF CONTENTS (Contd.)

CHAPTER	TITLE		PAGE NO.
IV	**RESULTS AND DISCUSSIONS**		
	4.1	Growth parameters	
	4.1.1	Plant height	
	4.1.1.1	Effect of plant density	
	4.1..1.2	Effect of source-sink manipulation	
	4.1.1.3	Interaction effect of population density and source-sink manipulation	
	4.1.2	4.1.2 Number of branches plant^{-1}	
	4.1.2.1	4.1.2.1 Effect of plant density	
	4.1.2.2	4.1.2.2 Effect of source-sink manipulation	
	4.1.2.3	4.1.2.3 Interaction effect of population density and source-sink manipulation	
	4.1.3	4.1.3 Leaf area index	
	4.1.3.1	4.1.3.1 Effect of plant density	
	4.1.3.2	4.1.3.2 Effect of source-sink manipulation	
	4.1.3.3	4.1.3.3 Interaction effect of population density and source-sink manipulation	
	4.1.4	Dry weight plant^{-1}	
	4.1.4.1	Effect of plant density	
	4.1.4.2	Effect of source-sink manipulation	
	4.1.4.3	Interaction effect of population density and source-sink manipulation	
	4.1.5	Dry weight m^{-2}	
	4.1.5.1	Effect of plant density	
	4.1.5.2	Effect of source-sink manipulation	
	4.1.5.3	Interaction effect of population density and source-sink manipulation	
	4.1.6	Crop growth rate	
	4.1.6.1	Effect of plant density	
	4.1.6.2	Effect of source-sink manipulation	
	4.1.6.3	Interaction effect of population density and source-sink manipulation	
	4.2	Yield contributing characters	
	4.2.1	Number capsules plant^{-1}	
	4.2.1.1	Effect of plant density	
	4.2.1.2	Effect of source-sink manipulation	
	4.2.1.3	Interaction effect of population density and source-sink manipulation	

LIST OF CONTENTS (Contd.)

CHAPTER	TITLE		PAGE NO.
	4.2.2	Number of capsules m^{-2}	
	4.2.2.1	Effect of plant density	
	4.2.2.2	Effect of source-sink manipulation	
	4.2.2.3	Interaction effect of population density and source-sink manipulation	
	4.2.3	Number of seeds capsule^{-1}	
	4.2.3.1	Effect of plant density	
	4.2.3.2	Effect of source-sink manipulation	
	4.2.3.3	Interaction effect of population density and source-sink manipulation	
	4.2.4	Weight of 1000 seeds (g)	
	4.2.4.1	Effect of plant density	
	4.2.4.2	Effect of source-sink manipulation	
	4.2.4.3	Interaction effect of population density and source-sink manipulation	
	4.3	Yield	
	4.3.1	Yield plant^{-1}	
	4.3.1.1	Effect of plant density	
	4.3.1.2	Effect of source-sink manipulation	
	4.3.1.3	Interaction effect of population density and source-sink manipulation	
	4.3.2	Total yield (kg ha^{-1})	
	4.3.2.	1 Effect of plant density	
	4.3.2.2	Effect of source-sink manipulation	
	4.3.2.3	Interaction effect of population density and source-sink manipulation	
	4.3.3	Stover yield	
	4.3.3.1	Effect of plant density	
	4.3.3.2	Effect of source-sink manipulation	
	4.3.3.3	Interaction effect of population density and source-sink manipulation	
	4.3.4	Harvest Index	
	4.3.4.1	Effect of plant density	
	4.3.4.2	Effect of source-sink manipulation	
	4.3.4.3	Interaction effect of population density and source-sink manipulation	
V	**SUMMERY AND CONCLUSION**		
VI	**REFERENCES**		
	APPENDICES		

LIST OF TABLES

TABLE NO.	TITLE	PAGE NO.
01	Interaction effect of population density and source-sink manipulation on plant height of sesame at different days after sowing	
02	Interaction effect of population density and source-sink manipulation on number of branches plant^{-1} of sesame at different days after sowing	
03	Interaction effect of population density and source-sink manipulation on leaf area index of sesame at different days after sowing	
04	Effect of population density and source-sink manipulation and their interaction on dry weight plant^{-1}of sesame at different days after sowing	
05	Effect of population density and source-sink manipulation and their interaction on dry weight m^{-2} of sesame at different days after sowing	
06	Interaction effect of population density and source-sink manipulation on crop growth rate of sesame at different days after sowing	
07	Effect of population density and source-sink manipulation and their interaction on different yield contributing characters of sesame	
08	Effect of population density and source-sink manipulation and their interaction on yield parameters of sesame	

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE NO.
01	Effect of population density on plant height of sesame at different days after sowing	
02	Effect of source-sink manipulation on plant height of sesame at different days after sowing	
03	Effect of population density on number of branches plant^{-1} of sesame at different days after sowing	
04	Effect of source-sink manipulation on number of branches plant^{-1} of sesame at different days after sowing	
05	Effect of population density on leaf area index of sesame at different days after sowing	
06	Effect of source-sink manipulation on leaf area index of sesame at different days after sowing	
07	Effect of population density on crop growth rate of sesame at different days after sowing	
08	Effect of source-sink manipulation on crop growth rate of sesame at different days after sowing	

LIST OF APPENDICES

APPENDICES	TITLE	PAGE NO.
I	Morphological, physical and chemical characteristics of the soil	
II	Monthly records of air temperature, relative humidity, rainfall and sunshine hours during the period from March 2008 to May 2008	
III	Effect of population density and source-sink manipulation and their interaction on plant height of sesame at different days after sowing	
IV	Effect of population density and source-sink manipulation and their interaction on number of branches plant^{-1} of sesame at different days after sowing	
V	Effect of population density and source-sink manipulation and their interaction on leaf area index of sesame at different days after sowing	
VI	Effect of population density and source-sink manipulation and their interaction on dry weight plant^{-1} of sesame at different days after sowing	
VII	Effect of population density and source-sink manipulation and their interaction on dry weight m^{-2} of sesame at different days after sowing	
VIII	Effect of population density and source-sink manipulation and their interaction on crop growth rate of sesame at different days after sowing	
IX	Effect of population density and source-sink manipulation and their interaction on different yield contributing characters of sesame	
X	Effect of population density and source-sink manipulation and their interaction on yield parameters of sesame	

LIST OF ABBRIVIATIONS

BARI	=	Bangladesh Agricultural Research Institute
cm	=	Centimeter
^{0}C	=	Degree Centigrade
DAE	=	Days after emergence
et al.	=	and others *(at elli)*
Kg	=	Kilogram
Kg/ha	=	Kilogram/hectare
g	=	gram (s)
LSD	=	Least Significant Difference
MP	=	Muriate of Potash
m	=	Meter
P^{H}	=	Hydrogen ion conc.
RCBD	=	Randomized Complete Block Design
TSP	=	Triple Super Phosphate
t/ha	=	ton/hectare
%	=	Percent

CHAPTER I

INTRODUCTION

Sesame (*Sesamum indicum* L.) is a broadleaf plant that grows about 5 to 6 feet tall, with height dependent on the variety and growing conditions. It is an ancient oilseed, first recorded as a crop in Babylon and Assyria over 4,000 years ago. The crop has since spread from the Fertile Crescent of the Ancient Near East to be grown in many parts of the world on over 5 million acres. The biggest area of production is currently believed to be India, but the crop is also grown in China, Korea, Russia, Turkey, Mexico, South America and several countries in Africa. U.S. commercial production reportedly began in the 1950s.

Sesame seeds are unusually high in oil, around 50% of the seed weight, compared to 20% seed oil in soybeans. Sesame is a fairly high value food crop, being harvested both for whole seed used in baking, and for the cooking oil extracted from the seed. This warm season annual crop is primarily adapted to areas with long growing seasons and well drained soils. It is considered drought tolerant, but needs good soil moisture to get established. Sesame has been researched extensively in Missouri and seems to be well adapted to our growing conditions.

The total global production of sesame seed sums up to around 30 lakh tonne annually. The world production of sesame is dominated by a few countries that lie in the African and Asian continents. China produces the maximum out of them all sharing approximately 25% share in the world's total production. Other producers include Nigeria, Pakistan, Ethiopia, Bangladesh, Central African Republic, Thailand, Tanzania, Egypt, Guatemala, Chad, Paraguay, Iran, Senegal, Turkey and Mexico (Rob Owen, Pittsburgh Post-Gazette, 2006).

The world economy on sesame can be concluded that Asia produces 64% of the world's supply of seed and Africa 31% for a total of 95%. Very significantly, 28% of the seed produced in the world enters international trade and the amount traded is increasing, indicating a major world market for "US grown sesame." Africa's net exports represent 43% of its production. While Asia exports 17% of its crop, it imports twice as much as it exports. Europe is a major importer (FAO, 2008).

In 2007, there were 19.1 million acres harvested, producing 3.7 million short tons of whole sesame seed for an average yield of 390 lbs/acre. Much of the sesame in the world is grown in semi-arid areas where there is very little irrigation.

Major Sesame producers with area harvested and production (FAO, 2007) are given below:

Country	**Area harvested (000 acres)**	**Production (000 tons)**
India	4,324	739
Myanmar	3,954	661
China	1,534	615
Sudan	3,781	287
Uganda	692	185
Ethiopia	544	181
Nigeria	484	110
Paraguay	148	58
Bangladesh	198	55
Tanzania, United Republic	284	51
Thailand	162	47
Central African Republic	99	44
Egypt	77	41
Pakistan	210	41

Oilseeds are important in the economy of Bangladesh. They constitute the second most important group of crop next to cereals occupying 4.22% of the total cropped area (BBS, 2009). Among the oilseed crops, sesame *(Sesamum indicum* L.) contributes about 11.03% of the country's total oilseed production. Sesame is the second largest source of edible oil in Bangladesh (Hossain and Salahuddin, 1994). It is cultivated in over 80 thousands ha of land with a production of 50 thousand tons annually (BBS, 2009). The average yield of this crop is very low.

Major reasons of such low yield are inadequate management practices and in appropriate plant stand (Zaman, 1986). Little work has been done to improve yield of this crop (Hossain *et al.*, 1995). Sesame is generally a photosensitive crop. Eighty percent of its total production of Bangladesh is grown during Kharif season only (BBS, 2009). With the increase in population, demand for edible oil has increased greatly, and production of sesame has been raised also (Kaul and Das, 1986).

Planting density has considerable effect on vegetative growth as well as on yield of legume pulses (Rowden *et al.*, 1981). It is one of the most important aspect of crop growing which can be manipulated to maximize yield (Babu and Mitra, 1989). In soybean increased planting density is positively related to yield and plant height and negatively related with the number of branches, extent of flowering and yield per plant (Mackenzie *et al.*, 1975). Plant population closely relates to optimum spacing and also extraction of nutrients from the soil (Reddy *et al.*, 1978). The physiological processes can indicate the direction for improving the yield and yield stability (Chopra and Sinha, 1987). The optimization of planting density leads to both vegetative growth as well as yield (Hossain and Salahuddin, 1994).

Canopy structure of sesame is such that lower branches and leaves overlap one another and develop mutual shading particularly at high population density (Ghungarde *et al.*, 1992). Defoliation may improve light interception into the canopy and results in a greater photosynthetic efficiency in faba bean (Pommer *et al.*, 1984).

The production and utilization of photosynthates are in dynamic balance within a plant (Ho, 1992). This balance is achieved by adjusting either the capacity of leaf production (source) or the capacity of utilization of photosynthates by the growing tissues (sinks) (Evans, 1989). There are reports that sink size and its activity are affected by leaf photosynthesis through the amount and rate of supply of photosynthates, the source activity of leaf photosynthesis is affected by sink activity and its size through the amount and rate of accumulation of photosynthate in the sink (Nakatani *et al.*, 1992).

Sink capacity depends on the number of pods per unit area, the number of seeds per pod, and the individual seed size in mungbean (AVRDC, 1974). Leaf and branch clipping enhances the reproductive growth in mungbean (Howlader, 1995). Top clipping enhances the seed weight of grasspea (Parvez, 1992). Understanding of the mechanisms of yield formation through manipulation of source-sink relationship may help in designing in plant ideotype or management options for achieving higher yield in sesame.

Optimum growth is a prerequisite for optimum productivity of a crop. Crop growth is greatly influenced by population density which also affects the rate of canopy development. Plant population is one of the agronomic practices that promote vegetative growth ensuring early canopy closure help maximize radiation interception. Consequently, crop yield is very sensitive to population density. Under ideal growing condition, optimum population density is that which allows maximum light interception and avoids excessive vegetative growth. Optimum plant population varies with cultivar and growing season. When the population density exceeds an optimum, crop growth slows down. On the other hand, there is a reduction in crop efficiency in utilizing environmental factors with a population density less than the optimum.

Population density regulates the shape of canopy in mungbean (Hashem and Hamid, 1986), exerts marked effect on plant height in rapeseed (Islam, 1992) and determines the number of branches in sesame (Tomar *et al.*, 1992; Hossain *et al.*, 1994).

Plant population influences the physiological growth attributes such as leaf area index (LAI), crop growth rate (CGR), relative growth rate (RGR) and net assimilation rate (NAR). The LAI increases with increasing population density in sesame (Hossain *et al.*, 1994), in edible podded pea (Rahman, 1997) and in mungbean (Jahan, 1998). The CGR increases with increasing population density in cowpea and mungbean (Miah, 1988) and in sesame (Hossain *et al.*, 1994). The RGR increases with wider row spacing in pea (Yadav *et al.*, 1991).

Sesame is an oil crop with low productivity. The productivity of crop depends on the biotic and abiotic resources of crop growing that affect growth, development and maintenance of photosynthetically active surface area (Mukand *et al.*, 1987). Optimal canopy structure defined by its optimal density shows the assimilation surface of the canopy and is capable of receiving about 95% solar radiation (Ross, 1975) Crop productivity is directly related with radiation interception. It has been shown that the rate of dry matter production is proportional to the amount of radiation intercepted by the plant (Murty and Venkateswaralu, 1978). For the harvest of solar radiation, a crop requires an optimum LAI which can be maintained by regulating population density. The increase in LAI beyond the optimum creates mutual shading of leaves and reduces the photosynthetic efficiency of lower leaves. Shading reduces productivity of mungbean (Liyanage and Mc Willium, 1981). It has been also reported that partial defoliation increases yield in mungbean (Clifford, 1979).

Sesame is an indeterminate crop. Vegetative growth and fruit development occur simultaneously, as a result there exists a competition for assimilate among source and sink organs of the plant. At high population density lower leaves become photosynthetically inefficient due to mutual shading and play the role of parasites which also compete for assimilate supplied by remaining leaves. Thus removal of lower leaves and top of the inflorescences reduce the competition for assimilate allowing the remaining fruits to develop properly. It has been reported that the removal of lower leaves together with inflorescences and axillary buds increased seed yield in mungbean (Clifford, 1979).

The productivity of sesame may be increased by agronomic manipulation. Source-sink manipulation may improve light interception into the canopy and reduce the competition between vegetative and reproductive sinks during seed filling period, and may help in achieving higher yield. However, the possibility of increasing productivity of sesame by modifying population density in combination with source-sink manipulation has not yet been explored. Taking this into consideration the present study was undertaken with the objectives.

1. To find out the optimum population density for high yield of sesame and
2. To evaluate the effect of source-sink manipulation on the dry matter production and yield performance of sesame.

CHAPTER II

Review of literature

Sesame is an important oil crop in Bangladesh which can contribute to a large extent in the national economy. But the research works done on this crop with respect to agronomic practices are inadequate. Only some limited studies have so far been done in respect of agronomic management practices of the crop.

2.1 Effect of population density

The effects of plant density on yield and related traits were studied in ten cultivars of spring barley, *Hordeum vulgare* L., to determine if selection in low density stands is effective in improving expression in dense stands. Five plant densities (1.6, 6.2, 25, 100, and 400 plants/m^2) were evaluated in each of 3 years. Spikes/plant, shoot weight and grain yield were the only characteristics that had significant cultivar x density interactions. All three characteristics increased asymptotically as density decreased and did not show significant changes in cultivar rank. Interplant variability, although minimum at a density of 100 plants/m^2 for spikes/plant, shoot weight and grain yield, showed a significant decrease at a density of 6.2 plants/m^2 (40 x 40 cm) for all traits. Our results show that single plant selection may be most effective at plant spacings near 40 x 40 cm and that selection under low densities should be effective in improving dense seeding expression of yield and several related traits (Baker and Briggs, 2007).

A field experiment was conducted to evaluate the effect of row spacing on the yield and yield contributing characters of sesame during Kharif season, using the varieties (V_1 = T_6, V_2 = Batiaghata local Til and V_3 = BINA Til) and the row spacings (S_1 = 15 cm, S_2 = 30 cm and S_3 = 45 cm). Yield were significantly influenced by the varieties and row spacings. The highest seed yield was produced by the variety BINA Til while the lowest was by the variety Batiaghata local Til and the highest seed yield was produced by row spacing 30 cm while the lowest was by row spacing 45 cm. Seed yield was well correlated with capsules plant^{-1} and seeds capsule^{-1} (Nandita *et al.*, 2009).

Yield components in oil palm were recorded in a spacing experiment comparing 56, 110, 148 and 186 palms ha^{-1}. The higher densities reduced the number of female inflorescences (due to a decrease in the proportion of female to total inflorescences and an increase in the proportion of leaves with aborted inflorescences), the weight of the frame and the number of flowers per inflorescence. The results suggest that the production of seed per bunch can be increased by at least 15% by thinning around selected palms in seed gardens. The sex ratio and the components of flower number per inflorescence were more sensitive to competition for light than the weight of the frame and floral abortion. Components determining the oil and kernel extraction showed no response to density when assisted pollination was used, but with the successful introduction of insect pollinators, oil and kernel extraction increased with planting density as a result of an increase in fruit per bunch (Breure *et al*., 2007).

Little information is known concerning cultivar differences for optimal plant population (minimal plant population for best yield) in soybean (*Glycine max* L.). Development of cultivars or genotypes having low optimal plant population would reduce seeding costs, avoid some diseases, and minimize lodging. The objectives of this study were to determine cultivar variability for optimal plant population, determine quantitative relationships between yield and other parameters as affected by plant population–cultivar treatment combinations, and to develop a regression model for identifying cultivars that have low optimal populations. The study was planted on a commerce silt loam soil (fine-silty, mixed, nonacid, thermic, Aeric, Fluvaquent) in a randomized complete block experimental design in a split plot arrangement with four replications and two years. Main plots were14 cultivars and split plots were low (95 000 plants ha^{-1}) and normal (250 000 plants ha^{-1}) plant populations. Cultivars that optimized yield at low plant population were ‘NKRA452’ and ‘A6911’. Yields were optimized for cultivar–plant population treatment combinations achieving a total vegetative dry matter at R5 of 500 g m^{-2} or greater. Partitioning of dry matter into branches was the most important parameter accounting for cultivar yield differences within low plant populations (r^2 = 0.56), and with the addition of a few other parameters a regression model was developed (r^2 = 0.83) that could rapidly and easily identify cultivars with low optimal plant population. In conclusion, genotypic differences in low optimal plant population exist and are influenced by dry matter partitioning into branches (Brian and James, 2006).

A field experiment was conducted to determine if greater tolerance to increased plant density and more efficient use of cumulative intercepted photosynthetically active radiation (CIPAR) partially explained the yield difference of two old soybean cultivars and two new cultivars. Soybean cultivars were grown in 38-cm spaced rows at final plant densities of 4.9, 14.8, 24.7, 34.6, and 44.5 plants m^{-2} for 2 years. New cultivars averaged 914 kg ha^{-1} and 4.9 g $plant^{-1}$ greater yield compared with old cultivars averaged across years and plant densities. Yield plateaus occurred at plant densities of 23.0 plants m^{-2} for new cultivars and 19.9 plants m^{-2} for old cultivars. Each cultivar group showed a similar yield decline per plant to increased plant density. New and old cultivars showed a similar response to increasing values of CIPAR, attaining a 95% relative yield plateau at 466 MJ m^{-2}. Soybean yield response to increased plant density and CIPAR has not changed over time, and genetic gain from new cultivars is associated with more efficient use of light (Jason *et al*., 2006).

It is generally recognized that appropriate plant density is necessary for optimum yield of crops. These variables also affect the quality of some crops. The objectives of this research were to determine the effects of three plant densities upon seed yield, head size, oil concentration of oil cultivars, and seed size of confectionery cultivars. Increasing plant density increased seed yield, yield of oil from oil-type sunflower, and percentage of medium-size seeds from confectionery cultivars. Increasing plant density reduced head size and percentage of large-size seeds of confectionery cultivars. Percentage of small sized confectionery seeds was increased by increasing plant density. Results of this study show that nitrogen and plant density have a relatively large effect on seed yield and a smaller effect on oil concentration and seed size (Zubriski and Zimmerman, 2004).

Field experiments utilizing a systematic design that made it possible to evaluate a wide range of plant densities in a single experiment were conducted with an indeterminate ('Cumberland'- 2 yr) and a determinate ('Pixie'-1 yr) soybean (*Glycine mar* L.). Population densities used in the analyses varied from 0.6 to 24 plants m^{-2}. At low population densities, where there was no interplant competition, yield increased in direct proportion to increases in plant density. At plant densities providing interplant competition, the rate of yield increase was reduced. Yield of the indeterminate cultivar increased as plant density increased above the density required for 95% insolation interception at growth stage R5. The increase in yield was a result of increases in seed m^{-1} in both years along with seed size in 2002. However, the determinate cultivar exhibited maximum yield at the plant density that provided 95% insolation interception at growth stage R5. The data for the indeterminate cultivar confirms a recently published theoretical analysis of soybean yield responses to plant density. The data suggest that plant densities higher than those required to maximize insolation interception by growth stage R5 may be required for maximum yields of indeterminate cultivars (Egli, 2004).

Increased population density gradually increased the plant height but decreased plant population or optimum population gave higher grain yield and harvest index. However, as plant population increases per unit area, a point is reached at which each plant begins to compete for essential growth resources like nutrients, light and water (Saharia and Thakuria, 1988) in peas. Plant competition due to crowding for space might have elongated the densely populated plants (Willey and Heath, 1969).

Increase in population density gradually decreased the number of branches per plant, dry weight per plant and yield per plant. Plant density regulates the shape of the canopy (eg. in mungbean, Hashem and Hamid, 1996). Increase in population density increased intra-specific competition which eventually caused reduction in number of branches per plant dry weight per plant and yield per plant. Similar results were observed by Channabasavanna *et al.,* 1992.

LAI is significantly affected by population density. The total leaf area of the plant material per unit area of ground is known as the leaf area index (LAI) of the canopy (Radford, 1967). Dry matter production of a crop plant depends almost wholly on the amount and pattern of photoactive radiation (PAR) intercepted by the crop and the efficiency of the crop to use the absorbed radiation. The interception of PAR by a crop depends on leaf area index. It is evident that during the whole growth period LAI was highest in the highest population density than that of others (Malcolm *et al*., 2000).

This increase in number of capsules per plant might be attributed to wider plant to plant spacing in rows arid less inter or intra plant competition in the community and this trend in number of capsules per plant in sesame was reported by Tomar *et al.,* (1992). Singh and Yadav (1987) also reported an increase in pods per plant due to decrease in planting density in field peas.

The process of photosynthesis, mineral uptake, respiration and abscision usually determine the dry weight of plants and photosynthesis is the main contributing factor in increasing plant dry matter (Evans, 1983). Tanaka (1992) expressed total dry matter (TDM) as the product of average crop growth rate (CGR) and growth duration. Accumulation of TDM in sesame increased progressively over time attaining the highest amount at physiological maturity. The rate of increase, however, varied depending on the growth stage.

The widely populated plant had accumulated more dry matter than densely planted ones. The result indicated that although per plant dry matter increased with the decrease in population density. TDM per unit area continued to increase with the increasing population density. Similar results was observed by Jahan (1998) in mungbean.

The crop growth rate (CGR) is defined as the increase in plant material per unit time per unit of ground area (Radford, 1967). Rapid increase in CGR after capsule formation resulted in increased dry matter accumulation in the reproductive organs reported by Koller *et al*., (1975) in soybean. In higher population density, plant material per unit land area is higher than the lower one. The CGR is more a measure of the size of the plant than a measure of increase of growth (Campbell and Kondra, 1978).

The relative growth rate (RGR) of a plant at an instant in time is defined as the increase of plant material per unit of material present per unit time (Radford, 1967). Relative growth rate presents the efficiency of the plant in production of new material. RGR was lower in early plant growth stage and rose to a peak in all the population density treatments and then declined. It is evident that RGR abruptly decreased during mid growth stage and the decrease was less sharp during late growth stage was observed by Hossain and Salahuddin (1994) in sesame. At the early growth stages RGR values tended to be higher with the higher population density but the differences in RGR among the density treatments ware not statistically significant at any growth stage. Board *et al.,* (1990) also did not find any significant difference in RGR among row spacing in soybean.

2.2 Effect of source-sink manipulation

An experiment was conducted to determine the effects of the ratio of leaf removal from bottom of plants (0, 4, 8 and 12 leaves/plant) shortly before flowering on yield components and some quality characters of sunflower ecotypes. According to ecotype averages, seed setting, seed yield, kernel ratio, crude oil and crude protein contents in seed, crude oil yield and crude protein yield changed with different degree of leaf removal. Head diameter, seed setting, seed yield, 1000- seed weight, kernel ratio, crude oil, crude protein content, crude oil yield and crude protein yield varied with degree of leaf defoliation of some ecotypes while these characters were not affected by defoliation in other ecotypes (Karadogan and Akgün, 2009).

Soybean (*Glycine max* L.) yield formation in field environments can be either source-limited or sink-limited, depending on the assimilatory capacity of the mother plant relative to the assimilate demands of the developing seeds. The objective was to evaluate yield and seed quality relationships under source-limited and sink-limited conditions during the seed-filling period, as protein and oil comprise on average more than 600 g kg^{-1} of the soybean seed. Field experiments were conducted to examine the effects of multiple pod removal, shade, and defoliation treatments on soybean yield, seed size, seed protein concentration, and seed oil concentration. Pod removal, shade, and defoliation treatments each resulted in decreased yield and altered protein and oil concentrations relative to the control. Averaged across all levels for each treatment, pod removal increased seed size 19% over the control, while defoliation and shade resulted in respective seed size reductions of 7.7 and 15% when compared to the control. Despite differential treatment effects on individual seed growth, pod removal and shade treatments each resulted in increased seed protein concentration and decreased seed oil concentration. In contrast, defoliation resulted in seeds with lower protein concentration and higher oil concentration than pod removal and shade. Pod removal and shade effects on seed quality differed primarily in magnitude, as the average oil concentration across all shade treatments was 10 g kg^{-1} lower than the average oil concentration across all pod removal treatments. No individual treatment resulted in increased oil concentration relative to the control (Rob and Seth, 2008).

Plant leaves are major source of photosynthesis and obtain assimilates for growing parts. Effects of different levels of defoliation studied on maize's growth and yield. The study was conducted as completely randomized block design with 8 treatments in 4 replications. The treatments were: T_1= control (without leaf removal), T_2= removing of ear leaf, T_3= defoliating leaves on top of the ear, T_4= defoliating leaves under the ear, T_5= defoliating just two leaves under ear, T_6= defoliating two leaves on top of ear, T_7= defoliation whole leaves (complete defoliation) and T_8= defoliating just tassel leaf. Effects of these treatments were evaluated on the major traits of yield components.

Results showed that leaves defoliation had significantly effect on grain yield, rows number on cob, grains number on cob, grain dry weight and cob length ($P<1\%$). Leaf defoliation intensity and leaf position affected total dry matter. Complete defoliation reduced severely grains on cob. While defoliation on top of ear and underneath leaves of ear caused to reduce grains on row. The maximum LAI belonged to control and the least amount was connected to T4. The results suggest that the top leaves should not defoliate, because this treatment has negative effect on the yield (Barimavandi, *et al*., 2008).

The rate of accumulation of dry weight in the seed is an important process in yield production by grain crops. Information on factors influencing the seed growth rate is needed to help identify yield limiting processes. This study was undertaken to determine the effect of varying source-sink ratios on the rate of dry matter accumulation in seed of soybeans (*Glycine max* L.). The varying source-sink ratios were obtained by removing approximately 50% of the pods or 66% of the leaf area (two leaflets from each trifoliolate leaf) at the end of the flowering period. The study was conducted for 2 years in the field. The pod removal treatment reduced pod number by 20% at maturity and resulted in an increase in weight/seed over the control near the end of the filling period in one of the years. Removal of two-thirds of the leaf area reduced the weight per seed near the end of the filling period in both years of study. Pod weights of the pod removal treatments were generally heavier than the control and the pods from the leaf removal treatments were lighter than the control. Defoliation lowered the concentration of sugar in the stem sap compared with the control; but, pod removal increased the concentration of stem sugars only near the end of the filling period. The data are interpreted as suggesting that seed growth rates are not closely related to photosynthate production and that storage carbohydrates serve as a buffer between seed growth and photosynthate production (Egli and Leggett, 2006).

Little is known about soybean (*Glycine max* L.) yield response to defoliation during the last half of the seed-filling period (R6.3 to R7) and how it is affected by source/sink ratio. Because defoliating insect pests frequently attack soybean during this period, The objectives of this field study were to (i) determine yield losses to total defoliation near the temporal midpoint (R6.3) and three-quarter point (R6.6) the seed-filling period; (ii) determine if alterations in source/sink ratio affect this response; and (iii) determine yield component mechanisms responsible for the yield reduction. Treatments were no defoliation (control), 100% defoliation at R6.3, and 100% defoliation at R6.6 arranged as split plots within high, normal, and low source/sink ratios during seed filling (main plots). Defoliation at R6.3 resulted in 40% yield reduction, whereas defoliation at R6.6 caused a 20% yield loss. Lower yield resulted from reduced seed size. Source/sink ratio did not affect this response. Smaller seed size in both defoliation treatments resulted partly from reduced seed-filling rate (28% less than control). Shorter effective filling period also contributed to smaller seed size, but this effect was influenced by treatments and years. In conclusion, 100% defoliation during R6.3 to R6.6 must be avoided to maintain optimum yield (Alan and David, 2006).

Sunflower (*Helianthus annuus* L.) seed weight and oil concentration are commonly related to post-flowering source of assimilates (e.g., leaf area index duration, LAD). A predictive variable including both the source of assimilates and the sinks (i.e., seed number) would better account for seed weight and seed oil concentration variability of crops with contrasting seed number and canopy size. It is established quantitative relationships between oil weight per seed components and post-flowering source–sink ratio. Field experiments were conducted with four hybrids were cultivated under contrasting plant populations and nutrient supplies. A wide range of LAD (913–3130 m^2°Cd m^{-2}), seed number (4270–8880 seeds m^{-2}), and seed weight (41–62 mg) was recorded. In contrast, seed oil concentration was not modified (about 530 mg g^{-1}). Post-flowering source–sink ratio (LAD per seed) better accounted (r^2 = 0.69) for seed-weight prediction than LAD (r^2 = 0.42). Maximum seed weight (60 mg) was attained with source–sink ratios ≥0.33 m^2°Cd $seed^{-1}$. Results from our data set pooled together with others of different agro-ecological regions reveal that sunflower crops are normally growing under limiting post-flowering source–sink ratios and a 47% reduction of seed weight occurs when post-flowering source–sink ratio is dramatically (100%) reduced. Seed weight is only 23% increased at saturated source–sink ratios. In contrast, for the wide range of post-flowering source–sink ratios analyzed, seed oil concentration did not vary (Ricardo and Gustavo, 2005).

Poor seed development in sunflower may result from insufficient assimilate supply (source limitation). To test this hypothesis, the effects of changed source–sink ratio on seed set (measured as percentage of empty achenes) and seed filling (measured as dry mass per filled achene) in individual plants were investigated. Source–sink ratio, defined as leaf area per floret (LAF), was experimentally altered using invasive (floret removal, defoliation) and non-invasive (pulse of chilling, short days or shading during leaf or floret initiation) treatments. Shading at floret initiation proved the most effective non-invasive method. Generally, an increase, or decrease, in LAF improved, or impaired, both seed set and filling. Increasing LAF by 2.0 cm^2 [95% confidence interval (1.5, 2.5)] decreased the percentage of empty achenes by 36.9%-points (−41.9, −30.9) and increased dry mass per filled achene by 20.1 mg (13.6, 26.7) in the capitulum centre. The effect of source–sink ratio on seed set was always strongest in the centre, whereas peripheral whorls were not affected. Achene mass was affected in all parts of the capitulum. It is concluded that source limitation is a major cause for empty achenes in sunflower plants grown under non-stress conditions (Alkio *et al.,* 2003).

Field experiments using two soybean (*Glycine max* L.) cultivars (`Elgin 87' and `Essex') were conducted for 2 years to evaluate the effect of source-sink alterations on seed carbohydrate status and growth. Sucrose concentrations in developing cotyledons of control plants were consistently low (550 mM) early in seed development, but they increased to 100±150 mM by physiological maturity. The concentrations increased in both years by 47 to 59% when 90% of the pods were removed from `Elgin 87', but the increase had no effect on individual seed growth rate (SGR). These critical concentrations varied from 72±124 mM; in plant control cotyledon sucrose concentrations were below this critical level during the first half of seed growth but exceeded it in the later stages of growth in all experiments. The estimated critical concentration was consistent with the failure of in plant SGR to respond to an increase in assimilate supply and with the reduction in SGR associated with a decrease in assimilate supply. The results suggest that soybean SGR is generally sink limited if photosynthesis increases during seed filling, but source limited if photosynthesis is reduced (Egli and Bruening, 2001).

Defoliation caused reduction in all measures of yield. Severe, 8070, depodding reduced seed yield but increased weight per seed and stem yield. Moderate depodding, up to 40%, increased seed weight enough to maintain seed yield. Eighty percent depodding increased sugars, starch, and nitrogen in leaves and stems. Eighty percent defoliation increased the iodine number of seed oil, but decreased the oil and protein in seeds. Depodding increased seed protein but decreased the oil content and iodine number (Dean and Orland, 2000).

Removal of source-sink organs of the plant reduced the number of capsules per unit area over control. Flowering and development of capsules continued simultaneously. So, source-sink manipulation at capsule development stage reduced the number of capsules m^{-2} over non-manipulation treatment observed in soybean by Hintz and Fehr (1990) and they also observed that defoliation, branch and stem cutoff decreased the number of capsules per unit area over non-manipulation treatment. Again they also stated that incase of plant growth stage; the highest plant height and dry weight/plant was shown with defoliation and removal of branches considering at all stage over non-manipulation treatment. Hintz and Fehr (1990) observed that the defoliation of all leaves have resulted in an extreme limitation of source and sub-sequent availability of assimilates to the total demand for seed formation in soybean.

2.3 Interaction effect of population density and source-sink manipulation

Xinhua and Tony (2004) conducted an experiment with ideal rapeseed (*Brassica campestris*) production systems achieve both high seed yield and high concentrations of desired seed quality components. Four population density; 20, 30, 40 and 50 plants m^{-2} with four source-sink treatment; Removal of leaves, removal of top inflorescence, removal of leaves and top inflorescence and no removal was considered for the experiment. Source-sink treatment was done up to till 50 days after emergence. This study sought to determine the effect of yield performance and protein with seed yield of mustard across a limited range of yield levels. Field experiment was involving mustard response to N fertilizer applications with three doses; 80, 100 and 120 kg/ha. Mustard yield and the concentrations and yields of oil and protein were determined. Yield and oil concentration in seed decreased with lower plant density and control source-sink treatment with 80 kg N/ha. The highest seed yield and protein content was with 40 plants/m^2 and removal of leaves and top inflorescence with 100 kg N/ha. Highest plant height, dry matter/m^2, 1000 seed weight and harvest index were also obtained with the same combination. In addition, yields of individual and total combination, and yields of oil and protein, were all positively related to seed yield.

Increased number of capsules per plant was recorded in lowest population density when the source-sink organs were not removed and the lowest number of capsules per plant was obtained in the highest population density with the removal of all leaves because of the removal of all leaves at the higher density reduced the number of capsules per plant. This reduction might be due to extreme limitation of assimilate supply from the source for the formation and development of capsules Parvez (1992) and he also reported that the reduced number of pods per plant due to leaf and branch clipping in grasspea was shown.

Increase in planting density increased intra-specific competition which eventually caused reduction in yield and yield attributes eg. 1000 seed weight, grain yield and harvest index observed by Islam (1992) in brassica species. Defoliation of all leaves may be result in an extreme limitation of source and sub-sequent availability of assimilates to the total demand of all the seeds present in the capsules. Under ideal growth conditions, some of the lower empty leaves and branches may become parasitic due to mutual shading, during seed development period. At this period of seed development there is a competition for assimilates requirement among the capsules of different positions in the plants, such as newly formed capsules at the top of the inflorescence and relatively developed capsules of the lower position of the plants. The results indicate that the removal of leaves and top of the inflorescence in soybean increased the dry matter accumulation in reproductive sinks resulting in higher 1000-seed weight because of the reduction in competition for assimilation of dry matter (Hicks and Pandleton, 1969).

CHAPTER III

MATERIALS AND METHODS

In this chapter, the details of different materials used and methodology followed during the experimental period are described.

3.1 Experiment site and soil

A field experiment was conducted at the Sher-e-Bangla Agricultural University (SAU), Dhaka, Bangladesh during Kharif-1 (March – June), 2008 to study the yield performance of sesame in response to population density and source-sink manipulation. The experimental field is located at $23^{0}41'$ N latitude and 90^{o} 22' E longitude at a height of 8.6m above the mean sea level. It belongs to the AEZ 28, Madhupur Tract (FAO, 1988). It was Deep Red Brown Terrace soil and belonged to Nodda cultivated series. The soil was sandy loam in texture having pH ranged from 5.47 to 5.63, a member of hyperthermic Aeric Haplaquept under the order Inceptisol having only few horizons, developed under aquic moisture regime and variable temperature conditions. General characteristics of the soil are presented in Appendix I.

3.2 Climate

The experimental field was situated under Sub-tropical climate; usually the rainfall is heavy during kharif season, (April to September) and scantly in rabi season (October to March). In rabi season temperature is generally low and there is plenty of sunshine. The temperature tends to increase from February as the season proceeds towards kharif. The site where the experiment was conducted has a subtropical climate Kharif-1 season extends from March to early June. The monthly total rainfall, average temperature during the study period (March to early June) has been presented in Appendix II.

3.3 Crop

Sesame (*Sesamum indicum* L.) is a broadleaf plant that grows about 5 to 6 feet tall, with height dependent on the variety and growing conditions. Large, white, bell-shaped flowers, each about an inch long, appear from leaf axils on the lower stem, then gradually appear up the stem over a period of weeks as the stem keeps elongating. Depending on the variety, either one or three seed capsules will develop at each leaf axil. Seed capsules are 1 to 1 1/2 inches long, with 8 rows of seeds in each capsule. Some varieties are branched, while others are unbranched.

3.4 Treatments

Three levels of population density and four levels of source-sink manipulation and their interaction were used in the experiment. These were:

(A) Three levels of population density

i. D_1 = 30 plants m^{-2}
ii. D_2 = 40 plants m^{-2}
iii. D_3 = 50 plants m^{-2}

(B) Four levels of source-sink manipulation

i. M_0 = No removal
ii. M_1 = Removal of lower empty leaves, lower empty branches and top of the inflorescence
iii. M_2 = Removal of all branches
iv. M_3 = Removal of lower empty leaves and lower empty branches

(C) Interaction between population density and source-sink manipulation

i.	$D_1 \times M_0$	v.	$D_2 \times M_0$	ix.	$D_3 \times M_0$
ii.	$D_1 \times M_1$	vi.	$D_2 \times M_1$	x.	$D_3 \times M_1$
iii.	$D_1 \times M_2$	vii.	$D_2 \times M_2$	xi.	$D_3 \times M_2$
iv.	$D_1 \times M_3$	viii.	$D_2 \times M_3$	xii.	$D_3 \times M_3$

3.5 Land preparation

The experimental land was ploughed with a tractor followed by harrowing to attain a desirable filth. All uprooted weeds and stubbles of the previous crop were removed from the experimental field. The land was finally prepared with power tiller to ensure a good land preparation. The land was leveled by tractor drawn leveler.

3.6 Experimental design

The experiment was laid out in RCBD with 3 replications. The size of unit plot was 3 m x 1.5 m. The total number of treatments was (3 Levels of population density × 4 levels of source-sink manipulation) 12 and the number of plots were 36.

3.7 Layout of the experiment

The experiment was laid out on March 8, 2008. The whole area was divided into 36 plots. The replications and plots were separated by 1.0m distance. Fertilizer application; Cowdung at the rate of 10 tons per hectare was applied during land preparation. Other fertilizers at the rate of 40 kg N, 65 kg P_2O_5, 60 kg K_2O and 20 kg S per hectare in the form of Urea, Triple Super Phosphate, Muriate of Potash and Gypsum respectively were applied at the time of final land preparation. All fertilizers were incorporated into the soil as broadcast before sowing of seeds. Additional quantity of 40 kg N per hectare was topdressed during flower initiation in the form of Urea.

3.8 Sowing

The seeds of the variety T-6 were collected from the Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur. Seeds were subjected to germination test and seeds were treated with Vitavex-200 at the rate of 2.5 g kg^{-1} of seeds before sowing. Seeds were sown on March 11, 2008 in solid lines as per treatment corresponding to 30, 40 and 50 plants m^{-2}. Three to five seeds were sown per hill. Missing hills were sown with seeds to maintain desired plant population.

3.9 Cultural practices

The desired population density was maintained by thinning plants 8 days after emergence. Irrigation, mulching, weeding and plant protection measures etc. were performed as needed to uniform germination, better crop establishment and proper plant growth.

3.10 Harvesting

Harvesting At maturity, the crop was harvested from an area of 1 m^2 from each plot. The data on agronomic parameters and yield components of sampled plants were recorded. The harvested plants were segmented into components such as straw (leaf, branch and stem together) and seed. The straw and capsule were then dried in a drier at 70°C for 72 hours and weighed. The seeds were dried in the sun and weighed. The seed weight was adjusted at 8% moisture content.

3.11 Data collection and sampling procedure

Data on dry matter accumulation of different plan parts were recorded by sampling plants above ground parts from an area of 0.5 m^2 in each main plot. Plants were separated into their component parts (leaf, stem, branch, flower and capsule). Plants were sampled 7 times commencing from 20 DAE to 70 DAE (at harvest) at a 10-day interval. Sample plants were collected from second and third rows. The first rows were avoided from sampling for border effect. The plant parts were then dried to a constant weight in a drier at 70°C for 72 hours and weighed.

3.11.1 Plant height

Plant height was measured from the base of the plant up to the tip of the sample plants and the means were calculated.

3.11.2 Leaf area index (LAI)

All the green leaves of each sample plants were removed, put into a polyethene bag and bounded tightly to avoid any dehydration and tissue curling. The leaf area index (LAI) and Crop growth rate (CGR) were calculated using the following equations

$$LAI = \frac{\text{Surface area of leaf sample } (m^2)}{\text{Ground area from where the sample was collected } (m^2)}$$

3.11.3 Crop growth rate (CGR)

Calculation of crop growth rate depends of dry weight m-2 at certain time duration. Crop growth rate (CGR) were calculated using the following equations

$$CGR = \frac{W_2 - W_1}{T_2 - T_1} \times \frac{1}{GA}$$

Where, W_1 = Dry weight at time T_1 (g m^{-2})

W_2 = Dry weight at time T_2 (g $m^{-2'}$)

GA = Ground area (m^2).

3.12 Number of branches plant^{-1}

Number of branches of 10 plants selected randomly from each treatment was taken and branches of individual plant were then calculated.

3.13 Number of capsules plant^{-1}

Total number of capsules of 10 randomly selected plants from each treatment and the number of capsules per plant was calculated.

3.14 Number of seeds capsule^{-1}

A sub-sample was taken from the harvested capsules from each treatment and the capsules were split to count the seeds per capsule.

3.15 Weight of 1000 grains (g)

1000 seeds were counted randomly from the filled seeds by multi auto counter and weighed in an Electric Balance (FX- 300) at 8 % moisture level.

3.16 Seed yield ha^{-1}

An area of 1 m^2 was harvested from each plot for seed yield computation and was converted to yield kg ha^{-1} at 8 % moisture level.

3.17 Harvest index (HI)

Harvest index was calculated by the following formula

$$HI = \frac{\text{Grain yield} \times 100}{\text{Grain yield} + \text{Biological yield}}$$

3.18 Statistical analysis

The data were analyzed statistically by F-test to examine whether the treatment effects were significant. The mean comparisons of the treatments were evaluated by DMRT (Ducan's Multiple Range Test). The analysis of variance (ANOVA) for different parameters was done by a computer package programme ‘MSTAT’.

CHAPTER IV

RESULTS AND DISCUSSION

Effect of population density and source-sink manipulation on different growth, yield and yield contributing characters of sesame have been presented and discussed in this chapter. Effect of different population density, source-sink manipulation and their interactions on growth, yield contributing characters and yield of sesame have been presented in the table and figures.

4 .1 Growth parameters

4.1.1 Plant height

4.1.1.1 Effect of plant density

Plant height of sesame was significantly influenced by population density (Fig. 1 and Appendix III). Higher population density showed increased plant height at different days after sowing and lower plant density showed lower plant height. The progressive increase of plant height was about similar for all treatments up to 20 DAS but at 30, 40, 50, 60 DAS and at harvest, D_3 (50 plants m^{-2}) showed the highest plant height and that were 40.83, 58.43, 75.50, 77.55 and 77.32 cm respectively. On the other hand the lowest plant height; 37.32, 53.06, 68.53, 70.74 and 70.83 cm respectively was recorded at 30, 40, 50, 60 DAS and at harvest respectively with D_1 (30 plants m^{-2}). The population density D_2 (40 plants m^{-2}) showed intermediate results compared to all other population density. Similar phenomenon was observed by Saharia and Thakuria, (1988) in peas. Plant competition due to crowding for space might have elongated the densely populated plants (Willey and Heath, 1969).

4.1.1.2 Effect of source-sink manipulation

Source-sink manipulation of sesame had the great influence on plant height at different days after sowing (Fig. 2 and Appendix III). It was observed that at 20 DAS there was no significant effect on plant height but at 30, 40, 50, 60 DAS and at harvest M_2 (removal of all branches) showed the highest plant height (39.97, 56.93, 73.33, 75.61 and 75.27 cm respectively) which was not significantly different from M_3 (removal of lower empty leaves and lower empty branches) at 40 DAS and significantly similar with M_1 (removal of lower empty leaves, lower empty branches and top of the inflorescence) at 30, 40 DAS and M_3 (removal of lower empty leaves and lower empty branches) at 30, 50 DAS and at harvest. On the other hand the lowest plant height; 38.28, 54.29, 70.13, 72.16 and 72.25 cm respectively was recorded at 30, 40, 50, 60 DAS and at harvest respectively with control treatment M_0 (no removal) which was not significantly different from M_1 at 60 DAS and significantly similar at 50 DAS and at harvest. Similar phenomenon was observed by Hintz and Fehr (1990) in peas; the highest plant height and dry weight/plant was shown with defoliation and removal of branches considering at all stage over non-manipulation treatment.

4.1.1.3 Interaction effect of population density and source-sink manipulation

The interaction effect of population density and source-sink manipulation on plant height was significant at different days after sowing (Table 1 and Appendix III). It was observed that the plant height at 20 DAS had no significant effect but at 30, 40, 50, 60 DAS and at harvest the highest plant height was recorded in the treatment combination of D_3M_2 (41.44, 59.61, 77.39, 79.47 and 78.26 cm respectively) which was not significantly different from D_3M_3 at 30 DAS and at harvest and significantly similar with D_3M_1 at 30, 40 DAS and at harvest and D_3M_3 at 40, 50, 60 DAS. On the other hand the lowest plant height; 36.06, 51.19, 67.89, 69.82 and 69.89 cm at 30, 40, 50, 60 DAS and at harvest respectively was recorded in the treatment combination of D_1M_0 which was not significantly different from D_1M_1 at harvest and significantly similar with D_1M_1 at 30, 40, 50, 60 DAS and D_1M_2, D_1M_3, D_2M_0 at 60 DAS and at harvest. Similar result was observed by Xinhua and Tony (2004).

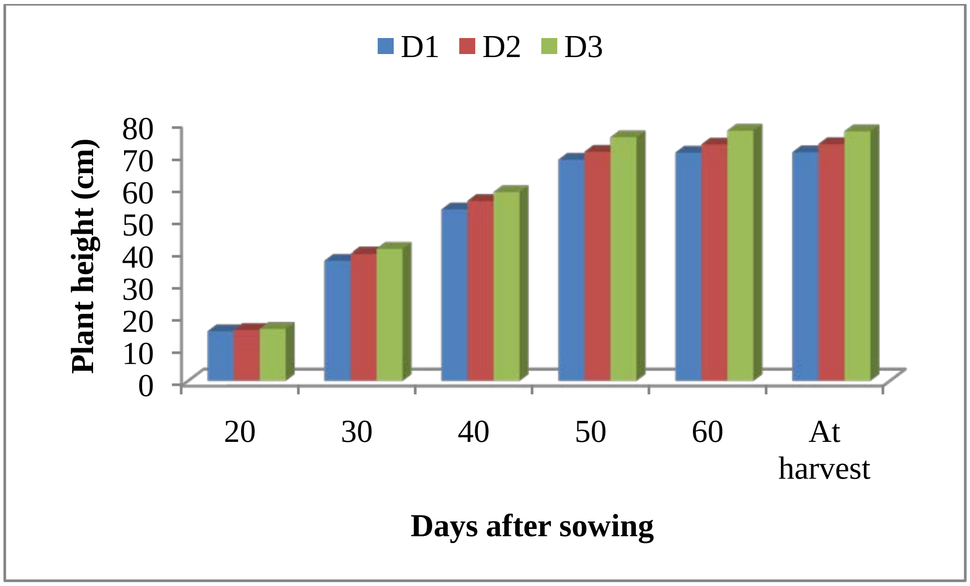

Fig. 1. Effect of population density on plant height of sesame at different days after sowing

Here,

D_1 = 30 plants m^{-2}

D_2 = 40 plants m^{-2}

D_3 = 50 plants m^{-2}

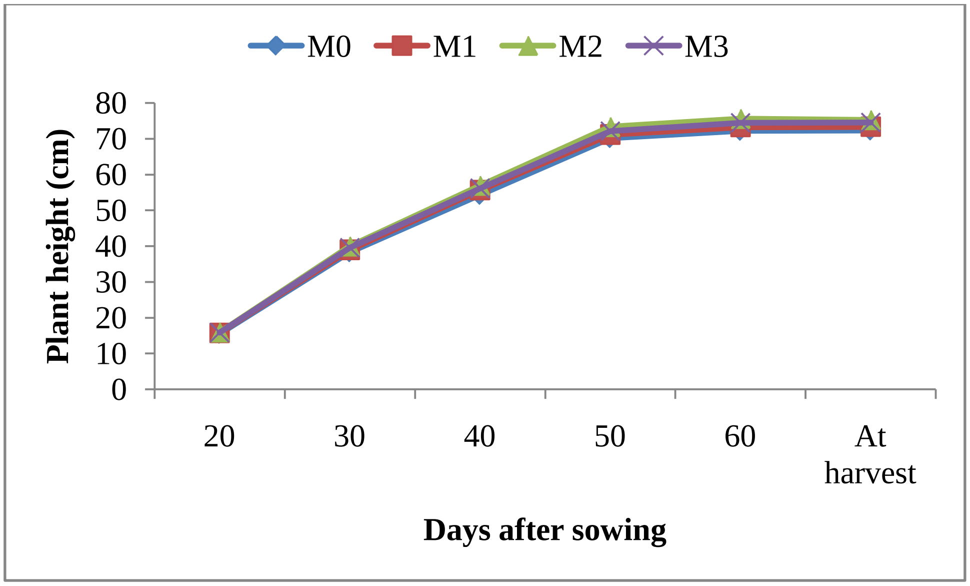

Fig. 2. Effect of source-sink manipulation on plant height of sesame at different days after sowing

Here,

M_0 = No removal

M_1 = Removal of lower empty leaves, lower empty branches and top of the inflorescence

M_2 = Removal of all branches

M_3 = Removal of lower empty leaves and lower empty branches

Table 1. Interaction effect of population density and source-sink manipulation on plant height of sesame at different days after sowing

Treatments	Plant height (cm)					
	20 DAS	**30 DAS**	**40 DAS**	**50 DAS**	**60 DAS**	**At harvest**
Plant m^{-2} × Source-sink manipulation						
D_1M_0	14.88	36.06 f	51.19 g	67.89 f	69.82 g	69.89 f
D_1M_1	15.38	37.11 ef	53.08 fg	68.14 ef	70.32 fg	70.41 f
D_1M_2	15.71	38.44 c-e	54.18 d-f	68.93 d-f	71.56 fg	71.68 ef
D_1M_3	15.59	37.67 d-f	53.78 ef	69.15 d-f	71.27 fg	71.33 ef
D_2M_0	15.67	38.61 c-e	54.45 d-f	69.01 d-f	71.10 fg	71.18 ef
D_2M_1	15.78	39.16 b-d	55.35 c-e	70.25 de	72.37 ef	72.44 de
D_2M_2	16.00	40.02 a-c	57.00 bc	73.68 c	75.81 cd	75.88 b
D_2M_3	15.80	39.76 a-c	56.06 cd	70.97 d	73.80 de	73.93 cd
D_3M_0	16.08	40.16 a-c	57.24 bc	73.49 c	75.55 cd	75.69 bc
D_3M_1	16.12	40.59 ab	58.37 ab	75.00 bc	77.04 bc	77.08 ab
D_3M_2	16.15	41.44 a	59.61 a	77.39 a	79.47 a	78.25 a
D_3M_3	16.11	41.12 a	58.51 ab	76.11 ab	78.15 ab	78.26 a
$LSD_{0.05}$	NS	1.746	1.922	2.076	1.940	1.806
CV(%)	5.29	7.91	9.22	8.56	6.44	7.36

Here,

D_1	=	30 plants m^{-2}	M_0	=	No removal
D_2	=	40 plants m^{-2}	M_1	=	Removal of lower empty leaves, lower empty branches and top of the inflorescence
D_3	=	50 plants m^{-2}	M_2	=	Removal of all branches
			M_3	=	Removal of lower empty leaves and lower empty branches

4.1.2 Number of branches plant^{-1}

4.1.2.1 Effect of plant density

Number of branches plant^{-1} was significantly influenced by population density of the crop (Fig. 3 and Appendix IV). Higher population density showed decreased number of branches plant^{-1} and lower population density showed increased number of branches plant^{-1}at different days after sowing. It was observed that at 30, 40, 50, 60 DAS and at harvest D_1 (30 plants m^{-2}) showed the highest plant height and that were 1.61, 2.26, 3.16 and 3.98 respectively. On the other hand the lowest number of branches plant^{-1}; 1.18, 1.92, 1.94 and 2.71 respectively was recorded at 30, 40, 50, 60 DAS and at harvest respectively with D_3 (50 plants m-^{2}). The population density D_2 (40 plants m^{-2}) showed intermediate results compared to all other population density. Plant density regulates the shape of the canopy (eg. in mungbean, Hashem and Hamid, 1996). Increase in population density increased intra-specific competition which eventually caused reduction in number of branches per plant. Similar results were observed by Channabasavanna *et al.,* 1992.

4.1.2.2 Effect of source-sink manipulation

Source-sink manipulation of sesame had the great influence on number of branches plant^{-1} at different days after sowing (Fig. 4 and Appendix IV). It was observed that at 30, 40, 50, 60 DAS and at harvest M_1 (removal of lower empty leaves, lower empty branches and top of the inflorescence) showed highest number of branches plant^{-1} (1.93, 2.83, 3.47 and 4.56 respectively) which was significantly similar with M_3 (removal of lower empty leaves and lower empty branches) at 30 and 40 DAS. On the other hand there was no branch observed with M_2 (removal of all branches). The results obtained from all other treatments showed intermediate results.

4.1.2.3 Interaction effect of population density and source-sink manipulation

The interaction effect of population density and source-sink manipulation on number of branches plant^{-1} was significant at different days after sowing (Table 2 and Appendix IV). It was observed that the highest number of branches plant^{-1} was with the treatment combination of D_1M_1 (2.21, 3.12, 4.58 and 5.78 respectively) which was not significantly different from D_1M_2 at 30 DAS. On the other hand there was no branch observed with the treatment combination of D_1M_2, D_2M_2 and D_3M_2. The results obtained from all other treatment combination was significantly different.

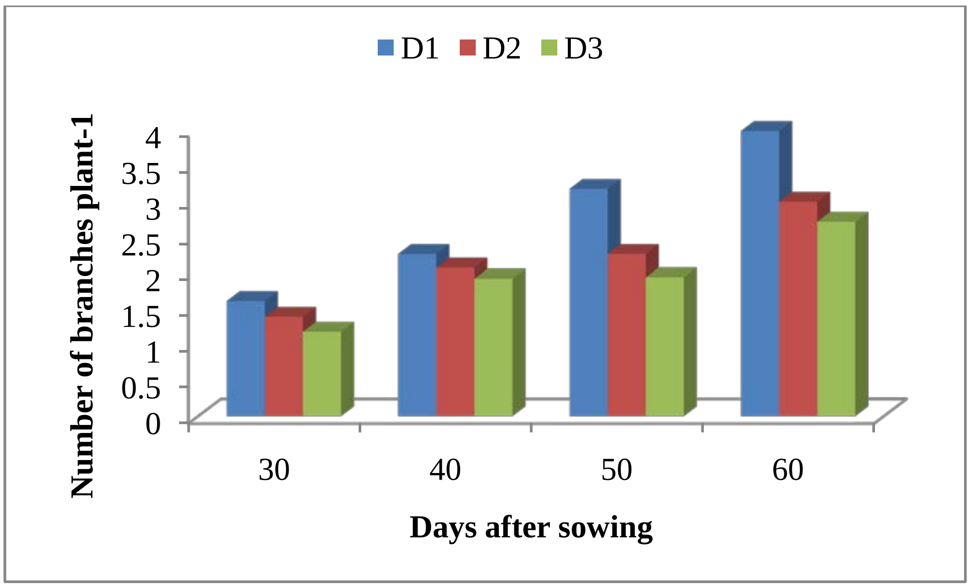

Fig. 3. Effect of population density on number of branches plant^{-1} of sesame at different days after sowing

Here,

D_1 = 30 plants m^{-2}

D_2 = 40 plants m^{-2}

D_3 = 50 plants m^{-2}

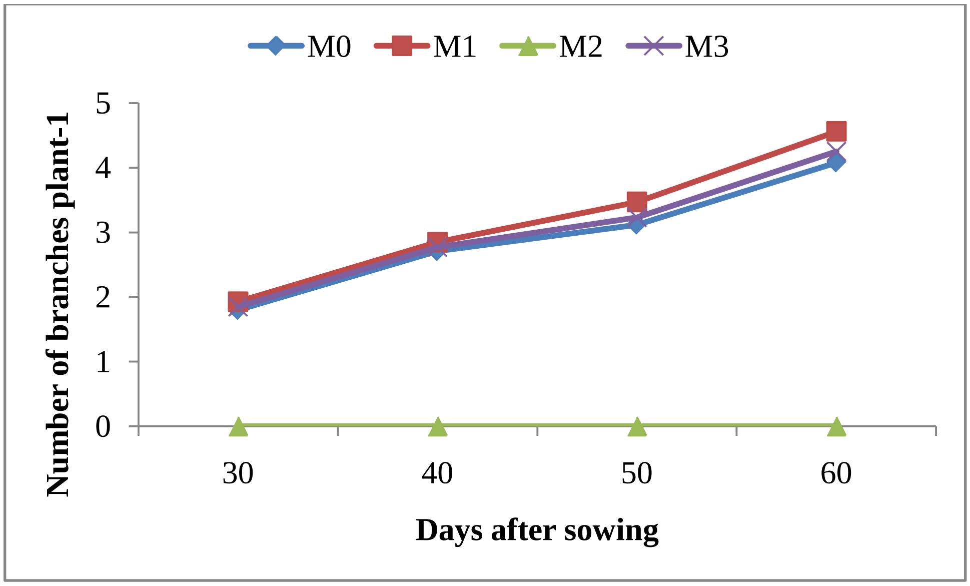

Fig. 4. Effect of source-sink manipulation on number of branches plant^{-1} of sesame at different days after sowing

Here,

M_0 = No removal

M_1 = Removal of lower empty leaves, lower empty branches and top of the inflorescence

M_2 = Removal of all branches

M_3 = Removal of lower empty leaves and lower empty branches

Table 2. Interaction effect of population density and source-sink manipulation on number of branches plant^{-1} of sesame at different days after sowing

Treatments	Number of branches plant^{-1}			
	30 DAS	**40 DAS**	**50 DAS**	**60 DAS**
Plant m^{-2}× Source-sink manipulation				
D_1M_0	2.09 ab	2.93 bc	3.96 b	4.92 c
D_1M_1	2.21 a	3.12 a	4.58 a	5.78 a
D_1M_2	0.00 f	0.00 h	0.00 g	0.00 h
D_1M_3	2.14 a	3.01 ab	4.12 b	5.20 b
D_2M_0	1.80 cd	2.70 d-f	2.87 de	3.81 ef
D_2M_1	1.92 bc	2.82 b-d	3.18 c	4.22 d
D_2M_2	0.00 f	0.00 h	0.00 g	0.00 h
D_2M_3	1.84 cd	2.76 c-e	2.98 cd	3.94 e
D_3M_0	1.52 e	2.50 g	2.52 f	3.56 g
D_3M_1	1.66 de	2.62 e-g	2.66 ef	3.69 fg
D_3M_2	0.00 f	0.00 h	0.00 g	0.00 h
D_3M_3	1.56 e	2.56 fg	2.58 f	3.60 fg
$LSD_{0.05}$	0.193	0.178	0.227	0.214
CV(%)	5.56	8.24	9.36	6.47

Here,

D_1 = 30 plants m^{-2}

D_2 = 40 plants m^{-2}

D_3 = 50 plants m^{-2}

M_0 = No removal

M_1 = Removal of lower empty leaves, lower empty branches and top of the inflorescence

M_2 = Removal of all branches

M_3 = Removal of lower empty leaves and lower empty branches

4.1.3 Leaf area index

4.1.3.1 Effect of plant density

Leaf area index was significantly influenced by population density of the plants (Fig. 5 and Appendix V). Higher population density showed increased leaf area index at different days after sowing and lower plant density showed lower leaf area index. It was observed that at 20 DAS there was no significant effect on leaf area index but at 30, 40, 50, 60 DAS and at harvest D_3 (50 plants m-^{2}) showed the highest leaf area index and that were 0.96, 1.77, 2.39, 1.78 and 0.98 cm respectively which was significantly same at 50 DAS and at harvest and significantly similar at 30, 40 and 60 DAS with D_2 (40 plants m-^{2}). On the other hand the lowest leaf area index; 0.66, 1.455, 1.905, 1.475 and 0.65 respectively was recorded at 30, 40, 50, 60 DAS and at harvest respectively with D_1 (30 plants m^{-2}). Similar phenomenon was observed by Malcolm *et al*., 2000 in soybean. It is evident that during the whole growth period LAI was highest in the highest population density than that of others.

4.1.3.2 Effect of source-sink manipulation

Source-sink manipulation of sesame had the great influence on leaf area index at different days after sowing (Fig. 6 and Appendix V). It was observed that at 20 DAS there was no significant effect on leaf area index but at 30, 40, 50, 60 DAS and at harvest M_1 (removal of lower empty leaves, lower empty branches and top of the inflorescence) showed highest leaf area index (0.98, 1.80, 2.47, 1.85 and 0.99 respectively) which was significantly similar with M_3 (removal of lower empty leaves and lower empty branches) at 30, 40, 50, 60 DAS and at harvest respectively. On the other hand the lowest leaf area index; 0.63, 1.22, 1.69, 1.24 and 0.63 was recorded at 30, 40, 50, 60 DAS and at harvest respectively with M_2 (removal of all branches). Similar phenomenon was observed by Alkio *et al.,* 2003.

4.1.3.3 Interaction effect of population density and source-sink manipulation

The interaction effect of population density and source-sink manipulation on leaf area index was significant at different days after sowing (Table 3 and Appendix V). It was observed that the leaf area index at 20 DAS had no significant effect but at 30, 40, 50, 60 DAS and at harvest; the highest leaf area index was recorded in the treatment combination of D_3M_1 (1.12, 1.92, 2.68, 1.98 and 1.14 respectively) which was not significantly different from D_2M_1, D_3M_3 at 50 DAS and at harvest. Significantly similar result was observed with D_2M_1 and D_3M_3 at 30, 40, 60 DAS, and D_2M_3 and D_3M_0 at 50, 60 DAS and at harvest compared to the highest leaf area index. On the other hand the lowest leaf area index; 0.49, 1.00, 1.53, 1.05 and 0.44 at 30, 40, 50, 60 DAS and at harvest respectively was recorded with the treatment combination of D_1M_2 which was significantly similar with D_2M_2 at all stages of crop duration and with D_1M_0 at 30 DAS and at harvest. The results obtained from all other treatments showed significantly different results compared to the highest and lowest leaf area index.

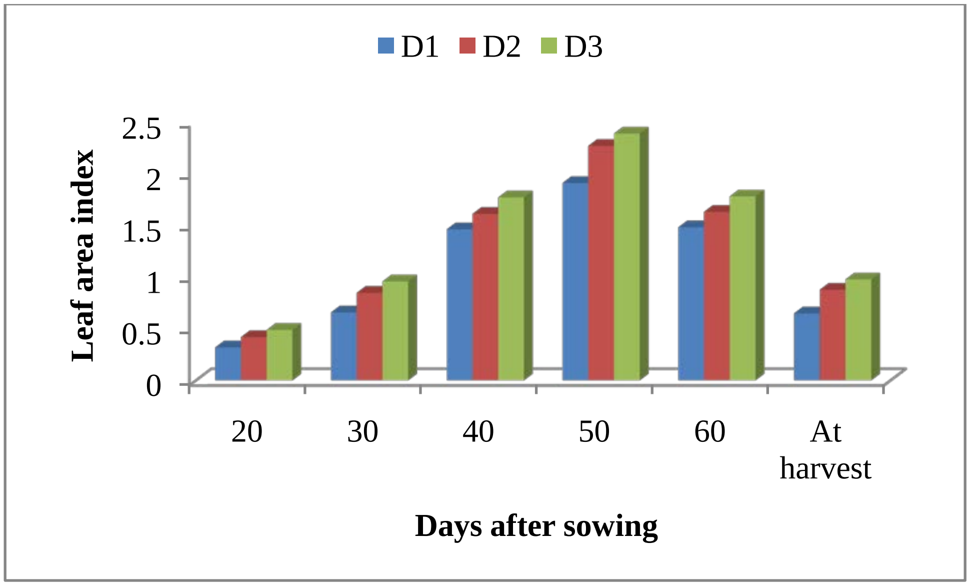

Fig. 5. Effect of population density on leaf area index of sesame at different days after sowing

Here,

D_1	=	30 plants m^{-2}
D_2	=	40 plants m^{-2}
D_3	=	50 plants m^{-2}

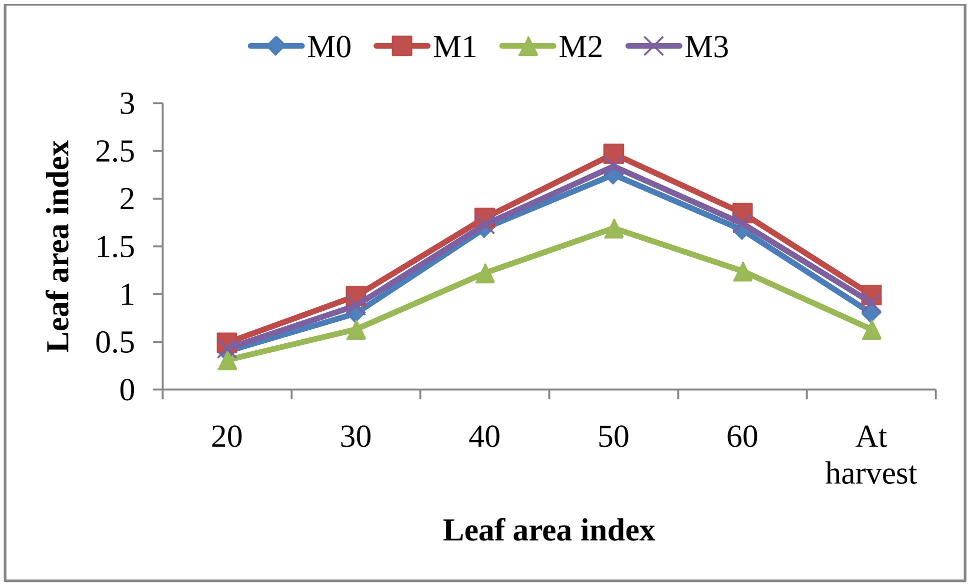

Fig. 6. Effect of source-sink manipulation on leaf area index of sesame at different days after sowing

Here,

M_0 = No removal

M_1 = Removal of lower empty leaves, lower empty branches and top of the inflorescence

M_2 = Removal of all branches

M_3 = Removal of lower empty leaves and lower empty branches

Table 3. Interaction effect of population density and source-sink manipulation on leaf area index of sesame at different days after sowing

Treatments	Leaf area index					
	20 DAS	**30 DAS**	**40 DAS**	**50 DAS**	**60 DAS**	**At harvest**
Plant m^{-2}× Source-sink manipulation						
D_1M_0	0.30	0.65 de	1.57 bc	1.89 cd	1.52 cd	0.66 cd
D_1M_1	0.38	0.78 cd	1.65 a-c	2.19 bc	1.69 a-d	0.76 bc
D_1M_2	0.26	0.49 e	1.00 d	1.53 e	1.05 f	0.44 d
D_1M_3	0.33	0.72 cd	1.60 bc	2.01 cd	1.64 b-d	0.74 bc
D_2M_0	0.41	0.83 b-d	1.68 a-c	2.38 a-c	1.65 b-d	0.80 bc
D_2M_1	0.50	1.04 ab	1.84 ab	2.54 a	1.88 ab	1.09 a
D_2M_2	0.31	0.64 de	1.19 cd	1.71 de	1.22 ef	0.68 cd
D_2M_3	0.44	0.90 a-c	1.73 a-c	2.44 ab	1.76 ab	0.94 ab
D_3M_0	0.48	0.93 a-c	1.81 a-c	2.48 ab	1.84 ab	0.95 ab
D_3M_1	0.59	1.12 a	1.92 a	2.68 a	1.98 a	1.14 a
D_3M_2	0.37	0.76 cd	1.48 c	1.84 de	1.45 de	0.78 bc
D_3M_3	0.52	1.02 ab	1.85 ab	2.57 a	1.83 ab	1.06 a
$LSD_{0.05}$	NS	0.201	0.251	0.328	0.273	0.214
CV(%)	3.67	5.22	7.38	6.49	8.44	7.13

Here,

D_1 = 30 plants m^{-2}

D_2 = 40 plants m^{-2}

D_3 = 50 plants m^{-2}

M_0 = No removal

M_1 = Removal of lower empty leaves, lower empty branches and top of the inflorescence

M_2 = Removal of all branches

M_3 = Removal of lower empty leaves and lower empty branches

4.1.4 Dry weight plant^{-1}

4.1.4.1 Effect of plant density

Dry weight plant^{-1} was significantly influenced by population density of the plants (Table 4 and Appendix VI). Lower population density showed increased dry weight plant^{-1} and higher population density showed decreased dry weight plant^{-1}. It was observed that at 20, 30, 40, 50, 60 DAS and at harvest D_1 (30 plants m^{-2}) showed the highest dry weight plant^{-1} and that were 1.49, 2.85, 5.15, 6.78, 7.38 and 7.57 g respectively. On the other hand the lowest dry weight plant^{-1}; 1.05, 2.26, 3.52, 4.43, 4.73 and 4.85 g respectively was recorded at 20, 30, 40, 50, 60 DAS and at harvest respectively with D_3 (50 plants m-^{2}). The results obtained from D_2 (40 plants m-^{2}) showed intermediate results compared to all other treatments. Similar result was supported by Hashem and Hamid (1996) and Channabasavanna *et al.*, 1992.

4.1.4.2 Effect of source-sink manipulation

Source-sink manipulation of sesame had the great influence on dry weight plant^{-1} at different days after sowing (Table 4 and Appendix VI). It was observed that at 20, 30, 40, 50, 60 DAS and at harvest M_1 (removal of lower empty leaves, lower empty branches and top of the inflorescence) showed the highest dry weight plant^{-1} (1.41, 2.69, 4.69, 5.87, 6.27 and 6.42 g respectively) which was not significantly different from M_3 (removal of lower empty leaves and lower empty branches) at 20 and 30 DAS. On the other hand the lowest dry weight plant^{-1}; 1.20, 2.31, 4.16, 5.40, 5.82 and 5.97 g respectively was recorded at 20, 30, 40, 50, 60 DAS and at harvest respectively with M_2 (removal of all branches) which was not significantly different from M_0 (control treatment) at 20, 40,50, 60 DAS and at harvest. Similar result was supported by Hintz and Fehr (1990).

4.1.4.3 Interaction effect of population density and source-sink manipulation

The interaction effect of population density and source-sink manipulation on dry weight plant^{-1} had significant effect at different days after sowing (Table 4 and

Appendix VI). It was observed that the highest dry weight plant^{-1} at 20, 30, 40, 50, 60 DAS and at harvest was recorded with the treatment combination of D_1M_1 (1.59, 3.06, 5.42, 6.97, 7.60 and 7.79 g respectively) which was not significantly different from D_1M_3 at 20 DAS and significantly similar with D_1M_0 and D_2M_1 at 20 DAS, D_1M_3 at 50 DAS and at harvest and D_3M_0 at 30 DAS. On the other hand the lowest dry weight plant^{-1}; 0.91, 1.76, 3.17, 4.14, 4.52 and 4.64 g at 20, 30, 40, 50, 60 DAS and at harvest respectively was recorded with the treatment combination of D_3M_2 which was not significantly different form D_3M_0 at 40 and 60 DAS and significantly similar with D_3M_0 at 20 DAS. The results obtained from all other treatment combinations were significantly different compared to highest and lowest results.

Table 4. Effect of population density and source-sink manipulation and their interaction on dry weight plant^{-1} of sesame at different days after sowing

Treatments	Dry weight plant^{-1}					
	20 DAS	**30 DAS**	**40 DAS**	**50 DAS**	**60 DAS**	**At harvest**
Plant m^{-2}						
D_1	1.49 a	2.85 a	5.15 a	6.78 a	7.38 a	7.57 a
D_2	1.34 b	2.56 b	4.48 b	5.55 b	5.89 b	6.05 b
D_3	1.05 c	2.26 c	3.52 c	4.43 c	4.73 c	4.85 c
$LSD_{0.05}$	0.089	0.105	0.114	0.083	0.059	0.123
Source-sink manipulation						
M_0	1.22 b	2.54 b	4.21 c	5.45 c	5.89 c	6.04 c
M_1	1.41 a	2.69 a	4.69 a	5.87 a	6.27 a	6.42 a
M_2	1.20 b	2.31 c	4.16 c	5.40 c	5.82 c	5.97 c
M_3	1.34 a	2.67 a	4.46 b	5.62 b	6.04 b	6.19 b
$LSD_{0.05}$	0.103	0.116	0.1312	0.093	0.069	0.142
Plant m^{-2}× Source-sink manipulation						
D_1M_0	1.45 ab	2.77 bc	5.06 b	6.73 bc	7.33 b	7.52 bc
D_1M_1	1.59 a	3.06 a	5.42 a	6.97 a	7.60 a	7.79 a
D_1M_2	1.40 a-c	2.69 b-d	4.94 bc	6.60 c	7.15 c	7.34 c
D_1M_3	1.50 a	2.88 a-c	5.17 b	6.81 ab	7.44 b	7.63 ab
D_2M_0	1.22 cd	2.33 ef	4.19 f	5.32 f	5.73 f	5.89 e
D_2M_1	1.45 ab	2.75 bc	4.76 cd	5.82 d	6.13 d	6.28 d
D_2M_2	1.29 b-d	2.49 de	4.37 ef	5.47 ef	5.79 f	5.94 e
D_2M_3	1.41 a-c	2.66 cd	4.59 de	5.60 e	5.94 e	6.09 de
D_3M_0	1.00 ef	2.91 ab	3.38 i	4.31 h	4.60 i	4.72 g
D_3M_1	1.18 de	2.27 fg	3.91 g	4.81 g	5.07 g	5.20 f
D_3M_2	0.91 f	1.76 h	3.17 i	4.14 i	4.52 i	4.64 g
D_3M_3	1.11 de	2.09 g	3.62 h	4.46 h	4.73 h	4.85 g
$LSD_{0.05}$	0.178	0.201	0.227	0.161	0.121	0.245
CV(%)	7.79	8.54	6.19	5.71	8.28	6.72

Here,

D_1 = 30 plants m^{-2}
D_2 = 40 plants m^{-2}
D_3 = 50 plants m^{-2}

M_0 = No removal
M_1 = Removal of lower empty leaves, lower empty branches and top of the inflorescence
M_2 = Removal of all branches
M_3 = Removal of lower empty leaves and lower empty branches

4.1.5 Dry weight m^{-2}

4.1.5.1 Effect of plant density

Dry weight m^{-2} was significantly influenced by population density of the plants (Table 5 and Appendix VII). It was observed that at 20, 30, 40, 50, 60 DAS and at harvest D_2 (40 plants m-^{2}) showed the highest dry weight m^{-2} and that were 53.71, 102.30, 179.10, 222.10, 235.80 and 241.80 g respectively which was statistically identical with D_3 (50 plants m-^{2}) at all stages that were mentioned. On the other hand the lowest dry weight m^{-2}; 44.49, 85.46, 154.50, 205.10, 221.20 and 227.10 g respectively was recorded at 20, 30, 40, 50, 60 DAS and at harvest respectively with D_1 (30 plants m-^{2}). The widely populated plant had accumulated more dry matter than densely planted ones. The result indicated that although per plant dry matter increased with the decrease in population density. TDM (total dry matter) per unit area continued to increase with the increasing population density. Similar result was observed by Jahan (1998) in mungbean.

4.1.5.2 Effect of source-sink manipulation

Source-sink manipulation of sesame had the great influence on dry weight m^{-2} at different days after sowing (Table 5 and Appendix VII). It was observed that at 20, 30, 40, 50, 60 DAS and at harvest M_1 (removal of lower empty leaves, lower empty branches and top of the inflorescence) showed highest dry weight m^{-2} (54.89, 104.90, 182.80, 227.50, 242.20 and 248.30 g respectively). On the other hand the lowest dry weight m^{-2}; 46.46, 89.35, 160.40, 208.00, 224.00 and 229.80 g respectively was recorded at 20, 30, 40, 50, 60 DAS and at harvest respectively with M_2 (removal of all branches) which was not significantly different from M_0 (control treatment) at 20, 30 and 60 DAS.

4.1.5.3 Interaction effect of population density and source-sink manipulation

The interaction effect of population density and source-sink manipulation on dry weight m^{-2} had significant effect at different days after sowing (Table 5 and Appendix VII). It was observed that the highest dry weight m^{-2} at 20, 30, 40, 50, 60 DAS and at harvest was recorded with the treatment combination of D_3M_1 (58.81, 113.30, 195.30, 240.60, 253.60 and 259.80 g respectively) which was not significantly different from D_2M_1 at 50 DAS and significantly similar with D_2M_1 at 20, 30 DAS and D_2M_3 at 30 DAS. On the other hand the lowest dry weight m^{-2}; 41.92, 80.60, 148.10, 198.10, 214.50 and 220.20 g at 30, 40, 50, 60 DAS and at harvest respectively was recorded with the treatment combination of D_1M_2 which was significantly similar with D_1M_0 at 20, 30 and 60 DAS and D_1M_3 at 50 DAS. The results obtained from all other treatment combinations were significantly different compared to highest and lowest results. These results are in general agreement with those of Hicks and Pandleton (1969) and Xinhua and Tony (2004).

Table 5. Effect of population density and source-sink manipulation and their interaction on dry weight m^{-2} of sesame at different days after sowing

Treatments	Dry weight m^{-2} (g)					
	20 DAS	30 DAS	40 DAS	50 DAS	60 DAS	At harvest
Plant m^{-2}						
D_1	44.49 b	85.46 b	154.50 b	205.10 b	221.20 b	227.10 b
D_2	53.71 a	102.30 a	179.10 a	222.10 a	235.80 a	241.80 a
D_3	52.44 a	100.30 a	175.90 a	221.50 a	236.40 a	242.50 a
$LSD_{0.05}$	1.517	2.005	3.143	1.637	2.018	1.632
Source-sink manipulation						
M_0	47.26 c	90.71 c	162.90 c	212.40 c	226.20 c	232.20 c
M_1	54.89 a	104.9 a	182.80 a	227.50 a	242.20 a	248.30 a
M_2	46.46 c	89.35 c	160.40 d	208.00 d	224.00 c	229.80 d
M_3	52.24 b	99.10 b	173.30 b	217.10 b	232.40 b	238.30 b
$LSD_{0.05}$	1.751	2.315	1.998	1.890	3.871	1.884
Plant m^{-2} × Source-sink manipulation						
D_1M_0	43.36 gh	83.23 hi	151.90 h	208.90 de	219.50 gh	225.70 h
D_1M_1	47.78 d-f	91.70 ef	162.70 f	209.10 de	227.90 ef	233.80 ef
D_1M_2	41.92 h	80.60 i	148.10 i	198.10 f	214.50 h	220.20 i
D_1M_3	44.88 f-h	86.30 gh	155.2 gh	204.50 ef	223.10 fg	228.80 gh
D_2M_0	48.62 c-e	93.31e	167.60 e	212.80 c-e	229.10 d-f	235.00 d-f
D_2M_1	58.07 ab	109.90 ab	190.40 b	232.70 a	245.00 b	251.10 b
D_2M_2	51.77 c	99.68 d	174.90 d	218.80 bc	231.50 c-e	237.50 d
D_2M_3	56.38 ab	106.3 bc	183.60 c	223.90 b	237.70 c	243.70 c
D_3M_0	49.81 cd	95.59 e	169.10 e	215.50 b-d	229.90 d-f	235.90 de
D_3M_1	58.81 a	113.30 a	195.30 a	240.60 a	253.60 a	259.80 a
D_3M_2	45.69 e-g	87.78 fg	158.30 g	207.30 de	225.90 e-g	231.80 fg
D_3M_3	55.45 b	104.7 c	181.00 c	222.80 b	236.40 cd	242.40 c
$LSD_{0.05}$	3.033	4.010	3.460	8.250	6.705	3.263
CV(%)	5.64	8.15	6.94	7.83	8.89	7.11

Here,

D_1 = 30 plants m^{-2}

D_2 = 40 plants m^{-2}

D_3 = 50 plants m^{-2}

M_0 = No removal

M_1 = Removal of lower empty leaves, lower empty branches and top of the inflorescence

M_2 = Removal of all branches

M_3 = Removal of lower empty leaves and lower empty branches

4.1.6 Crop growth rate

4.1.6.1 Effect of plant density

Crop growth rate was significantly influenced by population density of the plants (Fig. 7 and Appendix VIII). Here, crop growth rate was measured within 10 days interval and it begun from at 20 to 60 days after sowing. Crop growth rate mainly depends on accumulation of dry matter m^{-2} and from this point of view it was observed that at 50 – 60 DAS there was no significant effect on crop growth rate but at 20 – 30, 30 – 40 and 40 – 50 DAS; D_2 (40 plants $m\text{-}^2$) showed the highest crop growth rate and that were 4.86, 7.69 and 4.81 respectively which was statistically identical with D_3 (50 plants $m\text{-}^2$). On the other hand the lowest crop growth rate; 4.05, 6.90 and 4.29 was recorded at 20 – 30, 30 – 40 and 40 – 50 DAS respectively with D_1 (30 plants $m\text{-}^2$). Similar results were also reported by Koller *et al*. (1970) in soybean. In higher population density, plant material per unit land area is higher than the lower one. The CGR is more a measure of the size of the plant than a measure of increase of growth (Campbell and Kondra, 1978).

4.1.6.2 Effect of source-sink manipulation

Source-sink manipulation of sesame had the great influence on crop growth rate at different days of interval after sowing (Fig. 8 and Appendix VIII). It was observed that at 50 – 60 DAS there was no significant effect on crop growth rate but at 20 – 30, 30 – 40 and 40 – 50 DAS; M_1 (removal of lower empty leaves, lower empty branches and top of the inflorescence) showed highest crop growth rate (5.00, 7.78 and 4.80 respectively). On the other hand the lowest crop growth rate was obtained form M_2 ((removal of all branches) at 20 – 30 and 30 – 40 DAS (4.22 and 7.11 respectively) but at 40 – 50 DAS it was 4.05 from M_3 (removal of lower empty leaves and lower empty branches).

4.1.6.3 Interaction effect of population density and source-sink manipulation

The interaction effect of population density and source-sink manipulation on crop growth rate was significant at different days of interval after sowing (Table 6 and Appendix VIII). It was observed that the crop growth rate at 50 – 60 DAS had no significant effect but at 20 – 30, 30 – 40 and 40 – 50 DAS; the highest crop growth rate was recorded with the treatment combination of D_3M_1 (5.44, 8.20 and 5.53 respectively) which was significantly similar with D_2M_1 at 20 – 30 and 30 – 40 DAS. On the other hand the lowest crop growth rate (3.67 and 6.75 respectively) was recorded with the treatment combination of D_1M_2 at 20 – 30 and 30 – 40 DAS but at 40 – 50 DAS it was obtained from D_1M_3 (3.93).

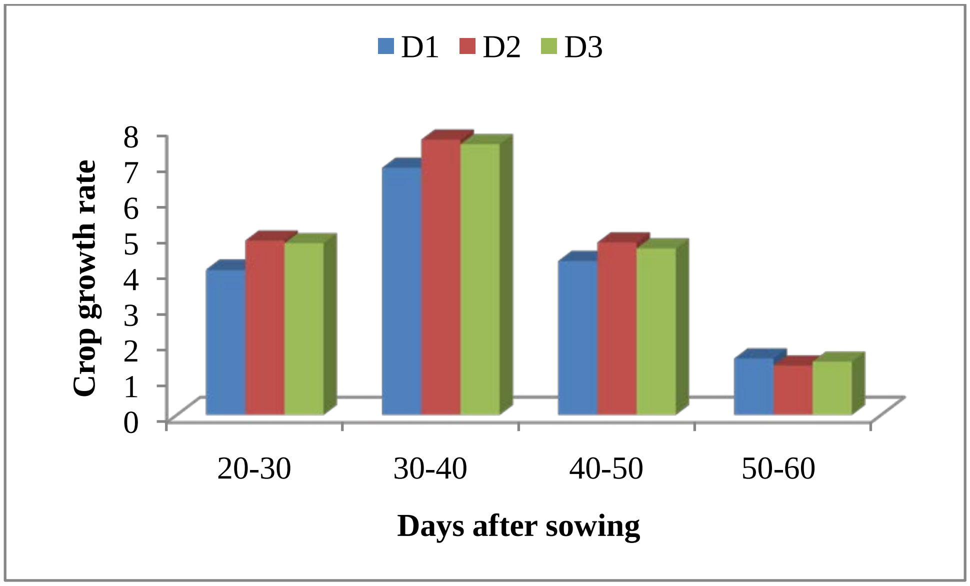

Fig. 7. Effect of population density on crop growth rate of sesame at different days after sowing

Here,

D_1 = 30 plants m^{-2}

D_2 = 40 plants m^{-2}

D_3 = 50 plants m^{-2}

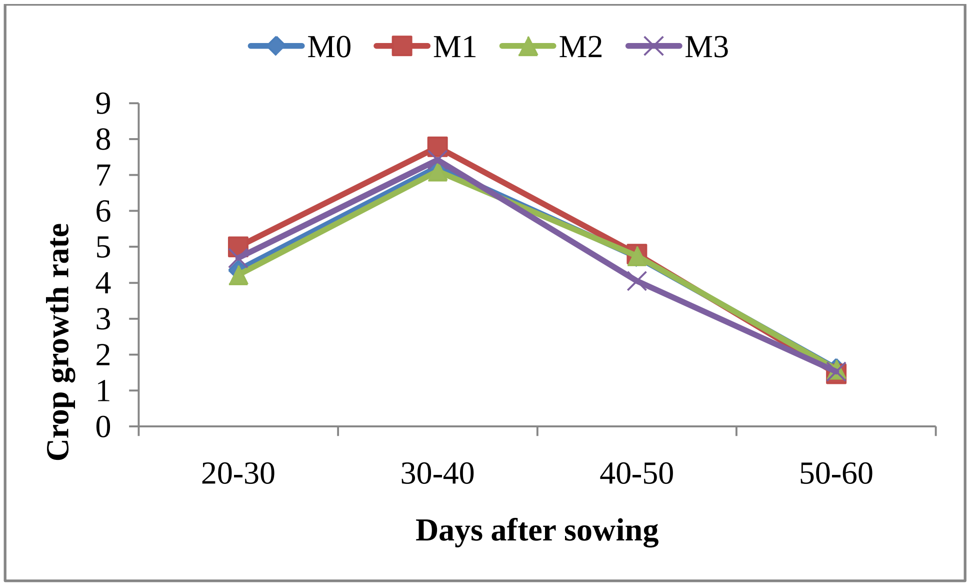

Fig. 8. Effect of source-sink manipulation on crop growth rate of sesame at different days after sowing

Here,

M_0 = No removal

M_1 = Removal of lower empty leaves, lower empty branches and top of the inflorescence

M_2 = Removal of all branches

M_3 = Removal of lower empty leaves and lower empty branches

Table 6. Interaction effect of population density and source-sink manipulation on crop growth rate of sesame at different days after sowing

Treatments	Crop growth rate			
	20-30 DAS	**30-40 DAS**	**40-50 DAS**	**50-60 DAS**
Plant m^{-2}× Source-sink manipulation				
D_1M_0	3.99 gh	6.87 f	5.00 b	1.81
D_1M_1	4.39 e-g	7.10 d-f	4.64 b-d	1.88
D_1M_2	3.67 h	6.75 f	4.99 b	1.64
D_1M_3	4.14 fg	6.89 f	3.93 g	1.86
D_2M_0	4.47 d-f	7.43 c-e	4.52 c-e	1.63
D_2M_1	5.18 ab	8.05 ab	4.23 e-g	1.23
D_2M_2	4.79 b-e	7.53 cd	4.38 d-f	1.27
D_2M_3	4.99 bc	7.73 bc	4.03 fg	1.38
D_3M_0	4.58 c-f	7.36 c-e	4.64 b-d	1.44
D_3M_1	5.44 a	8.20 a	5.53 a	1.30
D_3M_2	4.21 fg	7.05 ef	4.89 bc	1.86
D_3M_3	4.93 b-d	7.63 bc	4.18 e-g	1.36
$LSD_{0.05}$	0.428	0.401	0.371	NS
CV(%)	6.78	5.61	9.42	4.76

Here,

D_1	=	30 plants m^{-2}	M_0	=	No removal
D_2	=	40 plants m^{-2}	M_1	=	Removal of lower empty leaves, lower empty branches and top of the inflorescence
D_3	=	50 plants m^{-2}	M_2	=	Removal of all branches
			M_3	=	Removal of lower empty leaves and lower empty branches

4.2 Yield contributing characters

4.2.1 Number capsules plant^{-1}

4.2.1.1 Effect of plant density

Number of capsules plant^{-1} was significantly influenced by population density of the plants (Table 7 and Appendix IX). It was observed that at harvest D_2 (40 plants m^{-2}) showed the highest number of capsules plant^{-1} (21.09). On the other hand the lowest number of capsules plant^{-1} (17.93) was recorded with D_3 (50 plants m-^{2}). The result obtained from D_1 (30 plants m-^{2}) showed intermediate results compared to all other population density. Similar trend in number of capsules per plant in sesame was reported by Tomar *et al*., (1992). Singh and Yadav (1987) also reported an increase in pods per plant due to decrease in planting density in field peas.

4.2.1.2 Effect of source-sink manipulation

Source-sink manipulation of sesame had the great influence on number of capsules plant^{-1} at harvest (Table 7 and Appendix IX). It was observed that M_1 (removal of lower empty leaves, lower empty branches and top of the inflorescence) showed the highest number of capsules plant^{-1} (25.51). On the other hand the lowest number of capsules plant^{-1} (15.38) was recorded with M_2 (removal of all branches). The result obtained from all other source-sink manipulation effect showed intermediate result compared to the highest and lowest result. Similar result was stated by Parvez (1992) and he reported the reduced number of pods per plant due to leaf and branch clipping in grasspea.

4.2.1.3 Interaction effect of population density and source-sink manipulation

The interaction effect of population density and source-sink manipulation on the number of capsules plant^{-1} had significant effect at harvest (Table 7 and Appendix IX). It was observed that the highest number of capsules plant^{-1} was recorded with the treatment combination of D_2M_1 (28.38). On the other hand the lowest number of capsules plant^{-1} (14.25) was recorded with the treatment combination of D_1M_2 which was significantly similar with D_2M_2 and D_3M_0 at harvest. The results obtained from all other treatment combinations were significantly different compared to highest and lowest results.

4.2.2 Number of capsules m^{-2}

4.2.2.1 Effect of plant density

Number of capsules m^{-2} was significantly influenced by population density of the plants (Table 7 and Appendix IX). It was observed that at harvest D_2 (40 plants m^{-2}) showed the highest number of capsules m^{-2} (896.50). On the other hand the lowest number of capsules m^{-2} (573.00) was recorded with D_1 (30 plants m-^{2}). The result obtained from D_3 (50 plants m-^{2}) showed intermediate results compared to all other population density.

4.2.2.2 Effect of source-sink manipulation

Source-sink manipulation of sesame had the great influence on number of capsules m^{-2} at harvest (Table 7 and Appendix IX). It was observed that M_1 (removal of lower empty leaves, lower empty branches and top of the inflorescence) showed the highest number of capsules m^{-2} (1010.33). On the other hand the lowest number of capsules m^{-2} (622.73) was recorded with M_2 (removal of all branches). The result obtained from all other source-sink manipulation effect showed intermediate result compared to the highest and lowest value. The similar trends were observed in soybean by Hintz and Fehr (1990). They observed that defoliation, branch and stem cutoff decreased the number of capsules per unit area over non-manipulation treatment.

4.2.2.3 Interaction effect of population density and source-sink manipulation

The interaction effect of population density and source-sink manipulation on the number of capsules m^{-2} had significant effect at harvest (Table 7 and Appendix IX). It was observed that the highest number of capsules m^{-2} was recorded with the treatment combination of D_2M_1 (1135.20) which were not significantly different from D_3M_1. On the other hand the lowest number of capsules m^{-2} (427.50) was recorded with the treatment combination of D_1M_2 at harvest. The results obtained from all other treatment combinations were significantly different compared to highest and lowest results.

4.2.3 Number of seeds capsule^{-1}

4.2.3.1 Effect of plant density

Number of seeds capsules^{-1} was significantly influenced by population density of the plants (Table 7 and Appendix IX). It was observed that at harvest D_2 (40 plants m^{-2}) showed the highest number of seeds capsules^{-1} (69.75). On the other hand the lowest number of seeds capsules^{-1} (67.25) was recorded with D_3 (50 plants m-^{2}). The result obtained from D_1 (30 plants m-^{2}) showed intermediate results compared to all other population density.

4.2.3.2 Effect of source-sink manipulation

Source-sink manipulation of sesame had the great influence on number of seeds capsules^{-1} at harvest (Table 7 and Appendix IX). It was observed that M_1 (removal of lower empty leaves, lower empty branches and top of the inflorescence) showed the highest number of seeds capsules^{-1} (69.62) which was not significantly different from M_3 (removal of lower empty leaves and lower empty branches) and significantly similar with M_0 (no removal). On the other hand the lowest number of seeds capsules^{-1} (67.32) was recorded with M_2 (removal of all branches). Similar result was observed by Hintz and Fehr (1990) in soybean.

4.2.3.3 Interaction effect of population density and source-sink manipulation

The interaction effect of population density and source-sink manipulation on the number of seeds capsules^{-1} had significant effect at harvest (Table 7 and Appendix IX). It was observed that the highest number of seeds capsules^{-1} was recorded with the treatment combination of D_2M_1 (70.66). On the other hand the lowest number of seeds capsules^{-1} (66.30) was recorded with the treatment combination of D_3M_2 which was significantly similar with D_1M_2 and D_3M_0 at harvest. The results obtained from all other treatment combinations were significantly different compared to highest and lowest results.

4.2.4 Weight of 1000 seeds (g)

4.2.4.1 Effect of plant density

Weight of 1000 seeds was significantly influenced by population density of the plants (Table 7 and Appendix IX). It was observed that D_2 (40 plants m^{-2}) showed the highest 1000 seed weight (3.28 g). On the other hand the lowest 1000 seed weight (3.17 g) was recorded with D_3 (50 plants m-^{2}) which was not significantly different from D_1 (30 plants m-^{2}). Similar results were observed by Islam (1992) in brassica species.

4.2.4.2 Effect of source-sink manipulation

Source-sink manipulation of sesame had the great influence on 1000 seed weight at harvest (Table 7 and Appendix IX). It was observed that M_1 (removal of lower empty leaves, lower empty branches and top of the inflorescence) showed the highest 1000 seed weight (3.35 g). On the other hand the lowest number of 1000 seed weight (3.10 g) was recorded with M_0 (no removal). The result obtained from all other source-sink manipulation effect showed intermediate result compared to the highest and lowest result. Similar results were observed by Karadogan and Akgün, 2009.

4.2.4.3 Interaction effect of population density and source-sink manipulation

The interaction effect of population density and source-sink manipulation on 1000 seed weight had significant effect (Table 7 and Appendix IX). It was observed that the highest 1000 seed weight was recorded with the treatment combination of D_2M_1 (**3.45 g**). On the other hand the lowest 1000 seed weight (3.04 g) was recorded with the treatment combination of D_1M_0 which was significantly similar with D_3M_0. The results obtained from all other treatment combinations were significantly different compared to highest and lowest results. These results are in general agreement with those of Hicks and Pandleton (1969), Islam (1992) and Xinhua and Tony (2004).

Table 7. Effect of population density and source-sink manipulation and their interaction on different yield contributing characters of sesame

Treatments	Number capsules plant^{-1}	Number of capsules m^{-2}	Number of seeds capsule^{-1}	1000 seed weight (g)
Plant m^{-2}				
D_1	19.10 b	573.00 c	68.55 b	3.19 b
D_2	21.09 a	896.50 a	69.75 a	3.28 a
D_3	17.93 c	843.70 b	67.25 c	3.17 b
$LSD_{0.05}$	0.754	13.51	1.180	0.054
Source-sink manipulation				
M_0	17.19 c	681.40 c	68.34 ab	3.10 d
M_1	25.51 a	1010.33 a	69.62 a	3.35 a
M_2	15.38 d	622.73 d	67.32 b	3.18 c
M_3	19.41 b	769.80 b	68.79 a	3.25 b
$LSD_{0.05}$	0.870	15.60	1.363	0.062
Plant m^{-2}× Source-sink manipulation				
D_1M_0	17.13 e	513.90 g	68.30 a-d	3.04 f
D_1M_1	25.61 b	768.30 d	69.88 ab	3.33 b
D_1M_2	14.25 g	427.50 h	67.01 cd	3.14 d-f
D_1M_3	19.41 d	582.30 f	69.00 a-d	3.24 b-d
D_2M_0	19.22 d	768.80 d	69.68 a-c	3.15 d-f
D_2M_1	28.38 a	1135.20 a	70.66 a	3.450 a
D_2M_2	15.33 fg	613.20 e	68.64 a-d	3.21 c-e
D_2M_3	21.44 c	857.60 b	70.03 ab	3.30 bc
D_3M_0	15.23 fg	761.50 d	67.04 cd	3.11 ef
D_3M_1	22.55 c	1127.5 a	68.33 a-d	3.28 bc
D_3M_2	16.55 ef	827.5 c	66.30 d	3.18 c-e
D_3M_3	17.39 e	869.50 b	67.35 b-d	3.20 c-e
$LSD_{0.05}$	1.507	27.01	2.360	0.1071
CV(%)	9.44	8.68	6.49	7.33

Here,

D_1 = 30 plants m^{-2}

D_2 = 40 plants m^{-2}

D_3 = 50 plants m^{-2}

M_0 = No removal

M_1 = Removal of lower empty leaves, lower empty branches and top of the inflorescence

M_2 = Removal of all branches

M_3 = Removal of lower empty leaves and lower empty branches

4.3 Yield

4.3.1 Yield plant^{-1}

4.3.1.1 Effect of plant density

Yield plant^{-1} (g) was significantly influenced by population density of the plants (Table 8 and Appendix X). It was observed that D_1 (30 plants m-^{2}) showed the highest yield plant^{-1} (4.65 g). On the other hand the lowest yield plant^{-1} (2.41 g) was recorded with D_3 (50 plants m-^{2}). The result obtained from D_2 (40 plants m-^{2}) showed intermediate results compared to all other population density. Similar result was supported by Hashem and Hamid (1996) and Channabasavanna *et al.,* 1992.

4.3.1.2 Effect of source-sink manipulation

Source-sink manipulation of sesame had the great influence on yield plant^{-1} (g) (Table 8 and Appendix X). It was observed that M_1 (removal of lower empty leaves, lower empty branches and top of the inflorescence) showed the highest yield plant^{-1} (4.17 g). On the other hand the lowest yield plant^{-1} (3.04 g) was recorded with M_0 (no removal). The result obtained from all other source-sink manipulation effect showed intermediate result compared to the highest and lowest result.

4.3.1.3 Interaction effect of population density and source-sink manipulation

The interaction effect of population density and source-sink manipulation on yield plant^{-1} (g) had significant effect (Table 8 and Appendix X). It was observed that the highest yield plant^{-1} was recorded with the treatment combination of D_1M_1 (**5.17 g**). On the other hand the lowest yield plant^{-1} (1.96 g) was recorded with the treatment combination of D_3M_0. The results obtained from all other treatment combinations were significantly different compared to highest and lowest results.

4.3.2 Total yield (kg ha^{-1})

4.3.2.1 Effect of plant density

Total yield (kg ha^{-1}) was significantly influenced by population density of the plants (Table 8 and Appendix X). It was observed that D_2 (40 plants m^{-2}) showed the highest yield (1445.65 kg ha^{-1}). On the other hand the lowest yield (1205.29 kg ha^{-1}) was recorded with D_3 (50 plants m-^{2}). The result obtained from D_1 (30 plants m-^{2}) showed intermediate results compared to all other population density. The similar trends were observed in barley by Baker and Briggs (2007), Nandita *et al.* (2007) and Saharia and Thakuria (1988).

4.3.2.2 Effect of source-sink manipulation

Source-sink manipulation of sesame had the great influence on total yield (kg ha^{-1}) (Table 8 and Appendix X). It was observed that M_1 (removal of lower empty leaves, lower empty branches and top of the inflorescence) showed the highest yield (1595.82 kg ha^{-1}). On the other hand the lowest yield (1145.95 kg ha^{-1}) was recorded with M_0 (no removal). The result obtained from all other source-sink manipulation effect showed intermediate result compared to the highest and lowest result. Similar result was obtained by Karadogan and Akgün, 2009.

4.3.2.3 Interaction effect of population density and source-sink manipulation

The interaction effect of population density and source-sink manipulation on total yield (kg ha^{-1}) had significant effect (Table 8 and Appendix X). It was observed that the highest yield was recorded with the treatment combination of D_2M_1 (1725.45 kg ha^{-1}). On the other hand the lowest yield (980.50 kg ha^{-1}) was recorded with the treatment combination of D_3M_0. The results obtained from all other treatment combinations were significantly different compared to highest and lowest results. The similar trends were observed in mustard by Xinhua and Tony (2004).

4.3.3 Stover yield

4.3.3.1 Effect of plant density

Stover yield was significantly influenced by population density of the crop (Table 8 and Appendix X). It was observed that D_3 (50 plants m-^{2}) showed the highest stover yield (2424.88 kg ha^{-1}) which was not significantly different from D_2 (40 plants m-^{2}). On the other hand the lowest stover yield (2271.28 kg ha^{-1}) was recorded with D_1 (30 plants m-^{2}).

4.3.3.2 Effect of source-sink manipulation

Source-sink manipulation of sesame had the great influence on stover yield (Table 8 and Appendix X). It was observed that M_1 (removal of lower empty leaves, lower empty branches and top of the inflorescence) showed the highest stover yield (2551.28 kg ha^{-1}). On the other hand the lowest stover yield (2312.86 kg ha^{-1}) was recorded with M_2 (removal of all branches). The result obtained from all other source-sink manipulation effect showed intermediate result compared to the highest and lowest result.

4.3.3.3 Interaction effect of population density and source-sink manipulation

The interaction effect of population density and source-sink manipulation on stover yield (kg ha^{-1}) had significant effect (Table 8 and Appendix X). It was observed that the highest stover yield was recorded with the treatment combination of D_3M_1 (2598.20 kg ha^{-1}). On the other hand the lowest stover yield (2201.80 kg ha^{-1}) was recorded with the treatment combination of D_1M_2. The results obtained from all other treatment combinations were significantly different compared to highest and lowest results.

4.3.4 Harvest Index

4.3.4.1 Effect of plant density

Harvest Index was significantly influenced by population density of the crop (Table 8 and Appendix X). It was observed that the highest Harvest Index (37.98) was found with D_1 (30 plants m^{-2}) which was not significantly different from D_2 (40 plants m-^{2}). On the other hand the lowest Harvest Index (32.87) was recorded with D_3 (50 plants m-^{2}). These results are in general agreement with those of Saharia and Thakuria (1988).

4.3.4.2 Effect of source-sink manipulation

Source-sink manipulation of sesame had the great influence on Harvest Index (Table 8 and Appendix X). It was observed that M_1 (removal of lower empty leaves, lower empty branches and top of the inflorescence) showed the highest Harvest Index (38.99). On the other hand the lowest Harvest Index (32.98) was recorded with M_0 (no removal). The result obtained from all other source-sink manipulation effect showed intermediate result compared to the highest and lowest result.

4.3.4.3 Interaction effect of population density and source-sink manipulation

The interaction effect of population density and source-sink manipulation on Harvest Index had significant effect (Table 8 and Appendix X). It was observed that the highest Harvest Index (40.72) was recorded with the treatment combination of D_2M_1 which was significantly similar with D_1M_1 and D_1M_2. On the other hand the lowest Harvest Index (29.36) was recorded with the treatment combination of D_3M_0 which was significantly similar with D_3M_2. The results obtained from all other treatment combinations were significantly different compared to highest and lowest results. These results are in general agreement with those of Xinhua and Tony (2004).

Table 8. Effect of population density and source-sink manipulation and their interaction on yield parameters of sesame

Treatments	Yield plant^{-1} (g)	Total yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Harvest Index
Plant m^{-2}				
D_1	4.65 a	1394.99 b	2271.28 b	37.98 a
D_2	3.61 b	1445.65 a	2418.46 a	37.28 a
D_3	2.41 c	1205.29 c	2424.88 a	32.87 b
$LSD_{0.05}$	0.054	14.99	8.410	1.649
Source-sink manipulation				
M_0	3.04 d	1145.95 d	2468.23 c	32.98 c
M_1	4.17 a	1595.82 a	2551.28 a	38.99 a
M_2	3.46 c	1293.89 c	2312.86 d	35.90 b
M_3	3.56 b	1358.92 b	2538.61 b	36.30 b
$LSD_{0.05}$	0.062	17.300	12.871	1.904
Plant m^{-2}× Source-sink manipulation				
D_1M_0	4.04 e	1210.60 g	2257.20 i	34.91 cd
D_1M_1	5.17 a	1550.75 b	2338.40 f	39.88 ab
D_1M_2	4.88 b	1465.12 d	2201.80 j	39.96 ab
D_1M_3	4.51 c	1353.50 e	2287.70 h	37.17 a-c
D_2M_0	3.11 h	1246.75 f	2350.30 ef	34.66 cd
D_2M_1	4.31 d	1725.45 a	2511.83 b	40.72 a
D_2M_2	3.39 g	1355.80 e	2374.60 d	36.34 bc
D_2M_3	3.64 f	1454.60 d	2437.10 c	37.38 a-c
D_3M_0	1.96 k	980.50 i	2359.2 de	29.36 e
D_3M_1	3.02 h	1511.25 c	2598.20 a	36.38 bc
D_3M_2	2.12 j	1060.75 h	2318.40 g	31.39 de
D_3M_3	2.54 i	1268.65 f	2423.70 c	34.36 cd
$LSD_{0.05}$	0.107	29.97	16.82	3.298
CV(%)	8.91	6.28	7.88	9.22

Here,

D_1	=	30 plants m^{-2}	M_0	=	No removal
D_2	=	40 plants m^{-2}	M_1	=	Removal of lower empty leaves, lower empty branches and top of the inflorescence
D_3	=	50 plants m^{-2}	M_2	=	Removal of all branches
			M_3	=	Removal of lower empty leaves and lower empty branches

CHAPTER V

SUMMARY AND CONCLUSION

An experiment was conducted at the Sher-e-Bangla Agricultural University Farm Dhaka 1207 (Tejgaon series under AEZ No.28) during Kharif-1 (March – June), 2008 to study the yield performance of sesame in response to population density and source-sink manipulation. The soil was silty clay loam in texture having pH 6.16 and organic carbon content of 0.68%. Two factor randomized complete block design was followed with 12 treatments having unit plot size of 3 m x 1.5 m and replicated thrice. Two factors (A) population density and (B) source-sink manipulation were initiated. Three population densities viz. (1) 30 plants m^{-2} (D_1), (2) 40 plants m^{-2} (D_2) and (3) 50 plants m^{-2} (D_3) and four source-sink manipulation viz. (1) no removal (M_0), (2) removal of lower empty leaves, lower empty branches and top of the inflorescence (M_1), (3) removal of all branches (M_2) and (4) removal of lower empty leaves and lower empty branches (M_3) were comprised for the experiment. The treatment combinations were (i) D_1M_0 (30 plants m^{-2} + no removal), (ii) D_1M_1 (30 plants m^{-2} + removal of lower empty leaves, lower empty branches and top of the inflorescence), (iii) D_1M_2 (30 plants m^{-2} + removal of all branches), (iv) D_1M_3 (30 plants m^{-2} + removal of lower empty leaves and lower empty branches), (v) D_2M_0 (40 plants m^{-2} + no removal), (vi) D_2M_1 (40 plants m^{-2} + removal of lower empty leaves, lower empty branches and top of the inflorescence), (vii) D_2M_2 (40 plants m^{-2} + removal of all branches), (viii) D_2M_3 (40 plants m^{-2} + removal of lower empty leaves and lower empty branches), (ix) D_3M_0 (50 plants m^{-2} + no removal), (x) D_3M_1 (50 plants m^{-2} + removal of lower empty leaves, lower empty branches and top of the inflorescence), (xi) D_3M_2 (50 plants m^{-2} + removal of all branches) and (xii) D_3M_3 (50 plants m^{-2} + removal of lower empty leaves and lower empty branches).

Sesame seeds were sown on 11 March, 2008 and the crop was harvested on 27 May, 2008. The data were collected plot wise for plant height (cm), number of primary branches plant^{-1}, number of pods plant^{-1}, number of seeds pod^{-1}, weight of 1000-seed (g), grain yield (t ha^{-1}) and stover yield (t ha^{-1}) etc.

All the data were statistically analyzed following F-test and the mean comparison was made by DMRT. The results of the experiment are stated below.

Population density, source-sink manipulation and their interaction of sesame according to the experiment had significant effect on plant height (cm), number of branches plant^{-1}, leaf area index, dry weight plant^{-1}, dry weight m^{-2} (g), crop growth rate, number of capsules plant^{-1}, number of capsules m^{-2}, number of seeds capsule^{-1}, 1000 seed weight (g), yield plant^{-1} (g), total yield (kg ha^{-1}), stover yield (kg ha^{-1}) and harvest index.

Higher population showed increased plant height and here 50 plants m^{-2} (D_3) showed highest plant height (77.32 cm) at harvest and leaf area index (2.39) and dry weight m^{-2} (242.50 g) were also shown by this treatment. But incase of 30 plants m^{-2} (D_1) represented highest number of branches plant^{-1} (3.98), dry weight plant^{-1} (7.57 g), yield plant^{-1} (4.65 g) and harvest index (37.98). The Population density, 40 plants m^{-2} (D_2) showed highest crop growth rate (7.69), number of capsules plant^{-1} (21.09), number of seeds capsule^{-1} (69.75), number of capsules m^{-2} (896.50), 1000 seed weight (3.28 g) and total yield (1445.65 kg ha^{-1}). On the contrary the shortest plant (70.83 cm) at harvest, lowest leaf area index (1.91), dry weight m^{-2} (227.10 g), crop growth rate (6.90), number of capsules m^{-2} (573.00) and stover yield (2271.28 kg ha^{-1}) was found with 30 plants m^{-2} (D_1). The lowest number of branches plant^{-1} (2.71), dry weight plant^{-1} (4.85 g), number of capsules plant^{-1} (17.93), number of seeds capsule^{-1} (67.25), 1000 seed weight (3.17 g), yield plant^{-1} (2.41 g), total yield (1205.29 kg ha^{-1}) and harvest index (32.87) was obtained by 50 plants m^{-2} (D_3). But incase of 40 plants m^{-2} (D_2), there was lowest result was obtained.

The factor affecting source-sink manipulation on plant height (cm), number of branches plant^{-1}, leaf area index, dry weight plant^{-1}, dry weight m^{-2} (g), crop growth rate, number of capsules plant^{-1}, number of capsules m^{-2}, number of seeds capsule^{-1}, 1000 seed weight (g), yield plant^{-1} (g), total yield (kg ha^{-1}), stover yield (kg ha^{-1}) and harvest index. The tallest plant (75.27 cm) was obtained with M_2 (removal of all branches) where the shortest plant (72.25 cm) from M_0 (no removal) treatment. But incase of the highest number of branches plant^{-1} (4.56), leaf area index (2.47), dry weight plant^{-1} (6.42 g), dry weight m^{-2} (248.30 g), crop growth rate (7.78), number of capsules plant^{-1} (25.51), number of capsules m^{-2} (1010.33), number of seeds capsule^{-1} (69.62), 1000 seed weight (3.35 g), yield plant^{-1} (4.17 g), total yield (1595.82 kg ha^{-1}), stover yield (2551.28 kg ha^{-1}) and harvest index (38.99) were obtained from M_1 (removal of lower empty leaves, lower empty branches and top of the inflorescence) treatment. On the other hand the lowest leaf area index (1.69), dry weight plant^{-1} (5.97 g), dry weight m^{-2} (229.80 g), crop growth rate (7.11), number of capsules plant^{-1} (15.38), number of capsules m^{-2} (622.73), number of seeds capsule^{-1} (67.32), 1000 seed weight (3.18 g), stover yield (2342.86 kg ha^{-1}) and harvest index (35.90) were obtained with M_2 (removal of all branches) but the lowest yield plant^{-1} (3.04 g) and total yield (1145.95 kg ha^{-1}) were obtained with M_0 (no removal).

Plant height (cm), number of branches plant^{-1}, leaf area index, dry weight plant^{-1}, dry weight m^{-2} (g), crop growth rate, number of capsules plant^{-1}, number of capsules m^{-2}, number of seeds capsule^{-1}, 1000 seed weight (g), yield plant^{-1} (g), total yield (kg ha^{-1}), stover yield (kg ha^{-1}) and harvest index were also significantly affected by different interaction effect of plant density and source-sink manipulation. The tallest plant (78.26 cm) was produced by the combined effect of D_3M_2 **(**50 plants m^{-2} + removal of lower empty leaves, lower empty branches and top of the inflorescence**)** and the smallest (69.89 cm) by D_1M_0 **(**30 plants m^{-2} + no removal**)**. The highest number of branches plant^{-1} (5.78), dry weight plant^{-1} (7.79 g) and yield plant^{-1} (5.17 g) was recorded with the combined effect of D_1M_1 **(**30 plants m^{-2} + removal of lower empty leaves, lower empty branches and top of the inflorescence**)** but the highest leaf area index (2.68), dry weight m^{-2} (259.80 g), crop growth rate (8.20) and stover yield (2598.20 kg ha^{-1}) were found with D_3M_1 (50 plants m^{-2} + removal of lower empty leaves, lower empty branches and top of the inflorescence). The lowest leaf area index (1.53), dry weight m^{-2} (220.20 g), crop growth rate (6.75) and stover yield (2201.80 kg ha^{-1}) were recorded with the combined effect of D_1M_2 **(**30 plants m^{-2} + removal of all branches**)**.

In case of highest number of capsules $plant^{-1}$ (28.38), number of capsules m^{-2} (1135.20), number of seeds $capsule^{-1}$ (70.66), 1000 seed weight (3.45 g), total yield (1725.45 kg ha^{-1}) and harvest index (40.72) were obtained with the combined effect of D_2M_1 **(**40 plants m^{-2} + removal of lower empty leaves, lower empty branches and top of the inflorescence**)**.

But the lowest number of capsules m^{-2} (427.50), number of seeds $capsule^{-1}$ (66.30) and total yield (1060.75 kg ha^{-1}), 1000 seed weight (3.04 g), harvest index (29.36) respectively were obtained with the combined effect of D_1M_1 **(**30 plants m^{-2} + removal of lower empty leaves, lower empty branches and top of the inflorescence**)**, D_3M_2 **(**50 plants m^{-2} + removal of all branches**)**, D_1M_0 **(**30 plants m^{-2} + no removal**)** and D_3M_0 **(**50 plants m^{-2} + no removal**)** respectively.

Considering all the parameters studied the following conclusion may be drawn-

- The effective population density on growth and yield performance of sesame was observed by the population density, D_2 (40 plant m^{-2}) treatment.
- The effective source-sink manipulation on growth and yield performance of sesame was observed by the source-sink manipulation, M_1 (removal of lower empty leaves, lower empty branches and top of the inflorescence) treatment.
- The effective interaction effect on growth and yield performance of sesame was observed by the combined effect of, D_2M_1 (40 plants m^{-2} + removal of lower empty leaves, lower empty branches and top of the inflorescence) treatment.

Based on the results of the present study, the following recommendation may be drawn-

- The combined application of 40 plants m^{-2} with removal of lower empty leaves, lower empty branches and top of the inflorescence may be done in Tejgaon series under AEZ No. 28 to get higher yield and yield performance of sesame.

However, to reach a specific conclusion and recommendation, more research work on sesame should be done in different Agro-ecological zones of Bangladesh.

CHAPTER VI

LITERATURE CITED

Alan T. W. and David J. B. (2006). Soybean Yield Reductions Caused by Defoliation during Mid to Late Seed Filling. Dep. of Entomology, Louisiana Agric. Exp. Stn., LSU Agric. Ctr., Baton Rouge, LA 70803. Approved for publication by the Director of the Louisiana Agric. Exp. Stn. as manuscript no. 94-09-8012.

Alkio, M.A., Schubert, W., Diepenbrock and Grimm E. (2003). Effect of source–sink ratio on seed set and filling in sunflower (*Helianthus annuus* L.). Martin-Luther-Universität Halle–Wittenberg, Landwirtschaftliche Fakultät, Institut für Acker- und Pflanzenbau, Ludwig-Wucherer-Str. 2, D−06099 Halle (Saale), Germany.

Asian Vegetable Research and Development Center (AVRDC). (1974). Mungbean Annual Report for 1973. AVRDC. Shanhua, Tanian, Taiwan.

Babu, K.S and Mitra, S.K. (1989). Effect of planting density on grain yield of maize doing rabi season. *Madras Agric. J.* **76**: 292.

Baker, R.J. and Briggs, K.G. (2007). Effects of Plant Density on the Performance of 10 Barley Cultivars. Crop Development Ctr., Univ. of Saskatchewan, Saskatoon, Sask. S7N 0W0, and professor, Dep. of Plant Science, Univ. of Alberta, Edmonton, Alta. T6G 2H1, respectively.

Barimavandi, A. R., Sedaghathoor S., and Ansari, R. (2008). Effect of Different Defoliation Treatments on Yield and Yield Components in maize (*Zea mays* L.) Cultivar of S.C704. Agriculture College, Islamic Azad University, Rasht Branch, Rasht, Iran.

BBS (Bangladesh Bureau of Statistic). (2009). Statistical Year Book of Bangladesh. Statistics Division, Ministry of planning, Dhaka, Bangladesh.

Board, J.E., Harville, B.G. and Sexton, A.M. (1990). Growth dynamics of determinate soybean in narrow and wide rows at late planting date. Field Crop Res. 25: 203-213.

Breure, C. J., Menendez, T. and Powell, M. S. (2007). The Effect of Planting Density on the Yield Components of Oil Palm (*Elaeis Guineensis*)**.** Dami Oil Palm Research Station, Kimbe, West New Britain, Papua New Guinea. PNG Oil Palm Research Association, PO Box 97, Kimbe, West New Britain, Papua New Guinea.

Brian, R. and James, E. B. (2006). Identification of Soybean Cultivars That Yield Well at Low Plant Populations. Texas Cooperative Extension Service, Texas A&M University, 300 School Street, Rm. 101, Madisonville, TX 77864. Dep. of Agronomy, Louisiana Agric. Exp. Stn., LSU Agric. Ctr., Baton Rouge, LA 70803.

Campbell, D.C. and Kondra, Z.P. (1978). Relationship among growth pattern, yield components and yield of rape seed. *Canad. J. plant Sci*. **58**: 87-93.

Channabasavanna, A.S. and Setty, R.A. (1992). Response of sesame *(Sesamum indicum L.)* genotypes to plant densities under summer conditions. Indian J. Agron. 37(3): 601.

Cheu, C.L. and F.J.M. Sung. 1982. Effect of source-sink manipulation on nitrogen fixation in mungbean. Field crop Res., 5:225-231.

Chopra, R.K. and Sinha, S.K. (1987). The chickpea, physiological aspect of growth and yield, CAB international, ICRISAT, India. P, 163-180.

Clifford, P.E. (1979). Source limitation of sink yield in mungbeans. Annals of Botany **43**: 397-399.

Dean F. M. and Orland A. K. (2000). Response of Soybeans to Leaf and Pod Removal. Publication No. 308 of the U. S. Regional Soybean Laboratory, Urbana, Illinois. Department of Agronomy, University of Arizona; and Chemist, USDA, ARS, Crops Research Division.

Egli, D. B. (2004). Plant Density and Soybean Yield. Dep. of Agronomy, Univ. of Kentucky, Lexington, KY 40546-0091. Contribution from the Kenctuky Agric. Aexp. Stn. This paper is published with the approval of the director of the Kentucky Agric. Exp. Stn.

Egli, D. B. and Bruening, W. P. (2001). Source-sink Relationships, Seed Sucrose Levels and Seed Growth Rates in Soybean. Department of Agronomy, University of Kentucky, Lexington, KY 40546-0091, USA. Received: 17 January 2001 Returned for revision: 8 March 2001 Accepted: 8 April 2001 Published electronically 25 June 2001.

Egli, D. B. and Leggett, J. E. (2006). Rate of Dry Matter Accumulation in Soybean Seeds with Varying Source-Sink Ratios. Dep. of Agronomy, Univ. of Kentucky, Lexington, KY 40506. Contribution from the Dep. of Agronomy, Kentucky Agric. Exp. Stn. Lexington. This paper (75-3-36) is published with the approval of the Director of the Kentucky Agric. Exp. Stn.

Evans, E. (1983). Effect of leaf removal on the growth of winter oil seed rape (*Brassica napus* L.). p. 104-109. In: Proc. Intl. Rapeseed Conference, Paris, 17-19 May, 1983.

Evans, D.H., (1989). Effect of sink removal on photosynthesis and senescence in leaves of soybean *(Glycine max* L.)Plant physiol. 61:394-397.

FAO (Food and Agricultural Organization of the United Nations), Italy, Rome. (2008).

FAO (Food and Agricultural Organization of the United Nations), Italy, Rome. (2007).

FAO (Food and Agriculture Organization). (1988). Land resources Appraisal of Bangladesh for Agricultural development. Report 2. Agroecological Regions of Bangladesh. P. 212-221.

Ghungarde, S.R., Chavan, D.A., Alse, U.N., Yeasgaonkar, G.V.and Pangarkar, V.N. (1992). Effect of planting density and variety on yield of sesame *(Sesamum indicum L.). Indian J. Agro*. **37**(2) : 385.

Hamid, A.M., Islam, T. and Hashem, A. (1991). Effect of defoliation on the yield performance of rapeseed *Brassica campestries* L. *J. Asiat. Soc. Bangladesh Sci*. **17**: 89-91.

Hashem, A. and Hamid A. (1996). Canopy structure, light interception and productivity of three mungbean varieties, pp. 83-91. In Asthana, A.N. and D.H. Kim (eds.) Recent Advances in mungbean Research. ISPR, IIPR, Kanpur, India.

Hicks, D.R. and Pendleton, J.W. (1969). Effect of floral bud removal on performance of soybeans. *Crop Sci*. **9**: 435-437.

Hintz, W. and Fehr, R. (1990). Plant Density and Defoliation effect on the Recovery of Soybean Injured by Stem cut off During Vegetative Development. Agron. J. 82: 57-59.

Ho, L.C. (1992). The possible effects of Sink demand for assimilate on photosynthesis, pp. 729-736.

Hossain, M.A. and Salahuddin, A.B.M. (1994). Growth and yield of sesame in relation to population density. *Bangladesh J. of Life Sciences*. vo1. **6(**1): 5965.

Hossain, M.A., Begum, S. Arabinda, S. and Salahuddin, A.B.M. (1995). Study on the stages of development, growth and yield of sesame as influenced by Nitrogen. *Bangladesh J. Sci*. **3**(1): 11-20.

Howlader, M.A.H. (1995). Influence of source- manipulation on photosynthesis and dry matter partitioning in mungbean. M.S in Agronomy. Session 1988-89. Bangladesh Agricultural University, Mymonsingh.

Islam, N. (1992). Canopy structure, dry matter production and light interception in *brassica* species grown at oaring population densities. An unpublished thesis of Agronomy. Submitted to Bangladesh Agricultural University Mymensingh. June. 1992.

Jahan, M.S. (1998, summer). Allometry, Resource Allocation and yield in Mungbean: Effect of population density and planting configuration. Thesis of M.S. in Agronomy. Submitted to Institute of Postgraduate Studies in Agriculture, Gazipur. pp. 22-29.

Jason L., Bruin. D. and Palle P. ().New and Old Soybean Cultivar Responses to Plant Density and Intercepted Light. Dep. of Agronomy, Iowa State Univ., 2104 Agronomy Hall, Ames, IA 50011-1010.

Karadogan, T. and Akgün, I. (2009). Effect of leaf removal on sunflower yield and yield components and some quality characters. Süleyman Demirel University, Faculty of Agriculture, Department of Field Crops, 32260 Isparta, Turkey.

Kaul, AX and Das. M.L. (1986). Oilseeds in Bangladesh. Bangladesh-Canada-Agriculture Sector, team, Ministry of Agriculture, The Government of the people's republic of Bangladesh, P. 63.

Koller, E.A., Sandsted, R.F., Wallace, D.H., and Wien, H.G. (1975). Does variation in photosynthetic rate explain variation in growth rate and yield? *Netherlands J. of Agric. Sci.* **35**: 505519.

Liyanage, M.D.S. and McWillium, J.R. (1981). Effect of irradiance on the reproductive potential of mungbean plants *(Vigna radiata L.* Wilczek). Legume research **4**(2): 71-77.

Mackenzie, D.R., Chen, N.C., Liou, T.D., Henry, B.F.Wu and Oyer, E.B.. (1975). Response of Mungbean and Soybean to increasing planting *density. J. Amer. Soc. Hort. Sci.* **100**(5): 579-583.

Malcolm, J. M., Harvey D.V. and Elroy R. C. (2000). Agronomic changes from variation of plant densities incase of growth factors of short-season soybean cultivars in Canada. Agric. and Agri-Food Canada, Eastern Cereal and Oilseed Res. Cent., Central Exp. Farm, K.W. Neatby Bldg., Ottawa, ON, Canada, K1A 0C6.

Miah, A.M.M. (1988). Growth, yield and seed quality of two snapbean *(Phaseolus vulgaris L.)* variety as affected by irrigation frequency and fertilizer materials. Ph.D. Thesis.

Mukand, S., Brar, Z.S. and Shah, M.L. (1987). Effect of growth regulators in relation to sowing date and seed rate in wheat. Indian Journal of Ecology. **14**(1): 47-55.

Murty, K.S. and Venkateswaralu, B. (1978). Physiological constraints on growth and produtivity in rice during kharif season. IRRI, Cuttack. pp: 45-65.

Nakatani, H. Koide, K. and Ishihara, K. (1992). Effect of ear removal on dry matter production, its partitioning and photosynthesis in rice. Vol. iv : 25-28.

Nandita R. S., Abdullah, M. Mamun, H. and Jahan, S. (2009). Yield Performance of Sesame *(Sesamum Indicum* L.) Varieties at Varying Levels of Row Spacing. Agrotechnology Discipline, Khulna University, Khulna, Bangladesh.

Parvez, M.M. (1992). Effect of clipping at different stages of growth on the performance of grasspea *(Lathyrus sativus L.).* M.S in Agronomy. Session, 1986-87. B.A.U.

Pommer, G., Moritiz, M.B. and Fink K. (1984). Effect of an improvement of light penetration in faba bean canopies through leaf removal on pod survival and yield. Z. Acker pflanzenbau. **153**: 352-365.

Radford, P.J. (1967). Growth analysis of the soybean community. Crop Sci. 10: 407-412.

Rahman, M.H. (1997, winter). Influence of irrigation and planting density on growth and seed yield in edible-podded pea. Thesis of M.S., in Agronomy. Submitted to Institute of Postgraduate Studies in Agriculture. Guzipur.

Reddy, N.M., Havanagari, G.V. and Hedge, B.R. (1978). Effect of soil moisture level and geometry of planting on the yield and water use of groundnut, *Mysore J. Agric. Sci.* **12** (1), 50-55.

Ricardo, A. R. and Gustavo, A. M. (2005). Sunflower Seed Weight and Oil Concentration under Different Post-Flowering Source-Sink Ratios. Dep. de Producción Vegetal, Fac. de Agronomía, Univ. de Buenos Aires, Av. San Martín 4453, Ciudad de Buenos Aires (C1417DSE), Argentina.

Rob A. P. and Seth L. N. (2008). Pod Removal, Shade, and Defoliation Effects on Soybean Yield, Protein, and Oil. Research and Promotion Council and the Minnesota Agricultural Experiment Station. Dep. of Agronomy and Plant Genetics, Univ. of Minnesota, 411 Borlaug Hall, Upper Buford Cir., St. Paul, MN 55108.

Rob Owen, Pittsburgh Post-Gazette (2006). TV Review: Sesame Street travels the world. Sunday, October 22, 2006.

Ross, U.K. (1975). Solar radiation and architecture of canopy surface, Moscow, Nanka Publishers, 1975. 343p.

Rowden, R., Gardener, D., Whitman, D.C. and F.S. Wallus. (1981). Effect of planting density on growth, light interception and yield of photoperiod insensitive pigeonpea *(Cajanus cajan).* Field crops Res. 4. 201-213.

Saharia, D. and Thakuria, T.M. (1988). Effect of plant density and spatial arrangement on seed yield of cowpea *(Vigna unguiculata* L. Walp). *J. Amer. Hort. Sci*. **100**(5): 467-470.

Singh, V.K. and Yadav, D.S. (1987). Effect of sowing date and plant density on dwarf field peas. *Indian J. Agron*. **34**(1): 92-95.

Tanaka, H.S. (1992). Effect of flower and gynophore removal on the biomass partitionong in various vegetative and reproductive parts in groundnut *(Araches hypogaea L.). Indian J. Plant Physiol.*, Vol. xxxv, No. 2, pp. 125-129.

Tomar, D.P.S., Dhargava, S.C. and Dhaka, R.P.S. (1992). Productivity of seasame cultivars under oaring plant population. *Indian J. Plant Physiol.*, Vol. xxxv, No. 3, pp. 283-244.

Willey, R.W. and S.B. Health. (1969). The quantitative relationships between plant population and crop yield. Adv. in Agron. 21: 281-321.

Xinhua Y. and Tony J. V. (2004). Relationships of plant density and source-sink application with nitrogenous effect for oil, and protein in seed with yield of mustard. Mid-Columbia Agric. Res. and Ext. Cent., Oregon State Univ., Hood River, OR 97031-9512. Dep. of Agron., Purdue Univ., West Lafayette, IN 47907-2054.

Yadav, R.P., Chauhan, D.V.S. and Kushwalla, H.S. (1993). Effect of irrigation, Phosphorus and row spacing on physiological characters of pea *(Pisium sativum L.). Indian J. Agron*. **38**(1):25-27.

Zaman, S.M.H. (1986). Current status and prospects for rained foodgrain production in Bangladesh. BRRI Pub. No. 75. p. 56.

Zubriski, J. C. and Zimmerman D. C. (2004). Effects of Nitrogen, Phosphorus, and Plant Density on Sunflower. Contribution from the Departments of Soils and Biochemistry, North Dakota State University, Fargo, ND 58102. North Dakota State University of Agriculture and Applied Science, Fargo, ND 58102; and Research Chemist, ARS-USDA.

APPENDICES

Appendix I. Morphological, physical and chemical characteristics of the soil

A. Morphological characteristics

AEZ	:	Madhupur Tract (AEZ 28)
General Soil Type	:	Deep Red Brown Terrace Soils
Drainage	:	Moderate
Topography	:	Medium low land
Flood level	:	Above flood level

B. Physical characteristics

% Sand	:	36.45
% Silt	:	25.55
% Clay	:	38.00
Textural class	:	Clay loam

C. Chemical characteristics

Characteristics	Content	Interpretation
pH (soil : water=1:2.5)	5.62	Acidic
Organic matter (%)	1.37	Medium low
Total N (%)	0.078	Low
Available P (µg/ g)	9.92	Low
Available K (c mol /kg)	0.087	Low
Available S (µg /g)	14.35	Low
Available Zn (µg /g)	0.70	Low
Available B (µg /g)	0.19	Low

Source: BARC, 2008

Appendix II. Monthly records of air temperature, relative humidity, rainfall and sunshine hours during the period from March 2008 to May 2008

Year	Month	Air temperature (^{0}C)			Relative humidity (%)	Rainfall (mm)	Sunshine (h)
		Maximum	Minimum	Mean			
2008	March	32.20	21.80	27.00	66.69	66.70	155.0
	April	34.44	23.96	29.20	68.08	90.01	253.0
	May	33.23	24.11	28.67	86.13	297.9	96.00
	June	35.12	27.24	31.18	90.24	302.6	132.0

Source: Bangladesh Meteorological Department (Climate division), Dhaka-1212.

Appendix III. Effect of population density and source-sink manipulation and their interaction on plant height of sesame at different days after sowing

Plant height							
Source of variation	**Degrees of Freedom**	**Mean square value**					
		20 DAE	**30 DAE**	**40 DAE**	**50 DAE**	**60 DAE**	**At harvest**
Replication	2	0.348	0.551	1.274	0.585	0.778	0.314
Population density (D)	2	NS	37.301*	86.675*	150.028*	142.208*	128.51*
Source-sink manipulation (M)	3	NS	4.799*	11.011*	16.786*	19.964*	15.843*
D × M	6	NS	0.184**	0.291**	2.129*	1.285*	1.455*
Error	22	0.097	1.863	2.289	3.503	1.312	1.837

Appendix IV. Effect of population density and source-sink manipulation and their interaction on number of branches plant^{-1} of sesame at different days after sowing

Number of branches/plant					
Source of variation	**Degrees of Freedom**	**Mean square value**			
		30 DAE	**40 DAE**	**50 DAE**	**60 DAE**
Replication	2	0.002	0.003	0.008	0.001
Population density (D)	2	0.542*	0.356*	4.850*	5.275*
Source-sink manipulation (M)	3	7.809*	17.406*	24.292*	41.986*
D × M	6	0.060*	0.040*	0.572*	0.657*
Error	22	0.013	0.018	0.012	0.016

Appendix V. Effect of population density and source-sink manipulation and their interaction on leaf area index of sesame at different days after sowing

Leaf Area Index							
Source of variation	**Degrees of Freedom**	**Mean square value**					
		20 DAE	**30 DAE**	**40 DAE**	**50 DAE**	**60 DAE**	**At harvest**
Replication	2	0.001	0.007	0.002	0.007	0.012	0.001
Population density (D)	2	NS	0.273*	0.288*	0.769*	0.270*	0.347*
Source-sink manipulation (M)	3	NS	0.197*	0.619*	1.054*	0.645*	0.222*
D × M	6	NS	0.002**	0.012*	0.017*	0.007**	0.005**
Error	22	0.002	0.012	0.022	0.033	0.026	0.016

Appendix VI. Effect of population density and source-sink manipulation and their interaction on dry weight plant^{-1}of sesame at different days after sowing

Dry weight plant^{-1} (g)							
Source of variation	**Degrees of Freedom**	**Mean square value**					
		20 DAE	**30 DAE**	**40 DAE**	**50 DAE**	**60 DAE**	**At harvest**
Replication	2	0.002	0.007	0.005	0.001	0.004	0.011
Population density (D)	2	0.590*	1.053*	8.029*	16.555*	21.167*	22.258*
Source-sink manipulation (M)	3	0.086*	0.273*	0.552*	0.394*	0.353*	0.356*
D × M	6	0.005**	0.305*	0.032*	0.028*	0.013**	0.014**
Error	22	0.011	0.014	0.018	0.009	0.005	0.021

Appendix VII. Effect of population density and source-sink manipulation and their interaction on dry weight m^{-2} of sesame at different days after sowing

Dry weight/m2							
Source of variation	**Degrees of Freedom**	**Mean square value**					
		20 DAE	**30 DAE**	**40 DAE**	**50 DAE**	**60 DAE**	**At harvest**
Replication	2	14.043	4.563	21.126	29.989	74.552	67.176
Population density (D)	2	199.99*	216.92*	258.590*	211.875*	890.470*	906.074*
Source-sink manipulation (M)	3	46.172*	85.28*	96.449*	65.919*	97.585*	68.082*
D × M	6	15.306*	55.14*	110.501*	135.707*	48.856*	51.159*
Error	22	3.209	3.608	4.175	3.737	2.679	3.714

Appendix VIII. Effect of population density and source-sink manipulation and their interaction on crop growth rate of sesame at different days after sowing

Crop growth rate					
Source of variation	**Degrees of Freedom**	**Mean square value**			
		30 DAE	**40 DAE**	**50 DAE**	**60 DAE**
Replication	2	0.013	0.001	0.212	0.012
Population density (D)	2	2.424*	2.120*	0.844*	NS
Source-sink manipulation (M)	3	1.114*	0.787**	1.147*	NS
D × M	6	0.128*	0.107*	0.346**	NS
Error	22	0.064	0.116	0.255	0.141

Appendix IX. Effect of population density and source-sink manipulation and their interaction on different yield contributing characters of sesame

Source of variation	**Degrees of Freedom**	**Mean square value**			
		Number capsules plant^{-1}	**Number of capsules m^{-2}**	**Number of seeds capsule^{-1}**	**1000 seed weight (g)**
Replication	2	2.585	72.854	7.348	0.023
Population density (D)	2	30.681*	3614.159*	18.720*	0.031**
Source-sink manipulation (M)	3	175.281*	2618.080*	8.317*	0.104**
D × M	6	7.685**	109.132*	0.177**	0.004**
Error	22	0.792	25.472	1.943	0.004

Appendix X. Effect of population density and source-sink manipulation and their interaction on yield parameters of sesame

Source of variation	**Degrees of Freedom**	**Mean square value**			
		Yield plant^{-1} (g)	**Total yield (kg ha^{-1})**	**Stover yield (kg ha^{-1})**	**Harvest Index**
Replication	2	0.016	27.750	111.028	0.323
Population density (D)	2	15.080*	1926.580*	9059.17*	91.931*
Source-sink manipulation (M)	3	1.954*	3158.120*	6092.75*	54.588*
D × M	6	0.113**	220.542*	510.12*	5.833*
Error	22	0.004	31.295	19.664	3.794