

**“EFFECT OF SPACING AND FERTILIZERS ON
GROWTH, HERBAGE AND OIL YIELD OF
MINT (*Mentha viridis* L.) IN RED SANDY LOAM
SOILS OF COASTAL ANDHRA PRADESH”**

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**MASTER OF SCIENCE IN HORTICULTURE
(PLANTATION, SPICES, MEDICINAL AND AROMATIC CROPS)**



**DEPARTMENT OF PLANTATION, SPICES, MEDICINAL AND
AROMATIC CROPS**

**HORTICULTURAL COLLEGE AND RESEARCH INSTITUTE,
VENKATARAMANNAGUEM, WEST GODAVARI – 534 101**

Dr. Y. S. R. HORTICULTURAL UNIVERSITY

JULY, 2016

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BY

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B.Sc. (Hons.) Horticulture**

**THESIS SUBMITTED TO Dr. Y.S.R. HORTICULTURAL
UNIVERSITY IN PARTIAL FULFILMENT OF THE
REQUIREMENT FOR THE AWARD OF THE DEGREE OF**

**MASTER OF SCIENCE IN HORTICULTURE
(PLANTATION, SPICES, MEDICINAL AND AROMATIC CROPS)**



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JULY, 2016

CERTIFICATE

Ms. DEGALA MANJUSHA has satisfactorily prosecuted the course of research and that the thesis entitled “**EFFECT OF SPACING AND FERTILIZERS ON GROWTH, HERBAGE AND OIL YIELD OF MINT (*Mentha viridis* L.) IN RED SANDY LOAM SOILS OF COASTAL ANDHRA PRADESH**” is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination.

I certify that neither the thesis nor its part thereof has been previously submitted by her for a degree of any university.

Date:

Place: Venkataramannagudem

(D. V. SWAMI)

CHAIRMAN

CERTIFICATE

This is to certify that the thesis entitled “**EFFECT OF SPACING AND FERTILIZERS ON GROWTH, HERBAGE AND OIL YIELD OF MINT (*Mentha viridis* L.) IN RED SANDY LOAM SOILS OF COASTAL ANDHRA PRADESH**” submitted in partial fulfillment of requirements for the degree of Master of Science in Horticulture (Plantation, Spices, Medicinal and Aromatic crops) of Dr. Y.S.R Horticultural University, Venkataramannagudem, is a record of the bonafide research work carried out by **Ms. DEGALA MANJUSHA** under our guidance and supervision.

No part of the thesis has been submitted by the student for any other degree or diploma. The published part and all assistance received during the course of investigation have been duly acknowledged by the author of the thesis.

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I, Ms. DEGALA. MANJUSHA, hereby declare that the thesis entitled **“EFFECT OF SPACING AND FERTILIZERS ON GROWTH, HERBAGE AND OIL YIELD OF MINT (*Mentha viridis* L.) IN RED SANDY LOAM SOILS OF COASTAL ANDHRA PRADESH”** submitted to Dr. Y.S.R. Horticultural University, Venkataramannagudem, for the degree of Master of Science in Horticulture (Plantation, Spices, Medicinal and Aromatic crops) is the result of original research work done by me. I declare that no material contain in the thesis has been published earlier in any manner.

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LIST OF SYMBOLS AND ABBREVIATIONS

%	: Per cent
&	: And
@	: At the rate of
°C	: Degree centigrade
µg	: Micro gram
ANOVA	: Analysis of variance
A.P.	: Andhra Pradesh
AR	: Analytical Reagent
BaSO ₄	: Barium Sulphate
BaCl ₂	: Barium Chloride
CaCl ₂ .2H ₂ O	: Calcium Chloride
CD	: Critical difference
CGR	: Crop growth rate
cm	: Centimetre
cm ²	: Square Centimetres
conc.	: concentrate
cv.	: Cultivar
d ⁻¹	: per day
DAP	: Days after planting
DAS	: Days after sowing
DAT	: Days after transplanting
dil.	: dilute
Dist.	: District
dSm ⁻¹	: Decisiemen per metre
E	: East
EC	: Electrical conductivity
<i>et al.</i>	: And others
<i>etc.,</i>	: and so on
Fig.	: Figure

FRBD	:	Factorial Randomized Block Design
FYM	:	Farm yard manure
g	:	Gram
ha	:	Hectare
ha ⁻¹	:	Per hectare
HCl	:	Hydrochloric acid
HC&RI	:	Horticultural College and Research Institute
H ₂ SO ₄	:	Sulphuric acid
<i>i.e.</i> ,	:	That is
K ₂ O	:	Muriate of Potash
K ₂ SO ₄	:	Potassium sulphate
KNO ₃	:	Potassium nitrate
K	:	Potash
K ha ⁻¹	:	Potash per hectare
Kg	:	Kilogram
Kg ha ⁻¹	:	Kilogram per hectare
l	:	Litre
LAI	:	Leaf area index
l ha ⁻¹	:	Litres per hectare
Log	:	Logarithm
m	:	Metre
m ⁻²	:	Square metre
mm	:	Millimetre
mg	:	Milligram
MgCl ₂	:	Magnesium Chloride
ml	:	Millilitre
N	:	Nitrogen
N	:	Normality
N	:	North
N ha ⁻¹	:	Nitrogen per hectare
NaOH	:	Sodium hydroxide
NAR	:	Net assimilation rate

NH ₄	:	Ammonia
NHB	:	National Horticulture Board
nm	:	Nanometre
No.	:	Number
NS	:	Non-significant
P ₂ O ₅	:	Single Super Phosphate
P	:	Phosphorus
P ha ⁻¹	:	Phosphorus per hectare
pH	:	puissance de hydrogen
Plant ⁻¹	:	Per plant
ppm	:	parts per million
q	:	Quintal
q ha ⁻¹	:	Quintal per hectare
RH	:	Relative Humidity
S	:	Sulphur
S ha ⁻¹	:	Sulphur per hectare
SE(d)	:	Standard error difference
SE m±	:	Standard error of mean ±
sq.m	:	Square metre
t	:	Tonne
t ha ⁻¹	:	Tonnes per hectare
VAM	:	Vesicular arbuscular mycorrhizae
var.	:	Variety
<i>viz.</i> ,	:	Namely
wt.	:	Weight

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ABSTRACT

The present investigation entitled 'Effect of spacing and fertilizers on growth, herbage and oil yield of mint (*Mentha viridis* L.) in red sandy loam soils of coastal Andhra Pradesh' was carried out at Horticultural College and Research Institute, Venkataramannagudem, West Godavari District of Andhra Pradesh during *rabi*, 2015-2016. The experiment was laid out in a randomized block design with factorial concept (FRBD) with 12 treatment combinations and each replicated thrice. The data recorded on various parameters *viz.*, growth, physiological growth rates, yield, biochemical and nutrient status of plant at each harvest and soil after final harvest was statistically analyzed.

Significant differences were observed on growth parameters with different spacings and fertilizer doses. Growth parameters *viz.*, plant height, number of branches per plant, number of leaves per plant, leaf area per plant, fresh weight of leaf per plant and fresh weight of stem per plant were found maximum with 60×15 cm spacing and application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ at 150 DAP.

The combination of 60×15 cm spacing and application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ recorded significant differences with many of the growth parameters *viz.*, number of branches per plant, number of leaves per plant, fresh weight of leaf per plant and fresh weight of stem per plant.

Significant differences were observed on physiological growth parameters with different spacings and fertilizer doses. The maximum leaf area index was recorded with 30×15 cm spacing at 150 DAP. Physiological growth parameters *viz.*, dry weight of leaf per plant, dry weight of stem per plant and total dry matter production per plant were found maximum with 60×15 cm spacing at 150 DAP. The maximum crop growth rate and net assimilation rate were found maximum with 45×15 cm spacing.

Physiological growth parameters *viz.*, leaf area index, dry weight of leaf per plant, dry weight of stem per plant, total dry matter production per plant and crop growth rate were found maximum with the application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹.

Significant differences were observed on yield and biochemical parameters with different spacings and fertilizer doses. The maximum herbage yield per plant (215.29 g) was recorded with 60×15 cm spacing at 150 DAP. The maximum herbage yield per plot (21.15 kg) and herbage yield per hectare (235.05 q) and essential oil yield (159.94 kg ha⁻¹) were recorded with 45×15 cm spacing at 150 DAP.

Significantly the higher herbage yield per plant (187.82 g), herbage yield per plot (20.46 kg), herbage yield per hectare (227.43 q), essential oil content (0.734 %) and essential oil yield (166.91 kg ha⁻¹) were recorded with the application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ at 150 DAP. The combination of 45×15 cm spacing and application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ recorded maximum herbage yield per plant (235.58 g), herbage yield per plot (22.57 kg) and herbage yield per hectare (250.88 q) at 150 DAP.

Significant differences were observed on nutrient status of soil and plant samples with different spacings and fertilizer doses. The nitrogen content and sulphur content in plant were found maximum with 60×15 cm spacing at 150 DAP. The nitrogen content and sulphur content in the soil after final harvest were found maximum with 60×15 cm spacing. The uptake of nitrogen and sulphur were found maximum with 45×15 cm spacing. The maximum nitrogen and sulphur content in plant sample at 150 DAP, nitrogen and sulphur content in the soil after final harvest and uptake of nitrogen and sulphur at 150 DAP were recorded with the application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹.

Chapter-I

Introduction

CHAPTER- I

INTRODUCTION

Aromatic plants are generally referred to as 'natural bio-chemical factories' or 'chemical gold mines' due to the presence of a variety of complex chemical compounds in them. Aromatic plants possess odoriferous and volatile substances in the form of essential oils, gum exudates, oleoresins either in one or more plant parts such as root, wood, bark, foliage, flowers and fruits. The compounds are extensively used in perfumes, food flavouring, cosmetics, toiletries and in allied industries. Some of these compounds have an anti-bacterial, anti-fungal, insecticidal and germicidal properties and hence used in pharmaceutical industry. Now a days there is a high demand for utilization of plant based essential oils in preparation of drugs and in pharmaceutical industry. Cultivation of aromatic plants for their active principle and essential oils are usually highly remunerative.

The world's total essential oil production is estimated to be 1,00,000-1,10,000 tonnes and India stands third with a share of 16-17 %. In terms of value again, India stands second in position with a share of 21-22 %. This is because of the mint revolution in North India (Farooqi and Sreeramu, 2001).

Among various aromatic plants, mint is an essential oil bearing perennial herb, belongs to the genus *Mentha* and family Lamiaceae. It is believed to be originated from the Mediterranean basin. It is world's third most valuable flavouring agent (Fenarolics, 1971). In India, the total area under mint cultivation is confined to (Uttar Pradesh and Punjab) 10,000 ha only.

The presence of oil and aroma chemicals in pure form command a massive demand especially in food and allied industries. The essential oils derived from mint are economically important due to their extensive use of terpene menthol in food, pharmaceutical and perfume industries apart from linalool.

Approximately 25 species comes under the genus *Mentha*, among them *Mentha viridis* (2n=41), which is later classified as *Mentha spicata* (Ranade, 1982) is one of the important crops grown in the plains of India. *Mentha viridis* L. is commonly known as spearmint or garden mint or lamb mint. USA is the leading producer of spearmint. It is propagated through stolons and grows up to a height of 30-60 cm. The leaves are sessile, smooth, lanceolate or ovate-lanceolate, sharply serrated, smooth above and glandular below; the leaves are long up to 6.5 cm long with acute apex. The flowers are sharply pointed, long and narrow, hence called in the name of spearmint.

The distillation of fresh herb (flowers and leaves) yields to an amount of 0.25-0.50 % volatile oil known as spearmint oil. The principal constituent of spearmint oil is carvone (57.71 %). Freshly extracted oil is colourless, pale yellow or greenish but it changes to red colour as the age advances. The oil is mostly used as a flavouring agent in toothpastes and in foods such as pickles, spices, chewing gums, confectioneries, soaps and sauces. Green leaves are used for making chutney and for flavouring of culinary preparations. The oil is carminative stimulant and used as an ingredient in preparation of other medicines. At present, India contributes to about 40% of total world's mint oil production (Sharma and Kanjilal, 1999).

Spacing is an important factor, which can limit the absorption of water and nutrients in plants by creating competition between plants for water, nutrients and interception of light in preparation of food materials. Therefore, optimization of spacing is most important for an increase in herb and essential oil yields.

Nutrition is also an important factor that influences the growth, yield and quality of mint. Plants obtain nutrients from the soil, but they are inadequate to meet the increased demand of plants for higher production. The quantity of fertilizers (inorganic or organic) required by the crop depends on the species selected, type of soil and prevailing weather conditions during crop growth period. The use of optimum dose of fertilizer required by the crop is to be estimated to increase the productivity of a crop.

Nitrogen is an important nutrient in increasing the production of medicinal and aromatic plants, as 'N' is an integral component of organic compounds such as proteins, amino acids and nucleic acids, which forms the living material. Mint responds well to heavier doses of nitrogen application. The increase in herbage and essential oil yields by the application of phosphorus is not as remarkable as in case of nitrogen and potassium application has no significant effect on herb and oil yields in mint (Farooqi and Sreeramu, 2001). The key role of 'N' in plant metabolism and its high cost in developing countries like India, the optimization of 'N' fertilization has become more important. Sulphur is an important nutrient for improving plant growth and oil content in *Mentha viridis* (Farooqi and Sreeramu, 2001). kakjjaxxnmxznjznxnjanxjanxjnajnxjxnajnxjnxnxjxnajnxjnxjja.

Although the economic product of the crop has good export potential, much effort have not been made so far on agronomic requirements of minor leafy vegetable cum aromatic crop in coastal Andhra Pradesh. Therefore, an attempt has been made to study the effect of spacing and fertilizers (nitrogen and sulphur) on growth, herbage and oil yield of *Mentha viridis* in red sandy loam soils of coastal Andhra Pradesh with the following objectives.

OBJECTIVES:

1. To determine the suitable spacing for optimum growth, herbage and oil yield of mint grown under red sandy loam soils of coastal Andhra Pradesh.
2. To determine the optimum levels of nitrogen and sulphur for growth, herbage and oil yield of mint in red sandy loam soils of coastal Andhra Pradesh.
3. To determine the dry matter partitioning and essential oil content at various growth stages of mint grown under red sandy loam soils of coastal Andhra Pradesh.

Chapter-II

Review of Literature

CHAPTER II

REVIEW OF LITERATURE

Mentha is a small genus of aromatic herb belongs to Labiateae (Lamiaceae) family. *Mentha viridis* (L.) is considered as industrial crop as it is a source of essential oil, which is commercially exploited in food, flavor, cosmetic and pharmaceutical industries.

Essential oil biosynthesis in *Mentha viridis* (L.) is strongly influenced by several intrinsic and extrinsic factors including fertilizers, spacing, harvesting time and other agro-climatic factors. Spearmint is well adapted to climatic conditions in tropical and subtropical areas. A climate with adequate and regular rainfall and good sunshine during its growing periods ensures a good yield. Both high water moisture content and water stress conditions decrease essential oil yield in this crop.

Mentha viridis has proved out to be of great commercial importance in flavouring and pharmaceutical industries and consequently has fascinated the attention of the researchers. Spacing is one of the most important factor for increasing herb and essential oil yields. Nutrition is another important factor that influences the growth, yield and quality of mint. Nitrogen (N) and sulphur (S) are the major nutrients required by this crop for increasing herb and essential oil yields in spearmint.

The research work done in the above aspect is very limited. Hence, the relevant literature pertaining to the effect of spacing and fertilizer application at various levels on growth, herbage and oil yields and their uptake by mint (*Mentha viridis* L.) is reviewed. Since the available literature is scanty on this crop, the review pertaining to other crops were also furnished.

2.1 GROWTH PARAMETERS

2.1.1 Plant height (cm)

Izhar *et al.* (2015) reported maximum plant height (42.5 cm) with the application of NPK @ 225:60:60 kg ha⁻¹ in *Mentha arvensis*.

Kumar *et al.* (2015) observed that plant height (43.39 cm) was high under optimum dose of NPK (120:50:40 kg ha⁻¹) in *Mentha spicata*.

Hore *et al.* (2014) demonstrated that application of sulphur @ 60 kg ha⁻¹ and nitrogen @ 250 kg ha⁻¹ recorded maximum plant height (74.16 cm) in garlic.

Meena *et al.* (2014) reported that maximum plant height (84.87cm) was recorded with the fertilizer application of sulphur @ 40 kg ha⁻¹ in coriander (*Coriandrum sativum* L.).

Reddy *et al.* (2014) reported maximum plant height (174.75 cm) with the fertilizer application of sulphur @ 1.00 t ha⁻¹ at 60 DAP in lemon grass var. Krishna.

Saha *et al.* (2014) concluded that maximum plant height (118.03 cm) was recorded with fertilizer application of 120 kg N ha⁻¹ in square planting (50×50 cm) system in patchouli (*Pogostemon cablin* Benth.).

Salim *et al.* (2014) observed that 20 cm row spacing recorded the highest plant height (36.1cm) in summer season in spearmint (*Mentha spicata* var. *viridis*).

Yousuf *et al.* (2014) reported the highest plant height (74.20 cm and 76.43 cm) with the fertilizer application of N @ 70, P @ 50, K @ 30, S @ 20 kg ha⁻¹ in both the years (2008-2009 and 2009-2010 respectively) in coriander (*Coriandrum sativum* L.).

Kakaraparathi *et al.* (2013) reported that the fertilizer application of sulphur @ 50 kg ha⁻¹ produced maximum plant height (83.50 cm) at 240 DAT in *Ocimum tenuiflorum* variety CIM-AYU.

Patel and Kushwaha (2013) reported maximum plant height (103.99 cm) with the fertilizer application of nitrogen @ 160 kg ha⁻¹ by adopting 50×30 cm spacing at 90 DAP in *Ocimum basilicum* var. *glabratum* (Ob-15).

Patel *et al.* (2013) observed that the fertilizer application of nitrogen @ 80 kg ha⁻¹ recorded maximum plant height (74.61 cm) followed by sulphur @ 30 kg ha⁻¹ (72.97 cm) in coriander (*Coriandrum sativum* L.).

Raina *et al.* (2013) demonstrated that the conjunctive fertilizer use of N @ 60 kg ha⁻¹ and vermicompost @ 3 t ha⁻¹ recorded maximum plant height (66.80 cm) in *Ocimum sanctum*.

Roghaye *et al.* (2012) noticed that the fertilizer application of NPK @ 75:50:50 kg ha⁻¹ recorded maximum plant height (61 cm) in second cut in *Ocimum basilicum*.

Sumathi *et al.* (2012) reported maximum plant height (89.51 cm) with the application of nitrogen @ 200 kg ha⁻¹ and VAM @ 50 kg ha⁻¹ in patchouli (*Pogostemon patchouli* Pettle.).

Kumar and Sood (2011) found that 15th February planting with a spacing of 30×45 cm coupled with the fertilizer application of NPK (120:50:40 kg ha⁻¹) recorded maximum plant height (43.22 cm) in *Mentha piperita*.

Sharafzadeh (2011) concluded that maximum shoot height (38.37 cm) was achieved on 50 mg N, P₂O₅ and K₂O (in 1:1:1 ratio)/kg soil of pot application in *Thymus vulgaris*.

Kumar *et al.* (2010) reported that the highest plant height (87.5 cm) was recorded with the fertilizer application of sulphur @ 20 kg ha⁻¹ and zinc @ 25 kg ha⁻¹ along with 130 % of recommended NPK (150:60:40) in menthol mint (*Mentha arvensis*) var. Kosi.

Nandal *et al.* (2010) reported that the treatment combination 75 kg P₂O₅ and 20×20 cm spacing produced highest plant height (80.6 cm) in coriander cv. Hisar Anand.

Abbass (2009) noticed that the fertilizer application of 100 kg N ha⁻¹ + 150 kg P₂O₅ ha⁻¹ recorded the maximum plant height (64.26 cm) in local mint (*Mentha spicata* L.).

Shormin *et al.* (2009) observed that at 100% field capacity, the highest dose of N @ 240 kg ha⁻¹ produced maximum plant height (46.33 cm) in Japanese mint (*Mentha arvensis* L.).

Biesiada *et al.* (2008) recorded maximum plant height (54.9 cm) with the nitrogen fertilization @ 200 kg N ha⁻¹ in lavender (*Lavandula angustifolia* Mill.).

Ramachandra *et al.* (2003) reported that 45×45 cm spacing recorded the highest plant height (104.35 cm) in patchouli (*Pogostemon patchouli* Pellet.).

Sharma and Kanjilal (1999) reported maximum plant height (68.32 cm) with a closer row spacing of 45 cm in *Mentha piperata*.

Ram *et al.* (1995) reported that the fertilizer application of nitrogen @ 240 kg ha⁻¹ recorded maximum plant height (64.0 cm) in bergamot mint.

Rao *et al.* (1989) observed that the fertilizer application of nitrogen @ 200 kg ha⁻¹ recorded maximum plant height (46.9 cm) and a spacing of 30×30 cm (46.5 cm) in davana.

2.1.2 Number of branches per plant

Meena *et al.* (2014) reported that the fertilizer application of sulphur @ 40 kg ha⁻¹ significantly enhanced the number of branches per plant (6.6) in coriander (*Coriandrum sativum* L.).

Saha *et al.* (2014) observed that planting of patchouli at 50×50 cm spacing along with the application of 140 kg N ha⁻¹ produced significantly higher number of primary branches per plant (4.96).

Salim *et al.* (2014) noticed that row spacing of 40 cm recorded maximum number of branches (35.25) in spearmint (*Mentha spicata* var. *viridis*) during autumn season.

Yousuf *et al.* (2014) revealed that the maximum number of primary branches per plant (8.65) was found with the fertilizer application of N @ 70, P @ 50, K @ 30, S @ 20 kg ha⁻¹ in coriander (*Coriandrum sativum* L.).

Patel and Kushwaha (2013) reported that the maximum number of primary branches (17.00) was recorded with the fertilizer application of nitrogen @ 160 kg ha⁻¹ at 45×30 cm spacing on 90 DAP in *Ocimum basilicum* var. *glabratum* (Ob-15).

Patel *et al.* (2013) observed that the fertilizer application of nitrogen @ 80 kg ha⁻¹ recorded maximum number of primary branches (5.21) and sulphur @ 30 kg ha⁻¹ recorded (5.14) in coriander (*Coriandrum sativum* L.).

Raina *et al.* (2013) demonstrated that vermicompost @ 3 t ha⁻¹ and nitrogen fertilizer @ 60 kg ha⁻¹ along with a spacing of 60×60 cm recorded the highest number of primary branches per plant (17.47) in *Ocimum sanctum*.

Sumathi *et al.* (2012) reported that the fertilizer application at 150 kg ha⁻¹ of nitrogen and 50 kg ha⁻¹ of VAM recorded the highest number of laterals (20.27) in patchouli (*Pogostemon patchouli* Pettle.).

Nandal *et al.* (2010) concluded that the treatment combination 50 kg P₂O₅ ha⁻¹ and a spacing of 40×10 cm produced maximum number of branches (6.1) in coriander var. Hisar Anand.

Abbass (2009) revealed that the fertilizer application of 100 kg N ha⁻¹ and 150 kg P₂O₅ ha⁻¹ recorded maximum number of branches (8.36) in local mint (*Mentha spicata* L.).

Ramachandra *et al.* (2003) observed that 45×45 cm spacing recorded more number of branches per plant (45.8) in patchouli (*Pogostemon patchouli* Pellet.).

Sharma and Kanjilal (1999) noticed that the maximum number of branches per plant (35.29) with a closer row spacing of 45 cm in *Mentha piperata*.

Rao *et al.* (1989) revealed that 200 kg ha⁻¹ of nitrogen fertilizer recorded maximum number of branches per plant (8.0) and 30×30 cm spacing recorded (12.1) in davana.

2.1.3 Number of leaves per plant

Izhar *et al.* (2015) reported maximum number of leaves per plant (181) with the fertilizer application of N, P, K (225:60:60 kg ha⁻¹) without FYM in *Mentha arvensis*.

Hore *et al.* (2014) noticed that the application of sulphur @ 60 kg ha⁻¹ and nitrogen @ 250 kg ha⁻¹ recorded the highest number of leaves per plant (11.96) in garlic.

Reddy *et al.* (2014) demonstrated that the maximum number of leaves (123.50) were recorded with the fertilizer application of sulphur @ 1.25 t ha⁻¹ at 60 DAP in lemon grass var. Krishna.

Saha *et al.* (2014) concluded that planting at 70×50 cm spacing along with the fertilizer application of 140 kg N ha⁻¹ produced maximum numbers of leaves per plant (101.33) in patchouli.

Salim *et al.* (2014) observed that 40 cm row spacing recorded maximum number of leaves (98.85) in spearmint (*Mentha spicata* var. *viridis*) during autumn season.

Kakaraparathi *et al.* (2013) revealed that the application of sulphur fertilizer @ 50 kg ha⁻¹ produced maximum number of leaves (1617.3) per plant at 150 DAT in *Ocimum tenuiflorum* variety CIM-AYU.

Sumathi *et al.* (2012) noticed maximum number of leaves (361) with the fertilizer application of 150 kg N ha⁻¹ along with 50 kg of VAM ha⁻¹ in patchouli (*Pogostemon patchouli* Pettle.).

Abbass (2009) reported that the fertilizer application @ 100 kg N ha⁻¹ and 150 kg P₂O₅ ha⁻¹ recorded maximum number of leaves (100.62) in local mint (*Mentha spicata* L.).

2.1.4 Leaf area per plant (cm²)

Izhar *et al.* (2015) noticed that the maximum leaf area per leaf (12.4 cm²) was recorded with the fertilizer application of N, P, K (225:60:60 kg ha⁻¹) without FYM in *Mentha arvensis*.

Reddy *et al.* (2014) reported that the maximum leaf area per leaf (72.55 cm²) was recorded with the application of sulphur @ 1.25 t ha⁻¹ at 30 DAP in lemon grass var. Krishna.

Kakaraparathi *et al.* (2013) observed that by the application of sulphur fertilizer @ 50 kg ha⁻¹ produced maximum leaf area per leaf (87 cm²) at 240 DAT in *Ocimum tenuiflorum* variety CIM-AYU.

Patel and Kushwaha (2013) reported that the maximum leaf area per plant (46487.0 m² ha⁻¹) was recorded with the fertilizer application of nitrogen @ 160 kg ha⁻¹ and 50×30 cm spacing at 90 DAP in *Ocimum basilicum* var. *glabaratum* (Ob-15).

Ramachandra *et al.* (2003) concluded that planting at a spacing of 60×60 cm recorded the maximum leaf area per plant (5945.0 cm²) in patchouli (*Pogostemon patchouli* Pellet.).

2.1.5 Leaf/stem ratio on weight basis

Kassahun *et al.* (2011) reported that the maximum fresh leaf/stem ratio (2.13) was recorded with 30 cm row spacing in second harvest in pepper mint (*Mentha piperata* L.).

Kumar *et al.* (2010) noticed that the maximum leaf/stem ratio (1.46) was observed with the fertilizer application of sulphur @ 20 kg ha⁻¹ and zinc @ 25 kg ha⁻¹ along with 130 % of recommended NPK (150:60:40 kg ha⁻¹) in menthol mint (*Mentha arvensis*) var. Kosi.

Alsafar and Al-Hassan (2009) revealed that the maximum leaf/stem ratio (0.85) was recorded with the fertilizer application of 75 kg N and 50 kg P₂O₅ ha⁻¹ in indigenous mint (*Mentha longifolia*).

Kattimani and Reddy (2001) reported that the maximum leaf to stem ratio (1.44) was recorded at 90 DAP in Japanese mint.

Sharma and Kanjilal (1999) reported that the highest leaf/stem ratio (1.46) was recorded with a closer row spacing of 45 cm in *Mentha piperata*.

Ram *et al.* (1995) demonstrated that nitrogen @ 0 kg ha⁻¹ recorded maximum leaf/stem ratio (2.54) in bergamot mint.

2.1.6. Fresh weight of leaf per plant (g)

Reddy *et al.* (2014) reported that the maximum leaf weight (242.12 g) was recorded with the fertilizer application of sulphur @ 1.00 t ha⁻¹ at 30 DAP in lemon grass var. Krishna.

Kakaraparthi *et al.* (2013) observed that the application of sulphur fertilizer @ 50 kg ha⁻¹ produced maximum fresh weight of leaf per plant (915.75 g) at 150 DAT in *Ocimum tenuiflorum* variety CIM-AYU.

Patel and Kushwaha (2013) concluded that the highest leaf biomass (36.51 q ha⁻¹) was recorded with the fertilizer application of nitrogen @ 160 kg ha⁻¹ and 45×30 cm spacing at 60 DAP in *Ocimum canum* var. Oc-11.

Raina *et al.* (2013) reported that vermicompost @ 3 t ha⁻¹ and N @ 60 kg ha⁻¹ with a spacing of 60×60 cm recorded maximum fresh leaf weight (90.17 g) in *Ocimum sanctum*.

Roghaye *et al.* (2012) observed that the fertilizer application of NPK @ 100, 75 and 75 kg ha⁻¹ recorded the highest fresh leaf weight (1220 g) in *Ocimum basilicum* (L).

Mekonnen and Kassahun (2011) noticed that 30 cm inter row spacing recorded maximum fresh leaf weight (7,480 kg ha⁻¹) in spearmint (*Mentha spicata* L.).

2.1.7 Fresh weight of stem per plant (g)

Patel and Kushwaha (2013) reported that the maximum stem weight (120.25 q ha⁻¹) was recorded with the fertilizer application of nitrogen @ 160 kg ha⁻¹ and 50×30 cm spacing at 60 DAP in *Ocimum basilicum* var. *glabaratum* (Ob-15).

Mekonnen and Kassahun (2011) observed that the maximum fresh stem weight (7,515 kg ha⁻¹) was recorded with 30 cm inter row spacing in spearmint (*Mentha spicata* L.).

2.2 PHYSIOLOGICAL PARAMETERS

2.2.1 Leaf area index (LAI)

Saha *et al.* (2014) reported the highest LAI (10.47) with the application of 140 kg N ha⁻¹ at 50×35 cm in patchouli (*Pogostemon cablin* Benth.).

Mishu *et al.* (2013) observed that the highest leaf area index (0.77) was recorded with the application of 40 kg S ha⁻¹ at 75 DAT in onion.

Chegini *et al.* (2012) noticed the highest LAI (1.8) with 100 kg N ha⁻¹ in sweet basil.

Kumar *et al.* (2010) reported maximum leaf area index (7.00) with the fertilizer application of sulfur @ 20 kg ha⁻¹ and zinc @ 25 kg ha⁻¹ along with 130 % of recommended NPK (150:60:40) in menthol mint (*Mentha arvensis*) var. Kosi.

Alsafar and Al-Hassan (2009) observed the maximum leaf area index (> 3.0) with the application of 75 kg N ha⁻¹ and 50 P₂O₅ ha⁻¹ in indigenous mint (*Mentha longifolia*).

Sumathi *et al.* (2012) reported that 150 kg ha⁻¹ of nitrogen fertilizer and 50 kg VAM ha⁻¹ recorded the maximum leaf area index (2.01) in patchouli (*Pogostemon patchouli* Pettle.).

Ram *et al.* (1995) noticed that the maximum leaf area index (5.09) was recorded with the application of nitrogen @ 240 kg ha⁻¹ in bergamot mint.

2.2.2 Dry matter partitioning and total dry matter production per plant (g)

Saha *et al.* (2014) concluded that the highest dry matter accumulation (542.33 g/plant) was produced with the fertilizer application of 140 kg N ha⁻¹ and 70×50 cm spacing in patchouli (*Pogostemon cablin* Benth.).

Meena *et al.* (2014) observed that the per cent increase in dry matter accumulation (7.56 %) was recorded with the application of sulphur @ 40 kg ha⁻¹ in coriander (*Coriandrum sativum* L.).

Mishu *et al.* (2013) reported that the highest total dry matter production (16.92 g) was found with the application of 40 kg S ha⁻¹ in onion.

Abbass (2009) noticed that the application of 100 kg N ha⁻¹ and 150 kg P₂O₅ ha⁻¹ recorded maximum dry matter (1.22 t ha⁻¹) in local mint (*Mentha spicata* L.).

Alsafar and Al-Hassan (2009) revealed that the total dry matter production (634 g m⁻²) was recorded with the application of 100 kg N and 75 kg P₂O₅ ha⁻¹ in indigenous mint (*Mentha longifolia*).

Kassahun *et al.* (2011) reported that the maximum dry leaf yield (1999.9 kg ha⁻¹) was recorded with 30 cm row spacing in peppermint (*Mentha piperata* L.).

2.2.3 Crop growth rate (CGR) ($\text{g m}^{-2}\text{d}^{-1}$)

Ahirwar *et al.* (2014) reported maximum CGR ($3.22 \text{ g m}^{-2} \text{ d}^{-1}$) with the application of N: P: K @ $75:37.5:45 \text{ kg ha}^{-1}$ at 15 DAS in isabgol.

Chandana and Dorajeerao (2014) reported maximum crop growth rate ($5.37 \text{ g m}^{-2} \text{ d}^{-1}$) with the application of nitrogen @ 300 kg ha^{-1} in gladiolus cv. White prosperity.

Kakaraparthi *et al.* (2013) observed the maximum CGR ($0.0748 \text{ g m}^{-2} \text{ d}^{-1}$) with the fertilizer application of 25 kg ha^{-1} of sulphur at 120-150 DAT in *Ocimum tenuiflorum* variety CIM-AYU.

Aliyu *et al.* (2008) noticed maximum CGR ($1.04 \text{ g m}^{-2} \text{ d}^{-1}$) with the application of 100 kg ha^{-1} of nitrogen at 25 cm intra-row spacing in onion.

Nasreen *et al.* (2003) concluded that maximum CGR was recorded with the application of 45 kg ha^{-1} of sulphur in onion.

2.2.4 Net assimilation rate ($\text{mg cm}^{-2} \text{ d}^{-1}$)

Chandana and Dorajeerao (2014) reported maximum NAR ($7.47 \text{ g m}^{-2} \text{ d}^{-1}$) with the fertilizer application of nitrogen @ 400 kg ha^{-1} in gladiolus cv. White prosperity.

Kakaraparthi *et al.* (2013) observed the maximum NAR ($0.0392 \text{ g m}^{-2} \text{ d}^{-1}$) with 0 kg ha^{-1} of sulphur at 180-210 DAT in *Ocimum tenuiflorum* variety CIM-AYU.

Mishu *et al.* (2013) observed that the highest value of NAR was observed during 45-55 DAT with the application of 40 kg S ha^{-1} in onion.

2.3 YIELD PARAMETERS

Pal *et al.* (2016) reported that the highest rate of N ($150 \text{ Kg urea ha}^{-1}$), P ($250 \text{ kg phosphorus ha}^{-1}$) and K ($150 \text{ kg potash ha}^{-1}$) fertilization recorded maximum yield (19200 kg ha^{-1}) in *Thymus serphyllum*.

Izhar *et al.* (2015) concluded that the fertilizer application of N, P, K (150:45:45 kg ha⁻¹) along with FYM @ 8 t ha⁻¹ recorded the highest herb yield (20.87 t/ha) in *Mentha arvensis*.

Kumar *et al.* (2015) observed that the maximum herb yield (271.96 q ha⁻¹) was recorded with the application of NPK (120:50:40 kg ha⁻¹) in *Mentha spicata*.

Hore *et al.* (2014) demonstrated that the application of sulphur @ 60 kg ha⁻¹ and nitrogen @ 200 kg ha⁻¹ recorded the highest plot yield (3.00 kg m⁻²) in garlic.

Meena *et al.* (2014) reported that the highest seed yield (1394 kg ha⁻¹), straw yield (1991 kg ha⁻¹) and biological yield (3385 kg ha⁻¹) were recorded with the fertilizer application of 40 kg ha⁻¹ sulphur in coriander.

Saha *et al.* (2014) revealed that planting at 50×50 cm spacing and with the application of 140 kg N ha⁻¹ produced maximum fresh herbage yield (7.41 t ha⁻¹) in patchouli (*Pogostemon cablin* Benth.).

Salim *et al.* (2014) observed that 20 cm row spacing recorded the highest herb yield (1887.085 g m⁻²) during autumn season in spearmint (*Mentha spicata* var. *viridis*).

Sarma and Sarma (2014) reported that the herbage yield was highest with 40×35 cm spacing (21.84 kg plot⁻¹) in *Mentha citrata*.

Yousuf *et al.* (2014) found that the highest seed yield (2.09 t ha⁻¹) was obtained in treatment N @ 70, P @ 50, K @ 30 and S @ 20 kg ha⁻¹ in coriander (*Coriandrum sativum* L.)

Patel *et al.* (2013) observed that the fertilizer application of nitrogen @ 80 kg ha⁻¹ recorded the highest seed yield (1203 kg ha⁻¹) and sulphur @ 30 kg ha⁻¹ recorded (1184 kg ha⁻¹) in coriander (*Coriandrum sativum* L.).

Raina *et al.* (2013) demonstrated that the integrated dose of N @ 60 kg ha⁻¹ and vermicompost @ 3 t ha⁻¹ with a plant spacing of 40×40 cm recorded maximum fresh herb yield (10.91 t ha⁻¹) in *Ocimum sanctum*.

Kikon *et al.* (2012) noticed that the maximum fresh yield (86.76 t ha⁻¹) was recorded with the application of vermicompost @ 5 t ha⁻¹ and nitrogen @ 100 kg ha⁻¹ in patchouli.

Sumathi *et al.* (2012) reported that the highest herbage yield (13.60 t ha⁻¹) was recorded with 150 kg N ha⁻¹ of fertilizer application and 50 kg of VAM ha⁻¹ in patchouli (*Pogostemon patchouli* Pettle.).

Kassahun *et al.* (2011) concluded that the maximum fresh leaf yield (9,967.5 kg ha⁻¹) was obtained with 30 cm row spacing in pepper mint (*Mentha piperata* L.).

Kumar and Sood (2011) reported that 15th February planting and 30×45 cm spacing coupled with the application of NPK @ 120:50:40 kg ha⁻¹ fertilizers recorded maximum herb yield (204.42 q ha⁻¹) in *Mentha piperita*.

Mekonnen and Kassahun (2011) observed that the maximum fresh biomass yield (14,995 kg ha⁻¹) was found with 30 cm inter row spacing in spearmint (*Mentha spicata* L.).

Sharafzadeh (2011) revealed that the highest green herb weight (42.78 g plant⁻¹) was recorded with 100 mg N, P₂O₅ and K₂O (in 1:1:1 ratio)/kg soil of pot in *Thymus vulgaris* L.

Zheljazkov *et al.* (2011) reported that the fertilizer application of sulphur @ 60 kg ha⁻¹ and combined application of nitrogen @ 160 kg ha⁻¹ and sulphur @ 90 kg ha⁻¹ recorded maximum dry weight yields (25,975 and 19,375 kg ha⁻¹ respectively) at Verona region in lemon grass.

Anwar *et al.* (2010) concluded that the maximum herb yield (37.85 t ha⁻¹) was recorded with the application of NPK @ 200:80:80 kg ha⁻¹ in Shivalik cultivar of menthol mint.

Kumar *et al.* (2010) noticed that with the application of sulphur @ 20 kg ha⁻¹ and zinc @ 25 kg ha⁻¹ along with 130 % of recommended NPK (150:60:40)

recorded maximum herb yield (644.5 q ha⁻¹) in menthol mint (*Mentha arvensis*) var. Kosi.

Nandal *et al.* (2010) concluded that the treatment combination of 75 kg P₂O₅, 20×20 cm spacing and two cutting treatment combination recorded the highest green leaves yield (7.45 q ha⁻¹) in coriander cv. Hisar Anand.

Abbas (2009) reported that the fertilizer application of 100 kg N ha⁻¹ and 150 kg P₂O₅ ha⁻¹ recorded maximum yield (10.44 t ha⁻¹) in local mint (*Mentha spicata* L.).

Shormin *et al.* (2009) demonstrated that at 100% field capacity, 120 kg N ha⁻¹ produced maximum fresh herb yield (103.54 g pot⁻¹) in Japanese mint (*Mentha arvensis* L.).

Zheljazkov *et al.* (2009) noticed that at Verona region maximum biomass yield (8.56 t ha⁻¹) was recorded with the application of nitrogen @ 80 kg ha⁻¹ in peppermint (*Mentha piperita*).

Biesiada *et al.* (2008) revealed that the maximum yield (7.12 kg m⁻²) of fresh inflorescence was obtained with nitrogen fertilization @ 100 kg N ha⁻¹ in lavender (*Lavandula angustifolia* Mill.).

Singh *et al.* (2007) observed that the application of 200 kg N ha⁻¹ produced the highest fresh herbage (13.95 t ha⁻¹) in patchouli (*Pogostemon cablin* (Blanco) Benth.).

Sumathi *et al.* (2006) found that the fertilizer application of 150 kg N ha⁻¹ and 50 kg VAM ha⁻¹ recorded maximum fresh herbage (297.9 g plant⁻¹) in patchouli (*Pogostemon patchouli* Pettle.).

Singh *et al.* (2003) reported that closer row spacing of 45 cm recorded the highest total herb yield of 292.8 q ha⁻¹ in Kiran variety of bergamot mint (*Mentha citrata* Ehrh.).

Ram *et al.* (1995) concluded that the maximum herbage yield (32.11 t ha⁻¹) was recorded with the application of nitrogen @ 240 kg ha⁻¹ in bergamot mint.

Sharma and Kanjilal (1999) noticed that the maximum herbage yield (61.92 q ha⁻¹) was recorded with a closer row spacing of 45 cm in *Mentha piperata*.

Rao *et al.* (1998) revealed that the application of 160 kg ha⁻¹ of nitrogen fertilizer recorded maximum biomass yield (230.6 MT ha⁻¹) in davana.

Rao *et al.* (1991) demonstrated that 160 kg ha⁻¹ of nitrogen fertilizer recorded maximum biomass yield (89.1 q ha⁻¹) in *Artemisia pallens*.

Rao *et al.* (1989) observed that the application of nitrogen @ 100 kg ha⁻¹ and 7.5×7.5 cm spacing recorded the highest biomass yield (85.7 q ha⁻¹ and 86.6 q ha⁻¹) respectively in davana.

Rao *et al.* (1984) concluded that 75 Kg N ha⁻¹ of fertilizer application and 45 cm row spacing recorded maximum biomass yield (21.1 t ha⁻¹ and 22.5 t ha⁻¹) respectively in bergamot mint (*Mentha citrata*).

2.4 BIOCHEMICAL PARAMETERS

2.4.1 Essential oil content (%)

Izhar *et al.* (2015) concluded that the maximum menthol content (5.95 %) was recorded with the application of N, P, K @ 175:50:50 kg ha⁻¹ along with FYM @ 6 t ha⁻¹ in *Mentha arvensis*.

Kumar *et al.* (2015) observed that maximum oil content (0.42 %) was recorded with the application of NPK @ 120:50:40 kg ha⁻¹ in *Mentha spicata*.

Saha *et al.* (2014) revealed that the essential oil content varied from 1.88 to 1.93 per cent with the application of 80, 100, 120 and 140 kg N ha⁻¹ under different spacing 70×50, 50×50 and 50×35 cm indicating that nitrogen and planting geometry have only marginal effect on oil content in patchouli.

Sarma and Sarma (2014) reported that the mean oil per cent was ranged from 0.61-0.63 % during two consecutive years with 40×35 cm spacing in *Mentha citrata*.

Kakaraparthi *et al.* (2013) found that maximum oil content (0.53 %) was recorded with the fertilizer application of 25 kg ha⁻¹ of sulphur at 90 DAT in *Ocimum tenuiflorum* variety CIM-AYU.

Patel *et al.* (2013) observed that the application of nitrogen fertilizer @ 80 kg ha⁻¹ recorded maximum volatile oil content (0.51 %) and sulphur @ 30 kg ha⁻¹ recorded (0.51 %) volatile oil content in coriander (*Coriandrum sativum L.*).

Kassahun *et al.* (2011) demonstrated that the maximum essential oil content (1.28 %) was obtained at a row spacing of 40 cm in pepper mint (*Mentha piperata L.*).

Kumar and Sood (2011) reported that 15th February planting and 30×45 cm spacing coupled with the fertilizer application of NPK @ 120:50:40 kg ha⁻¹ recorded maximum oil content (0.36 %) in *Mentha piperita*.

Mekonnen and Kassahun (2011) found that a spacing of 50 cm at 180 DAT recorded maximum essential oil content (0.67 %) in spearmint (*Mentha spicata L.*).

Sharafzadeh (2011) noticed that 100 mg N, P₂O₅ and K₂O (in 1:1:1 ratio)/kg soil of pot recorded maximum essential oil percentage (0.73 %) in *Thymus vulgaris (L.)*.

Kumar *et al.* (2010) found that with the fertilizer application of NPK @ 150:60:40 kg ha⁻¹ along with zinc @ 25 kg ha⁻¹ recorded maximum oil content (0.97 %) in menthol mint (*Mentha arvensis*) var. Kosi.

Anwar *et al.* (2010) observed that the essential oil content (1.15 %) was highest with the application of 150 kg N, 60 kg P and 60 kg K ha⁻¹ in menthol mint cv. Saksham.

Alsafar and Al-Hassan (2009) reported that the highest essential oil content (1.46 %) was recorded with control (0 kg N and P₂O₅ ha⁻¹) in indigenous mint (*Mentha longifolia*).

Zheljazkov *et al.* (2009) noticed that at Verona region, the highest essential oil content (0.62 %) was recorded with the fertilizer application of nitrogen @ 80 kg ha⁻¹ in peppermint (*Mentha piperita*).

Ramachandra *et al.* (2003) observed that 45×45 cm and 45×30 cm spacing enhanced the oil content (32.13 %) in patchouli (*Pogostemon patchouli* Pellet.).

Singh *et al.* (2003) reported that the maximum essential oil content (0.65 %) was recorded with a closer row spacing of 75 cm in Kiran variety of bergamot mint (*Mentha citrata* Ehrh.).

Sharma and Kanjilal (1999) noticed that the maximum essential oil content (0.604 %) was recorded with a closer row spacing of 45 cm in *Mentha piperata*.

Rao *et al.* (1984) revealed that planting at a row spacing of 45 cm recorded highest essential oil concentration (0.5 %) in bergamot mint (*Mentha citrata*).

2.4.2 Essential oil yield (kg ha⁻¹)

Izhar *et al.* (2015) reported that the maximum oil yield (169.08 kg ha⁻¹) was recorded with the fertilizer application of N, P, K @ 150:45:45 kg ha⁻¹ along with FYM @ 8 t ha⁻¹ in *Mentha arvensis*.

Kumar *et al.* (2015) observed that the maximum essential oil yield (81.38 kg ha⁻¹) was recorded with the application of NPK @ 120:50:40 kg ha⁻¹ in *Mentha spicata*.

Saha *et al.* (2014) concluded that the application of nitrogen fertilizer @ 140 kg ha⁻¹ with 50×50 cm spacing recorded the highest oil yield (31.3 kg ha⁻¹) in patchouli (*Pogostemon cablin* Benth.).

Salim *et al.* (2014) revealed that 20 and 30 cm row spacing recorded the highest oil yield (0.69 ml 50 mg⁻¹) during summer season in spearmint (*Mentha spicata* var. *viridis*).

Kakaraparthi *et al.* (2013) noticed that the application of sulphur @ 50 kg ha⁻¹ produced maximum oil yield (0.5477 g plant⁻¹) at 150 DAT in *Ocimum tenuiflorum* variety CIM-AYU.

Patel *et al.* (2013) reported that the application of nitrogen @ 80 kg ha⁻¹ recorded maximum oil yield (6.16 %) and sulphur @ 30 kg ha⁻¹ recorded (5.98 %) in coriander (*Coriandrum sativum* L.).

Raina *et al.* (2013) demonstrated that the integrated dose of N @ 60 kg ha⁻¹ and vermicompost @ 3 t ha⁻¹ with a plant spacing of 40×40 cm recorded maximum essential oil yield (19.88 l ha⁻¹) in *Ocimum sanctum*.

Kikon *et al.* (2012) demonstrated that with the application of vermicompost @ 5 t ha⁻¹ and nitrogen @ 100 kg ha⁻¹ recorded maximum oil yield (499.49 l ha⁻¹) in patchouli.

Sumathi *et al.* (2012) concluded that the maximum essential oil yield (110.42 kg ha⁻¹) was recorded with the fertilizer application of 150 kg nitrogen and 50 kg VAM ha⁻¹ in patchouli (*Pogostemon patchouli* Petle.).

Kassahun *et al.* (2011) noticed that the maximum essential oil yield (17.88 kg ha⁻¹) was recorded with a row spacing of 30 cm in pepper mint (*Mentha piperata* L.).

Kumar and Sood (2011) reported that 15th February planting and 30×45 cm of spacing coupled with the application of NPK @ 120:50:40 kg ha⁻¹ recorded the highest oil yield (62.57 kg ha⁻¹) in *Mentha piperita*.

Mekonnen and Kassahun (2011) revealed that 30 cm inter row spacing recorded maximum essential oil yield (31.05 kg ha⁻¹) at 150 DAT in spearmint (*Mentha spicata* L.).

Sharafzadeh (2011) observed that the highest essential oil yield (86.98 mg plant⁻¹) was recorded with 100 mg N, P₂O₅ and K₂O (in 1:1:1 ratio)/kg soil of pot in *Thymus vulgaris* L.

Zheljazkov *et al.* (2011) found that the maximum oil yield (139 kg ha⁻¹) was recorded with application of nitrogen @ 160 kg ha⁻¹ during second harvest at Verona region in lemon grass.

Anwar *et al.* (2010) noticed that the highest essential oil yield (358.46 l ha⁻¹) was recorded with the fertilizer application of 150 kg N, 60 kg P and 60 kg K ha⁻¹ in menthol mint cv. Saksham.

Kumar *et al.* (2010) reported that the fertilizer application of sulphur @ 20 kg ha⁻¹ and zinc @ 25 kg ha⁻¹ along with the recommended dose of NPK @ 150:60:40 kg ha⁻¹ recorded maximum oil yield (439.1 and 446.9 l ha⁻¹) in menthol mint (*Mentha arvensis*) var. Kosi.

Abbass (2009) concluded that the maximum aromatic oil yield (53.72 kg ha⁻¹) was recorded with the application of 100 kg N ha⁻¹ and 150 kg P₂O₅ ha⁻¹ in local mint (*Mentha spicata* L.).

Alsafar and Al-Hassan (2009) reported that the fertilizer application of 75 kg N ha⁻¹ and 50 kg P₂O₅ ha⁻¹ recorded maximum essential oil yield (141 kg ha⁻¹) in indigenous mint (*Mentha longifolia*).

Zheljazkov *et al.* (2009) revealed that the highest essential oil yield (72.1 kg ha⁻¹) was recorded with the application of N @ 80 kg ha⁻¹ at Verona region in peppermint (*Mentha piperita*).

Zheljazkov *et al.* (2008) reported that the maximum essential oil yield was recorded at a nitrogen fertilization of 50 to 60 kg ha⁻¹, whereas maximum response to sulphur fertilization appeared to be beyond 80 kg ha⁻¹ in basil.

Singh *et al.* (2007) observed that the fertilizer application of 200 kg N ha⁻¹ recorded maximum oil yield (81.07 kg ha⁻¹) in patchouli (*Pogostemon cablin* (Blanco) Benth.).

Sumathi *et al.* (2006) noticed that the fertilizer application of 150 kg N ha⁻¹ and 50 kg VAM ha⁻¹ recorded maximum essential oil yield (110.4 kg ha⁻¹) in patchouli (*Pogostemon patchouli* Pettle.).

Ramachandra *et al.* (2003) observed that planting at 45×30 cm spacing recorded the highest essential oil yield (70.57 l ha⁻¹) in patchouli (*Pogostemon patchouli* Pellet.).

Singh *et al.* (2003) reported that the maximum essential oil yield (142.5 kg ha⁻¹) was recorded with a closer row spacing of 45 cm in Kiran variety of bergamot mint (*Mentha citrata* Ehrh.).

Sharma and Kanjilal (1999) revealed that the maximum essential oil yield (37.40 kg ha⁻¹) was recorded with a closer row spacing of 45 cm in *Mentha piperata*.

Rao *et al.* (1998) noticed that the application of 160 kg ha⁻¹ of nitrogen fertilizer recorded maximum essential oil yield (31.0 kg ha⁻¹) in davana.

Ram *et al.* (1995) concluded that the maximum essential oil yield (190.5 kg ha⁻¹) was recorded with the application of nitrogen @ 240 kg ha⁻¹ in bergamot mint.

Rao *et al.* (1991) demonstrated that the application of 80 kg ha⁻¹ nitrogen recorded maximum essential oil yield (11.4 kg ha⁻¹) in *Artemisia pallens*.

Rao *et al.* (1989) observed that the maximum essential oil yield (11.5 l ha⁻¹) was recorded with the application of nitrogen @ 100 kg ha⁻¹ and a spacing of 7.5×7.5 cm recorded (11.2 l ha⁻¹) of oil yield in davana.

Rao *et al.* (1984) reported that the maximum essential oil yield (112.5 kg ha⁻¹) and (107.3 kg ha⁻¹) was recorded with the application of 75 Kg N ha⁻¹ and 45 cm row spacing in bergamot mint (*Mentha citrata*).

2.5 NUTRIENT ANALYSIS OF SOIL AND PLANT

Pal *et al.* (2016) reported that the maximum nitrogen content (1.53 %) was recorded with the fertilizer application of N @ 150 Kg ha⁻¹, P @ 250 kg ha⁻¹ and K @ 150 kg ha⁻¹ in *Thymus serpyllum*.

Mishu *et al.* (2013) reported maximum sulphur content (0.49 %) in onion bulb with the application of 40 kg S ha⁻¹ at average of 45 and 85 days after transplanting.

Patel *et al.* (2013) reported maximum nitrogen uptake (53.35 kg ha⁻¹) with the application of nitrogen @ 80 kg ha⁻¹ and maximum sulphur uptake (6.04 kg ha⁻¹) with the application of sulphur @ 30 kg ha⁻¹ in coriander (*Coriandrum sativum* L.).

Singh *et al.* (2007) noticed that the increased uptake of nitrogen (52.34 kg ha⁻¹) was observed with the application of 200 kg N ha⁻¹ in patchouli (*Pogostemon cablin* (Blanco) Benth.).

Rao *et al.* (1998) reported maximum nitrogen uptake (82.9 kg ha⁻¹) with 160 kg ha⁻¹ of nitrogen fertilizer in davana.

Rao *et al.* (1991) reported the highest nitrogen uptake (63.9 kg ha⁻¹) with the application of nitrogen @ 80 kg ha⁻¹ in *Artemisia pallens*.

Rao *et al.* (1989) reported that the maximum nitrogen uptake (53.1 kg ha⁻¹ and 53.0 kg ha⁻¹) was recorded with the application of nitrogen @ 100 kg ha⁻¹ and 7.5 × 7.5 cm spacing respectively in davana.

2.6 HARVESTING AGE

Kassahun *et al.* (2011) reported maximum fresh leaf yield of 10882.1 kg ha⁻¹ at 120 DAP and the highest essential oil yield of 28.72 kg ha⁻¹ was recorded at 90 DAP with 30 cm spacing in pepper mint (*Mentha piperata* L.).

Mekonnen and Kassahun (2011) reported that the highest leaf/stem ratio (1.98) was recorded at 60 DAT, the maximum essential oil yield (31.05 kg ha⁻¹) was recorded with 30 cm inter row spacing at 150 DAT and 50 cm inter row spacing at 180 DAT recorded maximum essential oil content (0.67 %) in spearmint (*Mentha spicata* L.).

Chapter- III

Material and Methods

CHAPTER III

MATERIAL AND METHODS

The present investigation entitled “**Effect of spacing and fertilizers on growth, herbage and oil yield of mint (*Mentha viridis* L.) in red sandy loam soils of coastal Andhra Pradesh**” was carried out at Horticultural College and Research Institute, Dr. Y.S.R. Horticultural University, Venkataramannagudem, West Godavari District of Andhra Pradesh during Rabi, 2015-2016. The details pertaining to material used and methods adopted during the course of investigation are described in this chapter.

3.1 LOCATION OF THE EXPERIMENTAL SITE

The experimental site falls under ‘Agro-climatic zone – 10 of East Coastal Plain and Hills’ (Krishna-Godavari zone) with an annual rainfall of 900 mm and located at an altitude of 34 m above mean sea level. The experimental site is geographically situated at 16°83’ N latitude and 81°5’ E longitude. The zone experiences hot and humid summer with mild winter climate.

3.2 CHARACTERISTICS OF THE SOIL

Soil samples were collected at random prior to preparatory cultivation at a depth of 0 - 30 cm from the experimental field and a composite sample was analysed for its physico-chemical properties by adopting standard methods and the data was presented in table 1.

Table 1: Physico-chemical properties of composite soil sample collected from the experimental site

Properties	Value	Method of analysis
A. Physical composition		
Sand (%)	70	International pipette method (Piper, 1966)
Silt (%)	20	
Clay (%)	10	
Textural class	Red sandy loam	
B. Chemical composition		
Soil pH	7.51	Digital pH meter (DI-707) (Jackson, 1973)
Electrical conductivity (dS m ⁻¹)	0.138	Conductivity Bridge (Jackson, 1973)
Available Nitrogen (kg ha ⁻¹)	125	KELPLUS automatic nitrogen analyzer
Available Phosphorus (kg ha ⁻¹)	41	Olsen method (Jackson, 1967)
Available Potassium (kg ha ⁻¹)	170	Flame Photometer method (Jackson, 1973)
Available Sulphur (kg ha ⁻¹)	28	BaSO ₄ Turbidimetry method

3.3 METEOROLOGICAL DATA

The meteorological data pertaining to mean maximum and mean minimum temperatures, relative humidity, rainfall and sunshine hours were recorded during the period of investigation *i.e.*, Rabi, 2015-2016 at college farm of Horticultural College and Research Institute, Venkataramannagudem, from third week of October, 2015 to third week of April, 2016. Monthly averages were worked out and the data was presented in Appendix – I.

3.4 EXPERIMENTAL DETAILS

Location	:	College Farm, Horticultural College and Research Institute, Venkataramannagudem
Crop	:	Mint (<i>Mentha viridis</i> L.)
Season	:	Rabi, 2015-2016
Design	:	Factorial Randomized Block Design (FRBD)
Number of treatment combinations	:	12
Number of replications	:	3
Plot size	:	3 m × 3 m

3.4.1 TREATMENT DETAILS:

Number of Factors: 02

Factor – I: Spacing (S): 3 levels

S₁: 30×15 cm
S₂: 45×15 cm
S₃: 60×15 cm

Factor – II: Fertilizers (Nitrogen + Sulphur) (F): 4 levels

F₁: 0 kg ha⁻¹ + 0 kg ha⁻¹ (Control)
F₂: 80 kg ha⁻¹ + 20 kg ha⁻¹
F₃: 110 kg ha⁻¹ + 20 kg ha⁻¹
F₄: 140 kg ha⁻¹ + 20 kg ha⁻¹

Treatment combinations:

T₁ :		T₇ :	S ₂ F ₃
T₂ :	S ₁ F ₂	T₈ :	S ₂ F ₄
T₃ :	S ₁ F ₃	T₉ :	S ₃ F ₁
T₄ :	S ₁ F ₄	T₁₀ :	S ₃ F ₂
T₅ :	S ₂ F ₁	T₁₁ :	S ₃ F ₃
T₆ :	S ₂ F ₂	T₁₂ :	S ₃ F ₄

3.5 CULTURAL OPERATIONS

3.5.1 Preparation of experimental plot

The land was thoroughly ploughed for 2-3 times with mould board plough and brought into a fine tilth by harrowing. All the weeds and stubbles were completely removed. The entire experimental area was levelled and divided into plots with a dimension of 3×3 m. A spacing of 60 cm between two replications and 30 cm between two plots was left to prevent leaching losses of fertilizers.

3.5.2 Planting material

Healthy planting material (stolons) was procured from the crop grown during last season at Horticultural College and Research Institute, Dr. Y.S.R. Horticultural University, Venkataramannagudem. The healthy stolons were cut into small pieces of 7-10 cm long and were planted in shallow furrows at about 7-10 cm deep with a spacing schedule explained in the experiment details.

3.5.3 Manures and fertilizers

The crop was fertilized with nitrogen and sulphur as per the treatments scheduled in the experiment. FYM @ 25 t ha⁻¹ was applied at the time of land preparation. The phosphorus and potassium fertilizers were applied at the rate of 50 and 40 kg ha⁻¹, respectively. The NPK fertilizers were applied in the form of Urea, Rock Phosphate and Muriate of Potash respectively. Sulphur was applied in the form of gypsum. The entire dose of phosphorus and sulphur was applied as basal, potassium was applied as top dressing during initial stage of crop growth, while N was applied in three equal splits at 30, 60 and 90 days after planting.

3.5.4 Irrigation

Light irrigation was given immediately after planting, there after irrigation was given at weekly intervals depending upon the soil moisture and prevailing weather conditions during crop growth period.

3.5.5 Weeding

Hand weeding was done at 30 days after planting and there after weeding was done regularly depending upon the weed intensity and the plot was kept weed free throughout the crop growth period.

3.5.6 Plant protection

Plant protection measures were taken up to maintain a healthy crop in the field. Incidence of leaf eating caterpillar was observed at initial stage of crop growth and it was controlled immediately by spraying of neem oil @ 2 ml l⁻¹ and drenching was done with blitox @ 3 g l⁻¹ as against the stolon rot.

3.5.7 Harvesting

The crop was harvested by cutting the green herb with a sickle at 2-3 cm above the ground level at 90, 120, 150 and 180 days after planting. Extra plots were maintained for harvesting.

3.6 OBSERVATIONS RECORDED

3.6.1 Sampling procedure

Five plants were randomly selected from each plot, each replication and tagged for recording the observations on different characters as described below and the mean values were calculated.

3.6.2 Growth parameters

3.6.2.1 Plant height (cm)

The plant height was measured from the ground level to the tip of the growing point with the help of meter scale at 30, 60, 90, 120, 150 and 180 days after planting for five tagged plants separately. The average of plant height in each treatment was worked out and expressed in centimetres.

3.6.2.2 Number of branches per plant

The number of branches produced on main stem was counted separately for five tagged plants at 30, 60, 90, 120, 150 and 180 days after planting in each treatment and the average was worked out.

3.6.2.3 Number of leaves per plant

The number of leaves per plant was counted for five tagged plants separately at 30, 60, 90, 120, 150 and 180 days after planting in each treatment and the average was worked out.

3.6.2.4 Leaf area per plant (cm²)

The leaf area per plant was recorded by measuring area of all the leaves produced by the plant with the help of Leaf Area Meter model LI-3100 at 30, 60, 90, 120, 150 and 180 days after transplanting in each treatment and the average values were worked out and expressed in square centimetres.

3.6.2.5 Leaf/stem ratio on weight basis

The leaf/stem ratio on weight basis was recorded by taking fresh weights of leaf and stem at 30, 60, 90, 120, 150 and 180 days after planting for five tagged plants in each treatment by using electronic balance. The ratio was arrived by using the following formula.

$$\text{Leaf/stem ratio} = \frac{\text{Fresh weight of leaf (g)}}{\text{Fresh weight of stem (g)}}$$

3.6.2.6 Fresh weight of leaf per plant (g)

Five plants were cut to the ground level, the leaves were separated and weighed separately in each treatment by using electronic balance and the average values were calculated and expressed in grams.

3.6.2.7 Fresh weight of stem per plant (g)

Five plants were cut to the ground level, the stems were separated and weighed separately in each treatment by using electronic balance and the average values were calculated and expressed in grams.

3.6.3 Physiological parameters

3.6.3.1 Leaf area index (LAI)

Leaf area index was calculated at 30, 60, 90, 120, 150 and 180 days after planting by using the following formula suggested by Sestak *et al.* (1971).

$$\text{LAI} = \frac{\text{Total leaf area (cm}^2\text{)}}{\text{Land area (cm}^2\text{)}}$$

3.6.3.2 Dry matter partitioning and total dry matter production per plant (g)

The amount of dry matter produced and its partitioning in different plant parts were recorded for five randomly selected plants in each treatment. The plants were cut to the ground level, the leaves and stem were separated. The separated parts were kept in a brown cover, sundried for 3 days and later oven dried at 60-70°C separately until a constant dry weight was attained. The dry weights of leaves and stem per plant were recorded by using electronic balance. The average value of leaf and stem dry weights were worked out and expressed in grams. Total dry matter production per plant was calculated by adding dry weight of leaf and stem and expressed in grams.

3.6.3.3 Crop growth rate (CGR) (g m⁻² d⁻¹)

The dry matter accumulation per unit land area is called as crop growth rate. After calculating the dry weight per plant, CGR per plant was calculated at 30, 60, 90, 120, 150 and 180 days after planting by using the following formula (Watson, 1952).

$$\text{CGR} = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{1}{P}$$

Where W_1 and W_2 are dry weight of the whole plant at time t_1 and t_2 respectively per unit land area.

3.6.3.4 Net assimilation rate ($\text{mg cm}^{-2} \text{d}^{-1}$)

It describes the net production efficiency of assimilatory apparatus (Gregory, 1926). The NAR was calculated at 30, 60, 90, 120, 150 and 180 days after planting.

Net photosynthesis = Gross photosynthesis - Respiration

NAR is thus quantifying the respiration since we get net photosynthesis *i.e.*, net assimilation.

$$\text{NAR} = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{\text{Log}_e A_2 - \text{Log}_e A_1}{A_2 - A_1}$$

Where W_1 and W_2 are whole plant dry weights at times t_1 and t_2 and $\text{Log}_e A_1$ and $\text{Log}_e A_2$ are logarithms of leaf areas, A_1 and A_2 are leaf areas at t_1 and t_2 respectively.

3.6.4 Yield parameters

3.6.4.1 Herbage yield per plant (g)

The herbage yield per plant was calculated by recording the fresh weight of the herbage at 90, 120, 150 and 180 days after planting for five tagged plants in each treatment by using electronic balance and the average yield per plant was calculated and expressed in grams.

3.6.4.2 Herbage yield per plot (kg)

The herbage yield per plot was calculated by recording the fresh weight of herbage of the whole plot harvested at 90, 120, 150 and 180 days after planting by using electronic balance and the average yield per plot was calculated and expressed in kilograms.

3.6.4.3 Herbage yield per hectare (q)

The herbage yield per hectare was computed based on the herbage yield per plot in each treatment and expressed in quintal.

3.6.5 Biochemical parameters

3.6.5.1 Essential oil content (%)

Essential oil from fresh herbage was extracted by using Clevenger apparatus. One kilogram of fresh herbage was chopped and taken into the mantle. One litre of water was added to the mantle and boiled at 90°C. The percentage of oil extracted from fresh herbage was calculated by using the following formula.

$$\text{Essential oil (\%)} = \frac{\text{Weight of the oil}}{\text{Weight of the herbage}} \times 100$$

3.6.5.2 Essential oil yield (kg ha⁻¹)

The essential oil yield per hectare was computed by multiplying the oil content with corresponding fresh biomass per hectare in each treatment plot and expressed in kilograms.

3.7 NUTRIENT ANALYSIS OF SOIL AND PLANT

3.7.1 Estimation of N and S in soil before planting and after final harvest

Soil samples were collected from different corners of all the plots by using soil auger and the composite soil sample was taken by using quartering method to determine the N and S contents in the soil.

3.7.1.1 Estimation of available nitrogen content in soil (kg ha⁻¹)

Procedure:

One gram of finely sieved soil sample was weighed into a macro (200 ml) digestion tube. 3.0 g of catalytic mixture and 10.0 ml of concentrated sulphuric acid were added to each sample and the process of digestion was started. After completion of digestion, the test tubes were cooled to room temperature for about 10-15 minutes. 20 ml of 2 % boric acid containing mixed indicator was taken into 150 ml conical flask and the flask was placed under the receiver tube. The receiver tube end was dipped in the boric acid. Later the time was preset for 6

minutes and alkali (2.5 % NaOH) quantity for 35 ml. Alkali addition switch was pressed and 35 ml of NaOH was added. The tap connection was put on for condenser and the water from outlet was run continuously for cooling. The timer switch was switched on and the distillation was run for 6 minutes. After completion of distillation for 6 minutes, timer switch goes off automatically. When the timer switch goes off, the conical flask was taken out from the receiver tube end. The distillate was titrated with 0.02 N H₂SO₄ till the original shade (pinkish) starts appearing. A blank was run without any soil for 6 minutes after completion of distillation and the blank titre value was deducted from each sample titre value. The estimation was done by using KELPLUS assembly. N content in soil sample was calculated by using the following formula.

$$N \text{ (kg ha}^{-1}\text{)} = \frac{14.01 \times (\text{sample titre value} - \text{blank titre value}) \times N \times 100}{\text{Sample weight (g)} \times 1000}$$

3.7.1.2 Estimation of available sulphur content in soil (kg ha⁻¹)

Principle:

The amount of sulphate sulphur present in composite soil sample was extracted with 0.15 % CaCl₂. 2H₂O solution. The sulphate present in soil extract was precipitated by using BaCl₂ salt as BaSO₄. The BaSO₄ precipitate was kept under turbid condition in presence of stabilizing agent (gum acacia solution). The intensity of turbidity was measured at 420 nm by using spectrophotometer.

Instruments:

Spectrophotometer and mechanical shaker

Reagents:

- a. 0.15 % CaCl₂. 2H₂O: 1.5 g of calcium chloride (CaCl₂. 2H₂O) was dissolved in about 700 ml of distilled water and made up to 1 liter with distilled water
- b. 0.25 % gum acacia solution: 0.25 g of gum acacia powder was dissolved in 100 ml of distilled water (freshly prepared)
- c. Barium Chloride (BaCl₂. 2H₂O)

- d. 50 ppm standard sulphate solution: 0.272 g of potassium sulphate (K_2SO_4) was dissolved in distilled water and the volume was made up to one liter

Procedure:

Five grams of soil was weighed in a 150 ml conical flask. 25 ml of 15 % $CaCl_2 \cdot 2H_2O$ solution was added. The contents were shaken for 30 minutes on mechanical shaker and filtered immediately through Whatman No. 42 filter paper into a beaker. 10 ml of extract was pipetted out into a 25 ml volumetric flask. 1ml of gum acacia solution and 0.2 to 0.3 g of $BaCl_2$ salt with spatula was added to the extract in each flask and the volume was made up to the mark with distilled water. Then the volumetric flask was inverted thrice. Turbidity was measured by using blue filter or in spectrophotometer at 420 nm within 5 to 15 minutes. A blank was run without soil.

Standard curve for sulphur:

0, 0.5, 1, 1.5, 2.5, and 5 ml of 50 ppm sulphur solution was pipetted out into 25 ml volumetric flasks to get 0, 1, 2, 3, 5 and 10 ppm of sulphur, respectively. 1 ml of gum acacia solution and 0.2 to 0.3 g of $BaCl_2$ salt were added to each flask and the volume was made up to the mark with distilled water. The volumetric flasks were inverted thrice. Turbidity was measured with the help of calorimeter using blue filter paper or in spectrophotometer at 420 nm within 5 to 15 minutes. The absorbance values were recorded for each concentration and a graph was constructed by taking concentrations of sulphur on x-axis and the corresponding absorbance values on y-axis.

Calculation:

$$\text{Available sulphur (ppm)} = R \times \frac{25 \times 25}{5 \times 10} = R \times 12.5$$

Where R= ppm of 'S' from standard curve

3.7.2 Plant nutrient analysis for N and S after each harvest

The whole plant samples were collected, sun dried first and later oven dried at 68°C for 3 days to record the dry weights at the time of each harvest. These samples were ground into fine powder with the help of summit mixer and were used to determine the nutrient contents (N and S).

3.7.2.1 Nitrogen content in plant sample (%)

Nitrogen content in the plant sample was determined by employing KELPLUS Digestion and Distillation systems. This essentially involves conversion of organic N compounds to $\text{NH}_4\text{-N}$ form through digestion and determination of $\text{NH}_4\text{-N}$ in the plant digest through distillation.

Reagents:

- a. Concentrated sulphuric acid
- b. Catalyst mixture - A mixture of K_2SO_4 and CuSO_4 salts in 10:1 ratio
- c. 40 % NaOH: 400 g of NaOH was dissolved in 1 litre of distilled water
- d. Standard sulphuric acid (0.1 N): Approximately 0.1 N H_2SO_4 was prepared by taking 2.8 ml of conc. H_2SO_4 and made up to 1 litre with distilled water
- e. Four per cent boric acid solution: 40 g of pure boric acid powder was dissolved in warm water by stirring and dilute to one litre. 20 ml of mixed indicator was added to one litre of 4 % boric acid solution. The pH was adjusted to 4.5 with dilute HCl or dilute NaOH
- f. Mixed indicator - 0.066 g of methyl red and 0.099 g of bromocresol green was dissolved in 100 ml of 95 per cent ethyl alcohol

Digestion of plant samples by using KELPLUS:

1. One gram of plant sample was weighed into 100 ml capacity micro digestion test tube.
2. To the plant sample mixture, 1 g of catalyst mixture was added.
3. Two millilitres of conc. H_2SO_4 was added by using 2 ml tilt measure or acid dispenser and kept it over night.

4. The test tube was transferred to the KELPLUS digestion unit and heated initially at 200°C and gradually increased up to 450°C.
5. The test tube was removed from the digestion chamber and the test tube was kept on stand and cooled to room temperature.

Distillation of digested samples by using KELPLUS:

- a. The above micro test tube containing digested plant sample was transferred to the distillation unit.
- b. Twenty millilitres of 4 % boric acid containing mixed indicator was measured and taken into a 150 ml conical flask and placed it under the receiver tube. The receiver tube end was dipped in the boric acid.
- c. To add NaOH (40 %), the alkali addition was preset for 25 ml. Alkali addition switch was pressed and alkali was added.
- d. The time switch for 8 minutes was set and switched on the timer switch and had run the distillation unit for 8 minutes.
- e. After completion of distillation for 8 minutes, the conical flask was taken out and titrated the distillate with 0.1 N H₂SO₄ till the blue color was changed to pinkish color.

Calculation:

$$\% N = \frac{T.V \times 0.00028 \times 100}{0.1} = 0.28 \times T.V$$

Where,

Titration value (TV) = Sample of titration value-blank titration value

Weight of the sample = 0.1 g

Normality of H₂SO₄ = 0.1 N

3.7.2.2 Sulphur content in plant sample (%)

Principle:

The sulphur content in plant sample was determined by a number of techniques with comparable results. A common procedure followed is wet digestion or ashing of plant tissue and the sulphur content was then determined by barium sulphate turbidimetry method. During wet digestion of the plant sample, the organic plant sulphur was converted to inorganic form, which when treated with BaCl_2 was precipitated as BaSO_4 . It gives turbidity to the solution and the intensity of turbidity proportional to the amount of sulphur present was measured at 420nm by using spectrophotometer.

Reagents:

1. AR grade Barium chloride ($\text{BaCl}_2 \cdot 2\text{H}_2\text{O}$) crystals passed through 20 mesh sieve and retain on 60 mesh sieve (20 to 60 mesh crystals)
2. Gum acacia solution: 0.5 g of powdered gum acacia was dissolved in a mixture containing 50 ml of glacial acetic acid and 50 ml of distilled water
3. Salt buffer solution: This solution contains 50 g of $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$, 4.1 g of KNO_3 and 28 ml of ethanol per liter
4. 6 N HCl
5. Standard sulphur solution: To prepare 100 ppm S solution, 0.543 g analytical grade K_2SO_4 was dissolved in distilled water and diluted to one liter

Preparation of standard curve:

- a. 0, 2, 4, 6, 8 and 10 ml aliquot of S standard was pipette into 50 ml volumetric flasks. 1 ml of salt buffer solution was added to each flask.
- b. One millilitre of 6 N HCl and 1 ml of 0.5 % gum acacia solution was added.

- c. The contents were mixed by swirling and 0.5 g barium chloride crystals were added.
- d. The volume was made up with distilled water and mixed thoroughly. The resulting solutions provided 0, 4, 8, 12, 16 and 20 ppm S.
- e. The flasks were allowed to stand for one minute and then inverted the volumetric flasks gently thrice.
- f. The absorbance or transmittance of the solution on spectrophotometer at 420 nm was read.
- g. The absorbance was plotted against concentration of sulphur and the standard curve was drawn.

Estimation of Sulphur content in plant sample:

Ten milliliters of aliquot from diacid plant extract was pipetted into 50 ml volumetric flask and the turbidity was developed as described above for standard curve preparation. Sulphur content was obtained from standard curve. The percentage of sulphur present in plant sample was calculated by using the following formula.

$$\% \text{ S in plant sample} = R \times \frac{50}{10} \times \frac{100 \times 100}{1 \times 10^6} = R \times 0.05$$

Where R = concentration of S in ppm obtained from standard curve

3.7.2.3 Nitrogen and sulphur uptake (kg ha⁻¹)

The nutrient uptake was calculated by multiplying the concentration of N and S present in whole plant (%) with dry matter (kg ha⁻¹) by using the following formula.

$$\text{Uptake of nutrient} = \frac{\text{Concentration of nutrient in dry matter (\%)} \times \text{Total dry matter (kg ha}^{-1}\text{)}}{100}$$

3.8 STATISTICAL ANALYSIS

The data recorded on various parameters was statistically analysed by adopting Randomized Block Design with factorial concept as suggested by Panse and Sukhatme (1985). The critical difference values were calculated at 5 per cent level of probability where ever F-test was significant.

Chapter-IV

Results and Discussion

CHAPTER IV

RESULTS AND DISCUSSION

An experiment entitled “**Effect of spacing and fertilizers on growth, herbage and oil yield of mint (*Mentha viridis* L.) in red sandy loam soils of coastal Andhra Pradesh**” was carried out at Horticultural College and Research Institute, Venkataramannagudem, West Godavari District, Andhra Pradesh during 2015-2016. Observations were recorded on different growth parameters, physiological parameters, herbage and essential oil yield parameters and uptake of nutrients. The data was subjected to statistical analysis to get information on influence of spacing and fertilizers on the above parameters. The results were presented in this chapter under the following subheads with appropriate discussion.

4.1 Growth parameters

4.2 Physiological parameters

4.3 Yield parameters

4.4 Biochemical parameters

4.5 Nutrient analysis of plant and soil

4.1 GROWTH PARAMETERS

Observations on vegetative growth parameters *viz.*, plant height, number of branches per plant, number of leaves per plant, leaf area per plant, leaf/stem ratio, fresh weight of leaf and fresh weight of stem were recorded at 30, 60, 90, 120, 150 and 180 days after planting (DAP).

4.1.1 Plant height (cm)

The data recorded on plant height as influenced by different spacings, fertilizers and their interactions at different stages of crop growth was presented in table 2. There was an increased trend in plant height with increase in spacing and fertilizers up to 180 DAP.

It was observed that the plant height was significantly influenced by different spacings at all stages of crop growth except at 30 and 60 DAP. The

maximum plant height *i.e.*, 28.04, 37.00 and 44.18 cm was recorded with 60×15 cm spacing and was on par with 45×15 cm spacing, which recorded 26.62, 34.55 and 41.72 cm at 90, 120 and 180 DAP respectively. At 150 DAP, the maximum plant height (39.88 cm) was recorded with 60×15 cm spacing followed by 45×15 cm spacing (37.65 cm). The minimum plant height *i.e.*, 22.30, 31.87, 37.12 and 39.16 cm was recorded at 90, 120, 150 and 180 DAP respectively with a spacing of 30×15 cm.

The data clearly showed that different levels of fertilizer dose significantly influenced the plant height at all stages of crop growth except at 30 DAP. At 60 DAP, the maximum plant height (16.64 cm) was recorded with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ which was on par with the fertilizer application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ (16.27 cm) and 80 kg N ha⁻¹ + 20 kg S ha⁻¹ (15.89 cm).

At 90 DAP, the maximum plant height (28.20 cm) was recorded with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ which was on par with the fertilizer application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ (27.29 cm). At 120 DAP, the maximum plant height (37.03 cm) was recorded with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ which was on par with the fertilizer application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ (35.40 cm) and 80 kg N ha⁻¹ + 20 kg S ha⁻¹ (34.22 cm).

At 150 DAP, the maximum plant height (41.48 cm) was recorded with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ followed by the fertilizer application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ (39.22 cm). At 180 DAP, the maximum plant height (44.23 cm) was recorded with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ which was on par with the fertilizer application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ (42.70 cm) and 80 kg N ha⁻¹ + 20 kg S ha⁻¹ (41.41 cm). The minimum plant height *i.e.*, 15.34, 21.98, 31.23, 34.75 and 38.40 cm at 60, 90, 120, 150 and 180 DAP respectively was recorded with control treatment.

Interactions had shown a non-significant influence on plant height at all stages of the crop growth.

The plant height significantly increased with increase in spacing. It is apparent from these trends that with increase in spacing *i.e.* with concurrent

decrease in plant density, vegetative growth of the plant was promoted. This may be due to lesser competition between plants at lower plant densities for nutrients, water, light etc. Similar results were reported by Saha *et al.* (2014) in patchouli, Patel and Kushwaha (2013) in ocimum, Prasad and Saxena (1980) in pepper mint and Vadiel *et al.* (1980) in bergamot mint.

The plant height was increased with increase in fertilizer application. It is fact that nitrogen is very essential for plant growth because it is a main constituent of proteins, nucleic acids, certain hormones and chlorophyll, which are important for plant growth. The increase in plant height with the application of sulphur might be due to its use in the manufacture of chlorophyll. Similar results were observed by Izhar *et al.* (2015) in *Mentha arvensis*, Kumar *et al.* (2015) *Mentha spicata*, Hore *et al.* (2014) in garlic, Saha *et al.* (2014) in patchouli, Kumar *et al.* (2010) in menthol mint var. Kosi, Sharma and Kanjilal (1999) in *Mentha piperata* and Ram *et al.* (1995) in bergamot mint.

4.1.2 Number of branches plant⁻¹

The experiment revealed that there were significant differences in number of branches per plant due to different spacings and fertilizer doses and their interaction effects at 30, 60, 90, 120, 150 and 180 DAP (Table 3). There was an increased trend in number of branches per plant with increase in spacing and fertilizer dose up to 180 DAP.

It was observed that the number of branches per plant was significantly influenced by different spacings at all stages of crop growth except at 30 DAP. The maximum number of branches per plant *i.e.*, 20.04, 29.26, 37.35, 43.52 and 47.69 was recorded with 60×15 cm spacing followed by 45×15 cm spacing which recorded 16.94, 24.93, 30.38, 35.74 and 39.69 at 60, 90, 120, 150 and 180 DAP respectively. The minimum number of branches per plant *i.e.*, 14.04, 20.04, 23.33, 28.62 and 32.40 was recorded at 60, 90, 120, 150 and 180 DAP respectively with 30×15 cm spacing.

The data clearly showed that different levels of fertilizer dose significantly influenced the number of branches per plant at all stages of crop growth except at 30 DAP. At 60 DAP, the maximum number of branches per plant (19.25) was recorded with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ which was

on par with the fertilizer application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ (18.03). At 90, 120, 150 and 180 DAP, the maximum number of branches per plant *i.e.*, 28.15, 34.50, 40.61 and 45.20 was recorded with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ followed by the fertilizer application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ which recorded 25.44, 31.55, 37.26 and 41.18 respectively. The minimum number of branches per plant *i.e.*, 14.18, 21.40, 26.35, 31.48 and 34.95 was recorded at 60, 90, 120, 150 and 180 DAP respectively with control treatment.

Interactions had shown a significant influence on number of branches per plant at all stages of crop growth except at 30 and 60 DAP. At 90, 120, 150 and 180 DAP, the maximum number of branches per plant *i.e.*, 33.30, 41.20, 47.80 and 53.10 was recorded with 60×15 cm spacing and application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ followed by 60×15 cm spacing and application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ which recorded 30.10, 38.50, 44.56 and 49.06 respectively. The minimum number of branches per plant *i.e.*, 16.26, 19.10, 25.16 and 28.15 was recorded at 90, 120, 150 and 180 DAP respectively with 30×15 cm spacing in control treatment.

The number of branches per plant significantly increased with increase in spacing. These results showed that wider planting provided more space to plant and reduced the competition between plants, which led to more number of branches per plant. Similar results were reported by Saha *et al.* (2014) and Ramachandra *et al.* (2003) in patchouli.

The number of branches per plant was increased with increase in fertilizer application. This might be due to favourable function of nitrogen, which is a major structural constituent of cell, helps in stimulating the cell division and cell elongation. Sulphur played a significant role in overall biosynthesis processes and used in the manufacture of chlorophyll. These results were in confirmation with the findings of Meena *et al.* (2014) in coriander, Patel and Kushwaha (2013) in *Ocimum basilicum* var. *glaberratum*, Raina *et al.* (2013) in *Ocimum sanctum* and Abbass (2009) in *Mentha spicata*.

4.1.3 Number of leaves plant⁻¹

There were significant differences in number of leaves per plant due to different spacings and fertilizer doses and their interaction effects at 30, 60, 90, 150 and 180 DAP (Table 4). There was an increased trend in number of leaves per plant with increase in spacing, fertilizer dose up to 150 DAP and later it decreased at 180 DAP.

It was observed that the number of leaves per plant was significantly influenced by different spacings at all stages of crop growth except at 30 DAP. The maximum number of leaves per plant *i.e.*, 654.36, 1299.65, 1500.11, 1620.89 and 1492.61 was recorded with 60×15 cm spacing followed by 45×15 cm spacing which recorded 563.74, 1080.49, 1252.46, 1392.57 and 1263.57 at 60, 90, 120, 150 and 180 DAP respectively. The minimum number of leaves per plant *i.e.*, 407.95, 795.96, 934.26, 1050.77 and 918.70 was recorded at 60, 90, 120, 150 and 180 DAP respectively with 30×15 cm spacing.

The data clearly showed that different levels of fertilizer dose significantly influenced the number of leaves per plant at all stages of crop growth except at 30 DAP. The maximum number of leaves per plant *i.e.*, 587.94, 1181.58, 1359.80, 1500.53 and 1345.40 was recorded with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ followed by the fertilizer application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ which recorded 558.81, 1090.28, 1264.01, 1396.08 and 1258.86 at 60, 90, 120, 150 and 180 DAP respectively. The minimum number of leaves per plant *i.e.*, 496.70, 951.37, 1109.10, 1221.40 and 1115.78 was recorded at 60, 90, 120, 150 and 180 DAP respectively with control treatment.

Interactions had shown a significant influence on the number of leaves per plant at all stages of crop growth except at 30 DAP. At 60, 90, 120, 150 and 180 DAP, the maximum number of leaves per plant *i.e.*, 710.46, 1467.11, 1657.97, 1771.43 and 1638.21 was recorded with 60×15 cm spacing and fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ followed by 60×15 cm spacing and application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ which recorded 676.03, 1341.92, 1539.18, 1659.60 and 1540.74 respectively. The minimum number of leaves per plant *i.e.*, 386.13, 724.83, 842.80, 922.76 and 826.65 was recorded at 60, 90, 120, 150 and 180 DAP respectively with 30×15 cm spacing in control treatment.

The number of leaves per plant significantly increased with increase in age of the crop but at 180 DAP the number of leaves per plant decreased due to leaf fall and senescence of older leaves. The number of leaves per plant significantly increased with increase in spacing. These results showed that wider planting provided more space to plant and reduced the competition between plants, which led to more number of leaves per plant. Similar results were reported by Saha *et al.* (2014) in patchouli, Prasad and Saxena (1980) in pepper mint and Vadiel *et al.* (1980) in bergamot mint.

The number of leaves per plant increased with increase in fertilizer application. The production of more number of leaves per plant with combined application of nitrogen + sulphur might be due to the reason that higher concentration of nitrogen has tendency to increase cell number with an overall increase in leaf production (Bijimol and Singh, 2001). The number of leaves per plant increased by the application of sulphur, which played a pivotal role in various plant growth and development processes since sulphur is a constituent of amino acids. With the supply of sulphur, the process of tissue differentiation and development might have increased, resulting in increase in number and size of leaves (Kakaraparathi *et al.* 2013). The combined application of nitrogen and sulphur showed positive effects on the vegetative growth and in accumulation of materials. Similar results for number of leaves per plant were also noticed by Izhar *et al.* (2015) in *Mentha arvensis*, Hore *et al.* (2014) in garlic, Saha *et al.* (2014) in patchouli, Kakaraparathi *et al.* (2013) in *Ocimum tenuiflorum* var. CIM-AYU and Abbass (2009) in mint.

4.1.4 Leaf area per plant (cm²)

There were significant differences in leaf area per plant due to different spacings and fertilizer doses and their interaction effects at 30, 60, 90, 150 and 180 DAP (Table 5). There was an increased trend in leaf area per plant with increase in spacing and fertilizer dose up to 150 DAP and thereafter leaf area per plant decreased at 180 DAP.

It was observed that the leaf area per plant was significantly influenced by different spacings at all stages of crop growth except at 30 DAP. The maximum leaf area per plant *i.e.*, 889.78, 1615.05, 3153.87, 3735.22 and 2855.18 cm² was

recorded with 60×15 cm spacing followed by 45×15 cm spacing which recorded 770.14, 1296.70, 2384.01, 2953.67 and 2143.33 cm² at 60, 90, 120, 150 and 180 DAP respectively. The minimum leaf area per plant *i.e.*, 564.28, 880.32, 1654.67, 2024.67 and 1453.11 cm² was recorded at 60, 90, 120, 150 and 180 DAP respectively with 30×15 cm spacing.

Different levels of fertilizer dose significantly influenced the leaf area per plant at all stages of crop growth except at 30 DAP. The maximum leaf area per plant *i.e.*, 829.42, 1465.45, 2825.60, 3407.33 and 2512.50 cm² was recorded with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ followed by the application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ which recorded 763.31, 1322.39, 2519.84, 3063.23 and 2293.93 cm² at 60, 90, 120, 150 and 180 DAP respectively. The minimum leaf area per plant *i.e.*, 654.40, 1081.53, 1988.85, 2454.52 and 1773.89 cm² was recorded at 60, 90, 120, 150 and 180 DAP respectively with control treatment.

Interactions had shown a non-significant influence on leaf area per plant at all stages of the crop growth.

The leaf area per plant significantly increased with increase in spacing, which may be due to better utilization of sunlight and nutrients resulting in larger leaf area and there by better photosynthesis. These results were in confirmation with the findings of Patel and Kushwaha (2013) in *Ocimum basilicum* var. *glabratum* and Ramachandra *et al.* (2003) in patchouli.

The leaf area per plant was increased with increase in fertilizer application. It is the fact that nitrogen is very essential for plant growth because it is a main constituent of proteins, nucleic acids, certain hormones and chlorophyll, which are important for plant growth. The increase in leaf area per plant with the application of sulphur might be due to its use in the manufacture of chlorophyll. These results were in confirmation with the findings of Izhar *et al.* (2015) in *Mentha arvensis* and Kakaraparathi *et al.* (2013) in *Ocimum tenuiflorum* variety CIM-AYU.

4.1.5 Leaf/stem ratio on weight basis

There were significant differences in leaf/stem ratio due to different spacings and fertilizer doses and their interaction effects at 30, 60, 90, 150 and

180 DAP (Table 6). There was a decreased trend in leaf/stem ratio with increase in spacing and fertilizer dose up to 180 DAP.

It was observed that the leaf/stem ratio was significantly influenced by different spacings at all stages of the crop growth. The maximum leaf/stem ratio *i.e.*, 2.61, 2.18, 1.95, 1.90, 1.86 and 1.51 was recorded with 30×15 cm spacing followed by 45×15 cm spacing which recorded 2.37, 1.96, 1.90, 1.80 and 1.46 at 30, 60, 90, 150 and 180 DAP respectively and was on par with 45×15 cm spacing (1.86) at 120 DAP. The minimum leaf/stem ratio *i.e.*, 2.35, 1.87, 1.81, 1.69, 1.66 and 1.42 was recorded at 30, 60, 90, 120, 150 and 180 DAP with 60×15 cm spacing.

It was observed that different levels of fertilizer dose significantly influenced the leaf/stem ratio at all stages of crop growth except at 30 DAP. At 60 and 180 DAP, the maximum leaf/stem ratio *i.e.*, 2.09 and 1.50 was recorded with control treatment and was on par with the fertilizer application of 80 kg N ha⁻¹ + 20 kg S ha⁻¹ which recorded 2.05 and 1.48 respectively. At 90, 120 and 150 DAP, the maximum leaf/stem ratio *i.e.*, 2.00, 1.92 and 1.87 was recorded with control treatment followed by the application of 80 kg N ha⁻¹ + 20 kg S ha⁻¹ which recorded 1.94, 1.85 and 1.80 respectively. The minimum leaf/stem ratio *i.e.*, 1.91, 1.78, 1.71, 1.69 and 1.42 was recorded at 60, 90, 120, 150 and 180 DAP respectively with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹.

Interactions had shown a non-significant influence on leaf/stem ratio at all stages of crop growth.

The leaf to stem ratio significantly declined with increasing age, decreased with increase in spacing and fertilizer doses. This indicates that a proportionately higher accumulation of dry matter in stem was observed with increase in crop age, spacing and fertilizer doses. Similar results for leaf/stem ratio were reported by Kassahun *et al.* (2011) in mint, Kattimani and Reddy (2001) in Japanese mint, Ram *et al.* (1995) in *Mentha piperata* and Sharma and Kanjilal (1999) in bergamot mint.

4.1.6 Fresh weight of leaf per plant (g)

There were significant differences on fresh weight of leaf per plant due to different spacings and fertilizer doses and their interaction effects at 30, 60, 90,

150 and 180 DAP (Table 7). There was an increased trend in fresh weight of leaf per plant with increase in spacing and fertilizer dose up to 150 DAP and thereafter fresh weight of leaf per plant decreased at 180 DAP.

It was observed that the fresh weight of leaf per plant was significantly influenced by different spacings at all stages of crop growth except at 30 DAP. The maximum fresh weight of leaf per plant *i.e.*, 64.29, 111.07, 127.64, 133.05 and 117.52 g was recorded with a spacing of 60×15 cm followed by 45×15 cm spacing, which recorded 56.73, 100.08, 116.11, 121.64 and 104.85 g at 60, 90, 120, 150 and 180 DAP respectively. The minimum fresh weight of leaf per plant *i.e.*, 34.35, 60.98, 72.01, 74.77 and 63.87 g was recorded at 60, 90, 120, 150 and 180 DAP respectively with 30×15 cm spacing .

Different levels of fertilizer dose significantly influenced the fresh weight of leaf per plant at all stages of crop growth except at 30 DAP. At 60, 90, 120, 150 and 180 DAP, the maximum fresh weight of leaf per plant *i.e.*, 57.26, 96.97, 111.30, 116.84 and 102.04 g was recorded with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ followed by the fertilizer application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ which recorded 53.14, 91.77, 106.67, 111.85 and 97.26 g respectively. The minimum fresh weight of leaf per plant *i.e.*, 46.84, 85.51, 99.32, 103.45 and 88.46 g was recorded at 60, 90, 120, 150 and 180 DAP respectively with control treatment.

Among interactions, significant influence was observed on fresh weight of leaf per plant at 90, 120, 150 and 180 DAP and a non-significant influence was observed at 30 and 60 DAP. The maximum fresh weight of leaf per plant *i.e.*, 117.27, 136.61, 142.03 and 126.43 g was recorded with a spacing of 60×15 cm and application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ followed by 60×15 cm spacing and application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ which recorded 112.49, 130.11, 136.24 and 120.52 g at 90, 120, 150 and 180 DAP respectively. The minimum fresh weight of leaf per plant *i.e.*, 57.30, 68.10, 70.30 and 59.61 g was recorded at 90, 120, 150 and 180 DAP respectively with 30×15 cm spacing in control treatment.

The fresh weight of leaf per plant significantly increased with increase in spacing. These results showed that wider planting provided more space to plant

and reduced the competition between plants, which led to increase in fresh weight of leaf. The production of more fresh weight of leaf per plant with the application of nitrogen might be due to the reason that higher concentration of nitrogen has tendency to increase cell number with an overall increased in leaf production. The fresh weight of leaf per plant increased due to the function of sulphur, which played a pivotal role in various plant growth and development processes since sulphur is a constituent of amino acids. With the supply of sulphur, the process of tissue differentiation and development might have increased, resulting in increase in number, size of leaves and thereby fresh weight of leaf. The combined application of nitrogen and sulphur showed positive effects on the vegetative growth and in accumulation of materials. Similar results for fresh weight of leaf per plant were also reported by Reddy *et al.* (2014) in lemon grass var. Krishna, Kakaraparthi *et al.* (2013) in *Ocimum tenuiflorum* var. CIM-AYU, Patel and Kushwaha (2013) in *Ocimum canum* var. Oc-11, Raina *et al.* (2013) in *Ocimum sanctum* and Roghaye *et al.* (2012) in *Ocimum basilicum*.

4.1.7 Fresh weight of stem per plant (g)

There were significant differences in fresh weight of stem per plant due to different spacings and fertilizer doses and their interaction effects at 30, 60, 90, 150 and 180 DAP (Table 8). There was an increased trend in fresh weight of stem per plant with increase in spacing and fertilizer dose up to 180 DAP.

It was observed that the fresh weight of stem per plant was significantly influenced by different spacings at all stages of crop growth except at 30 DAP. The maximum fresh weight of stem per plant *i.e.*, 34.27, 61.26, 75.60, 80.15 and 82.81 g was recorded with a spacing of 60×15 cm followed by 45×15 cm spacing, which recorded 28.88, 52.68, 62.63, 67.48 and 71.66 g at 60, 90, 120, 150 and 180 DAP respectively. The minimum fresh weight of stem per plant *i.e.*, 15.77, 31.31, 38.21, 40.32 and 42.15 g was recorded at 60, 90, 120, 150 and 180 DAP respectively with 30×15 cm spacing .

Different levels of fertilizer dose significantly influenced the fresh weight of stem per plant at all stages of crop growth except at 30 DAP. At 60 DAP, the maximum fresh weight of stem per plant (30.33 g) was recorded with the

fertilizer application of $140 \text{ kg N ha}^{-1} + 20 \text{ kg S ha}^{-1}$ which was on par with the fertilizer application of $110 \text{ kg N ha}^{-1} + 20 \text{ kg S ha}^{-1}$ (27.33 g). At 90, 120, 150 and 180 DAP, the maximum fresh weight of stem per plant *i.e.*, 54.55, 65.56, 69.54 and 71.95 g was recorded with the fertilizer application of $140 \text{ kg N ha}^{-1} + 20 \text{ kg S ha}^{-1}$ followed by application of $110 \text{ kg N ha}^{-1} + 20 \text{ kg S ha}^{-1}$ which recorded 49.91, 60.68, 65.25 and 67.37 g respectively. The minimum fresh weight of stem per plant *i.e.*, 22.79, 43.18, 52.05, 55.81 and 59.27 g was recorded at 60, 90, 120, 150 and 180 DAP respectively with control treatment.

Among interactions, significant influence was observed on fresh weight of stem per plant at 90, 120, 150 and 180 DAP and a non-significant influence was observed at 30 and 60 DAP. The maximum fresh weight of stem per plant *i.e.*, 68.26, 84.80, 89.23 and 91.20 g was recorded with a spacing of $60 \times 15 \text{ cm}$ and application of $140 \text{ kg N ha}^{-1} + 20 \text{ kg S ha}^{-1}$ followed by $60 \times 15 \text{ cm}$ spacing and application of $110 \text{ kg N ha}^{-1} + 20 \text{ kg S ha}^{-1}$ which recorded 62.33, 78.41, 85.40 and 85.83 g at 90, 120, 150 and 180 DAP respectively. The minimum fresh weight of stem per plant *i.e.*, 27.01, 34.23, 36.01 and 38.31 g was recorded at 90, 120, 150 and 180 DAP respectively with a spacing of $30 \times 15 \text{ cm}$ in control treatment.

The fresh weight of stem per plant significantly increased with increase in spacing. These results showed that wider planting provided more space to plant and reduced the competition between plants, which led to increase in fresh weight of stem. The production of more fresh weight of stem per plant with the application of nitrogen might be due to reason that higher concentration of nitrogen has tendency to increase cell number with an overall increased in stem production. The fresh weight of stem per plant increased due to the function of sulphur, which played a pivotal role in various plant growth and development processes since sulphur is a constituent of amino acids. With the supply of sulphur, the process of tissue differentiation and development might have increased, resulting in increase in number of branches and thereby fresh weight of stem per plant. The combined application of nitrogen and sulphur showed positive effects on the vegetative growth and in accumulation of materials.

Similar results for fresh weight of stem per plant were reported by Patel and Kushwaha (2013) in *Ocimum basilicum* var. *glabratum*.

4.2 PHYSIOLOGICAL PARAMETERS

4.2.1 Leaf area index

There were significant differences in leaf area index due to different spacings and fertilizer doses and their interaction effects at 30, 60, 90, 120, 150 and 180 DAP (Table 9). There was an increased trend in leaf area index with decrease in spacing, increase in fertilizer doses and increased up to 150 DAP and thereafter declined at 180 DAP.

It was observed that the leaf area index was significantly influenced by different spacings at all stages of crop growth. At 30, 90, and 150 DAP, the maximum leaf area index *i.e.*, 0.511, 1.956 and 4.499 was recorded with a spacing of 30×15 cm and was on par with a spacing of 45×15 cm, which recorded 0.361, 1.921 and 4.376 respectively. At 60, 120 and 180 DAP the maximum leaf area index *i.e.*, 1.254, 3.676 and 3.229 was recorded with a spacing of 30×15 cm followed by 45×15 cm spacing, which recorded 1.141, 3.534 and 3.175 respectively. The minimum leaf area index *i.e.*, 0.303, 0.989, 1.795, 3.504, 4.150 and 3.172 was recorded at 30, 60, 90, 120, 150 and 180 DAP respectively with 60×15 cm spacing.

Different levels of fertilizer dose significantly influenced leaf area index at all stages of crop growth except at 30 DAP. The maximum leaf area index *i.e.*, 1.270, 2.191, 4.222, 5.140 and 3.754 was recorded with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ followed by the fertilizer application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ which recorded 1.161, 1.977, 3.756, 4.601 and 3.411 at 60, 90, 120, 150 and 180 DAP respectively. The minimum leaf area index *i.e.*, 0.990, 1.621, 2.960, 3.638 and 2.615 was recorded at 60, 90, 120, 150 and 180 DAP respectively with control treatment.

Among interactions, significant influence was observed on leaf area index at 120, 150 and 180 DAP and a non-significant influence was observed at 30, 60 and 90 DAP. At 120 and 150 DAP, the maximum leaf area index *i.e.*, 4.435 and 5.520 was recorded with a spacing of 30×15 cm and application of 140 kg N ha⁻¹

+ 20 kg S ha⁻¹ followed by 45×15 cm spacing and application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ which recorded 4.121 and 5.203 whereas the minimum leaf area index *i.e.*, 2.881 and 3.598 was recorded with a spacing of 60×15 cm in control treatment respectively.

At 180 DAP, the maximum leaf area index (3.985) was recorded with a spacing of 30×15 cm and application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ followed by 60×15 cm spacing and application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ (3.698). The minimum leaf area index (2.461) was recorded with a spacing of 30×15 cm in control treatment.

The green leaf surface that intercepts light radiation is one of the important physiological attributes for higher yields in any crop. The leaf area index significantly increased with age in all the treatment combinations up to 150 DAP. After this, LAI decreased possibly owing to senescence and leaf fall. Spacing has significant influence on LAI. LAI decreased with increase in spacing. The higher LAI in narrow spacing is due to more number of leaves per unit area. LAI increased with increase in fertilizer application due to increased number of leaves. These findings were in conformity with the results of Saha *et al.* (2014) in patchouli (*Pogostemon cablin* Benth.), Mishu *et al.* (2013) in onion and Ram *et al.* (1995) in bergamot mint.

4.2.2 Dry matter partitioning and total dry matter production per plant (g)

4.2.2.1 Dry weight of leaf per plant (g)

There were significant differences in dry weight of leaf per plant due to different spacings and fertilizer doses and their interaction effects at 30, 60, 90, 150 and 180 DAP (Table 10). There was an increased trend in dry weight of leaf per plant with increase in spacing and fertilizer dose up to 150 DAP and thereafter dry weight of leaf decreased at 180 DAP.

It was observed that the dry weight of leaf per plant was significantly influenced by different spacings at all stages of crop growth except at 30 DAP. The maximum dry weight of leaf per plant *i.e.*, 6.13, 13.88, 23.20, 24.97 and 20.48 g was recorded with a spacing of 60×15 cm followed by 45×15 cm spacing, which recorded 5.67, 12.20, 21.03, 22.76 and 18.83 g at 60, 90, 120, 150

and 180 DAP respectively. The minimum dry weight of leaf per plant *i.e.*, 3.45, 6.97, 13.29, 14.37 and 10.29 g was recorded at 60, 90, 120, 150 and 180 DAP respectively with 30×15 cm spacing.

Different levels of fertilizer dose significantly influenced the dry weight of leaf per plant at all stages of crop growth except at 30 DAP. At 60, 90, 120 and 180 DAP, the maximum dry weight of leaf per plant *i.e.*, 5.53, 11.99, 20.49 and 18.53 g was recorded with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ followed by the fertilizer application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ which recorded 5.15, 11.45, 19.91 and 17.38 g respectively. At 150 DAP, the maximum dry weight of leaf per plant (22.18 g) was recorded with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ which was on par with the fertilizer application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ (21.51 g). The minimum dry weight of leaf per plant *i.e.*, 4.74, 9.82, 17.71, 18.98 and 14.21 g was recorded at 60, 90, 120, 150 and 180 DAP respectively with control treatment.

Among interactions, non-significant influence was observed on dry weight of leaf per plant at all stages of crop growth.

4.2.2.2 Dry weight of stem per plant (g)

There were significant differences on dry weight of stem per plant due to different spacings and fertilizer doses and their interaction effects at 30, 60, 90, 120, 150 and 180 DAP (Table 11). There was an increased trend in dry weight of stem per plant with increase in spacing and fertilizer dose upto 180 DAP.

It was observed that the dry weight of stem per plant was significantly influenced by different spacings at all stages of crop growth except at 30 DAP. The maximum dry weight of stem per plant *i.e.*, 1.50, 11.86, 14.10 and 16.10 g was recorded with a spacing of 60×15 cm followed by 45×15 cm spacing, which recorded 1.30, 10.58, 12.94 and 15.07 g at 60, 120, 150 and 180 DAP respectively. At 90 DAP, the maximum dry weight of stem per plant (4.56 g) was recorded with a spacing of 60×15 cm, which was on par with 45×15 cm spacing (4.48 g). The minimum dry weight of stem per plant *i.e.*, 1.01, 3.21, 5.95, 7.15 and 9.00 g was recorded at 60, 90, 120, 150 and 180 DAP respectively with 30×15 cm spacing.

Different levels of fertilizer dose significantly influenced the dry weight of stem per plant at all stages of crop growth except at 30 DAP. At 60, 90, 120, 150 and 180 DAP, the maximum dry weight of stem per plant *i.e.*, 1.45, 4.56, 10.41, 12.63 and 14.74 g was recorded with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ which was on par with the fertilizer application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ which recorded 1.34 and 4.27 g at 60 and 90 DAP followed by the fertilizer application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ which recorded 9.80, 11.75 and 13.91 g at 120, 150 and 180 DAP respectively. The minimum dry weight of stem per plant *i.e.*, 1.08, 3.63, 8.50, 10.05 and 12.03 g was recorded at 60, 90, 120, 150 and 180 DAP respectively with control treatment.

Among interactions, non-significant influence was observed on dry weight of stem per plant at all stages of crop growth.

The dry weight of leaf and stem per plant significantly increased with increase in spacing and levels of fertilizer dose due to increased nutrient uptake with wider spacing. This might be due to lesser competition between plants at lower plant densities. The results on dry weight of leaf and stem per plant indicate that the dry matter partitioning was high in leaf compared to the stem with increase in spacing and fertilizer doses, as it is the economic part of the plant. Similar results were reported by Saha *et al.* (2014) in patchouli and Meena *et al.* (2014) in coriander.

4.2.2.3 Total dry matter production per plant (g)

There were significant differences in total dry matter production per plant due to different spacings and fertilizer doses and their interaction effects at 30, 60, 90, 150 and 180 DAP (Table 12). There was an increased trend in total dry matter production per plant with increase in spacing and fertilizer dose up to 150 DAP and thereafter decreased at 180 DAP.

It was observed that the total dry matter production per plant was significantly influenced by different spacings at all stages of crop growth except at 30 DAP. The maximum dry matter production per plant *i.e.*, 7.63, 18.44, 35.06, 39.07 and 36.58 g was recorded with a spacing of 60×15 cm followed by 45×15 cm spacing, which recorded 6.97, 16.69, 31.62, 35.70 and 33.91 g at 60, 90, 120, 150 and 180 DAP respectively. The minimum dry matter production per

plant *i.e.*, 4.47, 10.18, 19.24, 21.47 and 19.30 g was recorded at 60, 90, 120, 150 and 180 DAP respectively with 30×15 cm spacing.

Different levels of fertilizer dose significantly influenced the total dry matter production per plant at all stages of crop growth except at 30 DAP. At 60, 90, 120, 150 and 180 DAP, the maximum dry matter production per plant *i.e.*, 6.99, 16.55, 30.90, 34.82 and 33.28 g was recorded with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ followed by the fertilizer application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ which recorded 6.49, 15.72, 29.71, 33.20 and 31.29 g respectively. The minimum dry matter production per plant *i.e.*, 5.82, 13.45, 26.21, 29.03 and 26.24 g was recorded at 60, 90, 120, 150 and 180 DAP respectively with control treatment.

Among interactions, non-significant influence was observed on total dry matter production per plant at 30 DAP and a significant influence was observed at 60, 90, 120, 150 and 180 DAP. The maximum dry matter production per plant *i.e.*, 8.54, 19.82, 37.16, 41.64 and 39.13 g was recorded with a spacing of 60×15 cm and application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ followed by 60×15 cm spacing and application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ which recorded 7.75, 19.12, 36.00, 39.96 and 38.01 g respectively. The minimum dry matter production per plant *i.e.*, 4.23, 8.93, 16.88, 18.81 and 15.83 g was recorded at 60, 90, 120, 150 and 180 DAP respectively with a spacing of 30×15 cm in control treatment.

The total dry matter production per plant was significantly higher in wider spaced plants and higher fertilizer application, which could be due to lesser competition between plants, availability of more space for lateral growth and increased uptake of nutrients by plants. Similar results were reported by Mishu *et al.* (2013) in onion and Abbass (2009) in *Mentha spicata*.

4.2.3 Crop growth rate (g m⁻² d⁻¹)

There were significant differences in crop growth rate due to different spacings and fertilizer doses and their interaction effects at 30-60, 60-90, 90-120, 120-150 and 150-180 DAP (Table 13). There was an increased trend in crop

growth rate with increase in fertilizer dose up to 90-120 DAP and thereafter it decreased.

It was observed that crop growth rate was significantly influenced by different spacings at all stages of crop growth, and a non-significant influence was observed at 30-60 and 150-180 DAP. The maximum crop growth rate *i.e.*, 4.800, 7.373 and 2.017 was recorded with a spacing of 45×15 cm followed by 30×15 cm spacing, which recorded 4.233, 6.709 and 1.652 at 60-90, 90-120 and 120-150 DAP respectively. The minimum crop growth rate *i.e.*, 4.004, 6.156 and 1.483 was recorded at 60-90, 90-120 and 120-150 DAP respectively with 60×15 cm spacing.

Different levels of fertilizer dose significantly influenced crop growth rate at all stages of crop growth except at 30-60 and 150-180 DAP. The maximum crop growth rate *i.e.*, 4.825 and 7.179 was recorded with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ and was on par with the fertilizer application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ which recorded 4.576 and 7.035 at 60-90 and 90-120 DAP respectively. At 120-150 DAP, the maximum crop growth rate (1.957) was recorded with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ followed by the fertilizer application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ (1.748). The minimum crop growth rate *i.e.*, 3.727, 6.306 and 1.421 was recorded at 60-90, 90-120 and 120-150 DAP respectively with control treatment.

Among interactions, non-significant influence was observed on crop growth rate at all stages of crop growth.

Maximum CGR was recorded at optimum spacing and increased with increase in fertilizer doses due to optimum utilization of water, nutrients, light etc. CGR was low initially which progressively increased to reach the peak during 90-120 DAP and later decreased. The decrease may partly be due to start of leaf senescence. These results were in accordance with the findings of Ahirwar *et al.* (2014) in isabgol, Chandana and Dorajeerao (2014) in gladiolus cv. White prosperity, Kakaraparathi *et al.* (2013) in *Ocimum tenuiflorum* variety CIM-AYU, Aliyu *et al.* (2008) and Nasreen *et al.* (2003) in onion.

4.2.4 Net assimilation rate (mg cm⁻² d⁻¹)

There were significant differences on net assimilation rate due to different spacings and fertilizer doses at 30-60, 60-90, 90-120, 120-150 and 150-180 DAP (Table 14). The data did not follow any particular pattern but on an average over the observations, decreased trend in net assimilation rate was recorded with increase in fertilizer dose and age of the crop.

It was observed that net assimilation rate was significantly influenced by different spacings only at 90-120 and 120-150 DAP. The maximum net assimilation rate *i.e.*, 0.281 and 0.052 was recorded with a spacing of 45×15 cm followed by 30×15 cm spacing which recorded 0.247 and 0.044 at 90-120 and 120-150 DAP respectively. The minimum net assimilation rate *i.e.*, 0.243 and 0.039 was recorded at 90-120 and 120-150 DAP respectively with 60×15 cm spacing.

Different levels of fertilizer dose at 90-120 and 120-150 DAP significantly influenced net assimilation rate and a non-significant influence was observed at 30-60, 60-90 and 150-180 DAP. At 90-120 DAP, the maximum net assimilation rate (0.283) was recorded with control treatment which was on par with the fertilizer application of 80 kg N ha⁻¹ + 20 kg S ha⁻¹ (0.260) where as the minimum net assimilation rate (0.231) was recorded with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹. At 120-150 DAP, the maximum net assimilation rate (0.048) was recorded with control treatment and also with 80 kg N ha⁻¹ + 20 kg S ha⁻¹ (0.048). The minimum net assimilation rate (0.042) was recorded with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ and 110 kg N ha⁻¹ + 20 kg S ha⁻¹ (0.042).

Among interactions, non-significant influence was observed on net assimilation rate at all stages of crop growth.

Maximum NAR was recorded with optimum spacing due to optimum utilization of water, nutrients, light etc. and decreased in wider spacing due to increased leaf area and shading of lower leaves resulting in lower photosynthetic efficiency of canopy (Gupta, 1988). From the observations made on NAR, the data did not follow any particular pattern and indicative of any trends with the application of fertilizer doses. On an average over the observations, with increase in the fertilizer dose applied to the soil the NAR decreased with higher values

noticed in control treatment and $80 \text{ kg N ha}^{-1} + 20 \text{ kg S ha}^{-1}$. Similar results were reported by Kakaraparathi *et al.* (2013) in *Ocimum tenuiflorum* variety CIM-AYU, Singh *et al.* (1989) in mint and Vijay Kumar *et al.* (1986) in China aster cv. Ostrich Plume Mixed.

4.3 YIELD PARAMETERS

The yield parameters like herbage yield per plant (g), herbage yield per plot (kg) and herbage yield per hectare (q) were recorded at 90, 120, 150 and 180 DAP.

4.3.1 Herbage yield per plant (g)

The data pertaining to herbage yield per plant (Table 15) showed that there was an increased trend in herbage yield per plant with increase in spacing and fertilizer doses. The herbage yield per plant increased up to 150 DAP and thereafter decreased at 180 DAP.

It was observed that the herbage yield per plant was significantly influenced by different spacings at all stages of crop growth. The maximum herbage yield per plant *i.e.*, 172.33, 203.30, 215.29 and 200.61 g was recorded with a spacing of 60×15 cm followed by 45×15 cm spacing, which recorded 152.76, 178.86, 189.14 and 176.78 g at 90, 120, 150 and 180 DAP respectively. The minimum herbage yield per plant *i.e.*, 92.29, 110.30, 115.15 and 106.02 g was recorded at 90, 120, 150 and 180 DAP respectively with 30×15 cm spacing.

Different levels of fertilizer dose significantly influenced the herbage yield per plant at all stages of crop growth. At 90, 120, 150 and 180 DAP, the maximum herbage yield per plant *i.e.*, 151.52, 176.92, 187.82 and 174.09 g was recorded with the fertilizer application of $140 \text{ kg N ha}^{-1} + 20 \text{ kg S ha}^{-1}$ followed by the fertilizer application of $110 \text{ kg N ha}^{-1} + 20 \text{ kg S ha}^{-1}$ which recorded 141.68, 167.43, 177.17 and 164.77 g respectively. The minimum herbage yield per plant *i.e.*, 128.69, 151.47, 159.29 and 147.93 g was recorded at 90, 120, 150 and 180 DAP respectively with control treatment.

Among interactions, non-significant influence was observed on herbage yield per plant at 90 DAP and a significant influence was observed at 120, 150 and 180 DAP. The maximum herbage yield per plant *i.e.*, 221.52, 235.58 and 217.93 g was recorded with a spacing of 60×15 cm and application of 140 kg N

$\text{ha}^{-1} + 20 \text{ kg S ha}^{-1}$ followed by $60 \times 15 \text{ cm}$ spacing and application of $110 \text{ kg N ha}^{-1} + 20 \text{ kg S ha}^{-1}$ which recorded 208.56, 221.75 and 206.75 g at 120, 150 and 180 DAP respectively. The minimum herbage yield per plant *i.e.*, 102.43, 106.35 and 97.92 g was recorded at 120, 150 and 180 DAP respectively with a spacing of $30 \times 15 \text{ cm}$ in control treatment.

4.3.2 Herbage yield per plot (kg)

The data pertaining to herbage yield per plot (Table 16) showed that there was an increased trend in herbage yield per plot due to increased fertilizer doses and the maximum herbage yield per plot was recorded with optimum spacing. The herbage yield per plot increased up to 150 DAP and thereafter decreased at 180 DAP.

It was observed that the herbage yield per plot was significantly influenced by different spacings at all stages of crop growth. The maximum herbage yield per plot *i.e.*, 17.22, 20.14, 21.15 and 19.88 kg was recorded with an optimum spacing of $45 \times 15 \text{ cm}$ followed by $30 \times 15 \text{ cm}$ spacing, which recorded 14.95, 17.78, 18.50 and 17.22 kg at 90, 120, 150 and 180 DAP respectively. The minimum herbage yield per plot *i.e.*, 13.81, 16.36, 17.32 and 16.09 was recorded at 90, 120, 150 and 180 DAP respectively with $60 \times 15 \text{ cm}$ spacing.

Different levels of fertilizer dose significantly influenced the herbage yield per plot at all stages of crop growth. At 90, 120, 150 and 180 DAP, the maximum herbage yield per plot *i.e.*, 16.70, 19.58, 20.46 and 19.17 kg was recorded with the fertilizer application of $140 \text{ kg N ha}^{-1} + 20 \text{ kg S ha}^{-1}$ followed by the fertilizer application of $110 \text{ kg N ha}^{-1} + 20 \text{ kg S ha}^{-1}$ which recorded 15.68, 18.45, 19.45 and 18.18 kg respectively. The minimum herbage yield per plot *i.e.*, 14.18, 16.74, 17.57 and 16.30 kg was recorded at 90, 120, 150 and 180 DAP respectively with control treatment.

Among interactions, non-significant influence was observed on herbage yield per plot at 90 DAP and a significant influence was observed at 120, 150 and 180 DAP. The maximum herbage yield per plot *i.e.*, 21.48, 22.57 and 21.20 kg was recorded with an optimum spacing of $45 \times 15 \text{ cm}$ and application of $140 \text{ kg N ha}^{-1} + 20 \text{ kg S ha}^{-1}$ followed by $45 \times 15 \text{ cm}$ spacing and application of $110 \text{ kg N ha}^{-1} + 20 \text{ kg S ha}^{-1}$ which recorded 20.37, 21.54 and 20.26 kg at 120, 150 and

180 DAP respectively. The minimum herbage yield per plot *i.e.*, 14.66, 15.57 and 14.45 kg was recorded at 120, 150 and 180 DAP respectively with a spacing of 60×15 cm in control treatment.

4.3.3 Herbage yield per hectare (q)

The data pertaining to herbage yield per hectare (Table 17) showed that there was an increased trend in herbage yield per hectare due to increased fertilizer doses and the maximum herbage yield per hectare was recorded with optimum spacing. The herbage yield per hectare increased up to 150 DAP and thereafter decreased at 180 DAP.

It was observed that the herbage yield per hectare was significantly influenced by different spacings at all stages of crop growth. The maximum herbage yield per hectare *i.e.*, 191.39, 223.82, 235.05 and 220.91 q was recorded with an optimum spacing of 45×15 cm followed by a narrow spacing of 30×15 cm which recorded 166.15, 197.60, 205.60 and 191.38 q at 90, 120, 150 and 180 DAP respectively. The minimum herbage yield per hectare *i.e.*, 153.49, 181.80, 192.47 and 178.87 q was recorded at 90, 120, 150 and 180 DAP respectively with a wider spacing of 60×15 cm.

Different levels of fertilizer dose significantly influenced the herbage yield per hectare at all stages of crop growth. At 90, 120, 150 and 180 DAP, the maximum herbage yield per hectare *i.e.*, 185.59, 217.61, 227.43 and 213.01 q was recorded with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ followed by the fertilizer application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ which recorded 174.26, 205.02, 216.16 and 202.01 q respectively. The minimum herbage yield per hectare *i.e.*, 157.56, 186.06, 195.28 and 181.12 q was recorded at 90, 120, 150 and 180 DAP respectively with control treatment.

Among interactions, non-significant influence was observed on herbage yield per hectare at 90 DAP and a significant influence was observed at 120, 150 and 180 DAP. The maximum herbage yield per hectare *i.e.*, 238.68, 250.88 and 235.64 q was recorded with a spacing of 45×15 cm and application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ followed by 45×15 cm spacing and application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ which recorded 226.33, 239.43 and 225.21 q at 120, 150 and

180 DAP respectively. The minimum herbage yield per hectare *i.e.*, 162.96, 173.07 and 160.55 q was recorded at 120, 150 and 180 DAP respectively with a spacing of 60×15 cm in control treatment.

The herbage yield per plant increased up to 150 DAP and declined afterwards. The decline might be due to senescence and fall of older leaves. The herbage yield per plant significantly increased with wider row spacing. The increased number of leaves, branches and dry matter productions recorded in wider spaced plants might be responsible for the increase in herbage yield. However, the highest herbage yield per plant in wider row spacing (60×15 cm) was not commensurate with per plot and per hectare herbage yield. This could be due to less number of plants per unit area. Hence, the highest herbage yield per plot and hectare was recorded with optimum spacing due to optimum plant population.

The herbage yield per plant, per plot and per hectare increased with increase in the fertilizer dose due to better growth of plants as reflected in the yield contributing characters like number of leaves and branches. These findings were in agreement with the reports of Izhar *et al.* (2015) in *Mentha arvensis*, Kumar *et al.* (2015) in *Mentha spicata*, Anwar *et al.* (2010) in menthol mint cv. Shivalik, Kumar *et al.* (2010) in menthol mint var. Kosi, Singh *et al.* (2003) in bergamot mint var. Kiran and Sharma and Kanjilal (1999) in *Mentha piperata*.

4.4 BIOCHEMICAL PARAMETERS

4.4.1 Essential oil content (%)

The data pertaining to essential oil content (Table 18) showed that there were no significant differences in essential oil content due to different spacings and their interaction effects. Significant differences were observed among different levels of fertilizer dose at 90, 120, 150 and 180 DAP. The essential oil content increased with increase in age of the crop up to 180 DAP.

It was observed that the essential oil content was not significantly influenced by different spacings at all stages of crop growth.

Different levels of fertilizer dose significantly influenced the essential oil content at all stages of crop growth. At 90, 120, 150 and 180 DAP, the maximum essential oil content *i.e.*, 0.420, 0.702, 0.734 and 0.770 % was recorded with the

fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ and was on par with the fertilizer application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ which recorded 0.419, 0.692, 0.733 and 0.766 % and 80 kg N ha⁻¹ + 20 kg S ha⁻¹ which recorded 0.416, 0.683, 0.718 and 0.754 % respectively. The minimum essential oil content *i.e.*, 0.272, 0.401, 0.504 and 0.507 % was recorded at 90, 120, 150 and 180 DAP respectively with control treatment.

Among interactions, non-significant influence was observed on essential oil content at all stages of the crop growth.

The oil content significantly increased with the age of the crop. This might be due to presence of more number of biologically functional leaves in this stage (Bharadwaj and Srivastava, 1984) and due to the uptake of fertilizer dosage. The oil content was not influenced by spacing however, it was significantly increased with the application of fertilizer dose. The oil content increased with the application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ due to increased total leaf area, where essential oil glands are located, resulting in more oil glands and thereby increase in oil yield. The increase in oil content due to application of sulphur is due to increased availability of nutrients owing to favourable environment created by sulphur and it plays a significant role in overall biosynthesis processes. Sulphur is also an important constituent of glutathione, which helps in synthesis of essential oils (Patel *et al.* 2013). These findings were in agreement with the reports of Izhar *et al.* (2015) in *Mentha arvensis*, Kumar *et al.* (2015) in *Mentha spicata*, Mekonnen and Kassahun (2011) in spearmint and Kumar *et al.* (2010) in menthol mint var. Kosi.

4.4.2 Essential oil yield (kg ha⁻¹)

The data pertaining to essential oil yield (Table 19) showed that there was an increased trend in essential oil yield due to increased fertilizer doses and the maximum essential oil yield was recorded with optimum spacing. The essential oil yield increased up to 150 DAP and thereafter decreased at 180 DAP.

It was observed that the essential oil yield was significantly influenced by different spacings at all stages of crop growth. The maximum essential oil yield *i.e.*, 73.28, 140.41, 159.94 and 156.75 kg was recorded with a spacing of 45×15 cm followed by 30×15 cm spacing, which recorded 63.65, 123.25, 136.72 and

133.34 kg at 90, 120, 150 and 180 DAP respectively. The minimum essential oil yield *i.e.*, 59.55, 113.47, 131.89 and 126.60 kg was recorded at 90, 120, 150 and 180 DAP respectively with a spacing of 60×15 cm.

Different levels of fertilizer dose significantly influenced the essential oil yield at all stages of crop growth. At 90, 120, 150 and 180 DAP, the maximum essential oil yield *i.e.*, 77.92, 152.95, 166.91 and 164.17 kg was recorded with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ followed by the fertilizer application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ which recorded 73.00, 141.85, 158.48 and 154.77 kg respectively. The minimum essential oil yield *i.e.*, 42.92, 74.53, 98.47 and 91.78 kg was recorded at 90, 120, 150 and 180 DAP respectively with control treatment.

Among interactions, non-significant influence was observed on essential oil yield at all stages of crop growth.

It was observed that the essential oil yield increased gradually from 90 DAP to 150 DAP and thereafter decreased at 180 DAP. It was due to senescence and leaf fall, which decreased herbage yield at 180 DAP. The essential oil yield was found to be higher in optimum spacing *i.e.* 45×15 cm due to optimum utilization of resources compared to closer spacing 30×15 cm. Higher plant stand and higher herbage yield over 60×15 cm spacing resulted in maximum essential oil yield with 45×15 cm spacing.

The essential oil yield increased with the application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ due to increased total leaf area, where essential oil glands were located, resulting in more oil glands and thereby increase in oil yield. The increase in essential oil yield due to application of sulphur is due to increased availability of nutrients owing to favourable environment created by sulphur and it plays a significant role in overall biosynthesis processes. Sulphur is also an important constituent of glutathione, which helps in synthesis of essential oils (Patel *et al.* 2013). These results were in agreement with the findings of Izhar *et al.* (2015) in *Mentha arvensis*, Kumar *et al.* (2015) in *Mentha spicata*, Kumar *et al.* (2010) in menthol mint var. Kosi, Singh *et al.* (2003) in bergamot mint var. Kiran, Sharma and Kanjilal (1999) in *Mentha piperata*, Ram *et al.* (1995) and Rao *et al.* (1984) in bergamot mint.

4.5 NUTRIENT ANALYSIS IN SOIL AND PLANT

4.5.1 Nitrogen content in the plant sample (%)

The data on nitrogen content in the plant sample as influenced by different spacings, fertilizers and their interaction was presented in table 20. The nitrogen content in the plant sample increased with increase in spacing and fertilizer doses up to 180 DAP.

It was observed that the nitrogen content in the plant sample was significantly influenced by different spacings at all stages of crop growth. At 90 and 120 DAP, the maximum nitrogen content in the plant sample *i.e.*, 0.998 and 1.026 was recorded with a spacing of 60×15 cm and was on par with 45×15 cm spacing which recorded 0.996 and 1.020 % respectively. At 150 and 180 DAP, the maximum nitrogen content in the plant sample *i.e.*, 1.039 and 1.042 % was recorded with a spacing of 60×15 cm followed by 45×15 cm spacing which recorded 1.027 and 1.030 respectively. The minimum content of nitrogen in the plant sample *i.e.*, 0.974, 1.004, 1.011 and 1.013 % was recorded at 90, 120, 150 and 180 DAP respectively with 30×15 cm spacing.

It was found that there were significant differences in nitrogen content of plant sample among different fertilizer doses. The maximum nitrogen content in the plant sample *i.e.*, 1.034 and 1.060 % was recorded with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ and was on par with the fertilizer application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ which recorded 1.032 and 1.057 % at 90 and 180 DAP respectively. At 120 DAP, the maximum nitrogen content in the plant sample (1.054 %) was recorded with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ which was on par with the fertilizer application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ (1.050 %) and 80 kg N ha⁻¹ + 20 kg S ha⁻¹ (1.042 %). At 150 DAP, the maximum nitrogen content in the plant sample (1.059 %) was recorded with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ followed by the fertilizer application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ (1.055 %). The minimum content of nitrogen in the plant sample *i.e.*, 0.877, 0.920, 0.940 and 0.947 % was recorded at 90, 120, 150 and 180 DAP respectively with control treatment.

Among interactions, non-significant was observed in nitrogen content of plant sample at all stages of crop growth.

4.5.2 Sulphur content in the plant sample (%)

The data on sulphur content in the plant sample as influenced by different spacings, fertilizers and their interaction was presented in table 21. The sulphur content in the plant sample increased with increase in spacing and fertilizer doses up to 180 DAP.

It was observed that sulphur content in the plant sample was not significantly influenced by different spacings at all stages of the crop growth except at 150 DAP. At 150 DAP, the maximum sulphur content in the plant sample (0.409 %) was recorded with a spacing of 60×15 cm followed by 45×15 cm spacing (0.404 %) whereas the minimum sulphur content in the plant sample (0.401 %) was recorded with 30×15 cm spacing.

It was found that there were significant differences on sulphur content in the plant sample among different fertilizer doses. At 90 DAP, the maximum sulphur content in the plant sample (0.419 %) was recorded with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ which was on par with the fertilizer application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ (0.416 %). At 120, 150 and 180 DAP, the maximum sulphur content in the plant sample *i.e.*, 0.418, 0.421 and 0.422 % was recorded with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ and was on par with the fertilizer application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ which recorded 0.417, 0.420 and 0.421 % and 80 kg N ha⁻¹ + 20 kg S ha⁻¹ which recorded 0.415, 0.418 and 0.420 % respectively. The minimum sulphur content in the plant sample *i.e.*, 0.327, 0.343, 0.360 and 0.373 % was recorded at 90, 120, 150 and 180 DAP respectively with control treatment.

Among interactions, non-significant influence was observed on sulphur content in the plant sample at all stages of crop growth.

The nitrogen and sulphur content in the plant sample increased with increase in age of the crop, spacing and fertilizer dose. Nitrogen + sulphur might have promoted the availability of native soil 'N' and 'S' as reflected by their uptake. These results showed that wider planting provide more space to plant and

reduced the competition between plants for nutrients. Similar results were reported by Pal *et al.* (2016) in *Thymus serpyllum* and Mishu *et al.* (2013) in onion.

4.5.3 Nitrogen uptake (kg ha⁻¹)

The data on nitrogen uptake as influenced by different spacings, fertilizers and their interaction was presented in table 22. The uptake of nitrogen was maximum with optimum spacing and increased with increase in fertilizer dosage up to 150 DAP and thereafter decreased at 180 DAP.

It was observed that the uptake of nitrogen was significantly influenced by different spacings at all stages of crop growth. At 90 and 120 DAP, the highest amount of nitrogen uptake *i.e.*, 24.76 and 47.90 kg ha⁻¹ was recorded with a spacing of 45×15 cm and was on par with a spacing of 30×15 cm which recorded 22.15 and 43.11 kg ha⁻¹ respectively. At 150 and 180 DAP, the highest amount of nitrogen uptake *i.e.*, 54.46 and 51.91 kg ha⁻¹ was recorded with a spacing of 45×15 cm followed by 30×15 cm spacing, which recorded 48.44 and 43.69 kg ha⁻¹ respectively. The lowest amount of nitrogen uptake *i.e.*, 20.50, 40.03, 45.19 and 42.45 kg ha⁻¹ was recorded at 90, 120, 150 and 180 DAP respectively with a spacing of 60×15 cm.

It was found that there were significant differences in the uptake of nitrogen among different levels of fertilizer dose. At 90, 150 and 180 DAP, the highest amount of nitrogen uptake *i.e.*, 25.78, 55.44 and 53.08 kg ha⁻¹ was recorded with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ and was on par with the fertilizer application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ which recorded 24.26, 52.58 and 49.33 kg ha⁻¹ respectively. At 120 DAP, the highest amount of nitrogen uptake (49.00 kg ha⁻¹) was recorded with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ which was on par with the fertilizer application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ (46.83 kg ha⁻¹) and 80 kg N ha⁻¹ + 20 kg S ha⁻¹ (43.08 kg ha⁻¹). The lowest amount of nitrogen uptake *i.e.*, 17.53, 35.80, 40.58 and 36.64 kg ha⁻¹ was recorded at 90, 120, 150 and 180 DAP respectively with control treatment.

Among interactions, non-significant influence was observed in the uptake of nitrogen at all stages of crop growth.

4.5.4 Sulphur uptake (kg ha^{-1})

The data on sulphur uptake as influenced by different spacings, fertilizers and their interaction was presented in table 23. The uptake of sulphur was maximum with optimum spacing and increased with increase in fertilizer dosage up to 150 DAP and thereafter decreased at 180 DAP.

It was observed that sulphur uptake was significantly influenced by different spacings at all stages of crop growth. At 90, 150 and 180 DAP, the highest amount of sulphur uptake *i.e.*, 9.82, 21.46 and 20.59 kg ha^{-1} was recorded with a spacing of 45×15 cm followed by 30×15 cm spacing, which recorded 8.88, 19.22 and 17.45 kg ha^{-1} respectively. At 120 DAP, the highest amount of sulphur uptake (18.68 kg ha^{-1}) was recorded with a spacing of 45×15 cm which was on par with 30×15 cm spacing (17.02 kg ha^{-1}). The lowest amount of sulphur uptake *i.e.*, 8.12, 15.68, 17.79 and 16.88 kg ha^{-1} was recorded at 90, 120, 150 and 180 DAP respectively with a spacing of 60×15 cm.

It was found that there were significant differences in the uptake of sulphur among different levels of fertilizer dose. At 90 and 180 DAP, the highest amount of sulphur uptake *i.e.*, 10.45 and 21.14 kg ha^{-1} was recorded with the fertilizer application of 140 kg N ha^{-1} + 20 kg S ha^{-1} and was on par with the fertilizer application of 110 kg N ha^{-1} + 20 kg S ha^{-1} which recorded 9.78 and 19.66 kg ha^{-1} respectively. At 120 DAP, the highest amount of sulphur uptake (19.41 kg ha^{-1}) was recorded with the fertilizer application of 140 kg N ha^{-1} + 20 kg S ha^{-1} which was on par with the fertilizer application of 110 kg N ha^{-1} + 20 kg S ha^{-1} (18.58 kg ha^{-1}) and 80 kg N ha^{-1} + 20 kg S ha^{-1} (17.16 kg ha^{-1}).

At 150 DAP, the highest amount of sulphur uptake (22.02 kg ha^{-1}) was recorded with the fertilizer application of 140 kg N ha^{-1} + 20 kg S ha^{-1} followed by the fertilizer application of 110 kg N ha^{-1} + 20 kg S ha^{-1} (20.93 kg ha^{-1}). The lowest amount of sulphur uptake *i.e.*, 6.53, 13.35, 15.54 and 14.43 kg ha^{-1} was recorded at 90, 120, 150 and 180 DAP respectively with control treatment.

Among interactions, non-significant influence was observed on the uptake of sulphur at all stages of crop growth.

The nutrient uptake increased with increase in age of the crop up to 150 DAP and later declined due to lower dry matter production as a result of leaf fall. Nitrogen and sulphur uptake was maximum with optimum spacing 45×15 cm due to optimum plant stand compared to wider spacing. The maximum uptake of nitrogen and sulphur was recorded with the highest dose of fertilizer which might be due to the higher nutrient content at higher level of fertilizer together with higher dry matter production resulted in higher nutrient uptake. Similar results were reported by Patel *et al.* (2013) in coriander, Singh *et al.* (2007) in patchouli and Rao *et al.* (1998) in davana.

4.5.5 Nitrogen content in the soil after final harvest (kg ha⁻¹)

The data pertaining to nitrogen content in the soil from each plot after final harvest (Table 24) showed that the nitrogen content in the soil after final harvest was maximum with wider spacing and increased with increase in fertilizer dosage.

There were significant differences for nitrogen content in the soil among different spacings. The highest amount of nitrogen in the soil (128.53 kg ha⁻¹) was recorded with a spacing of 60×15 cm followed by 30×15 cm spacing (104.50 kg ha⁻¹). The lowest amount of nitrogen in the soil (83.60 kg ha⁻¹) was recorded with a spacing of 45×15 cm.

It was found that there were significant differences for nitrogen content in the soil among different levels of fertilizer dose. The highest amount of nitrogen in the soil (126.79 kg ha⁻¹) was recorded with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ which was on par with the fertilizer application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ (118.43 kg ha⁻¹) and with 80 kg N ha⁻¹ + 20 kg S ha⁻¹ (103.10 kg ha⁻¹). The lowest amount of nitrogen in the soil (73.84 kg ha⁻¹) was recorded with control treatment.

Among interactions, non-significant influence was observed on the amount of nitrogen in soil at all stages of crop growth.

4.5.6 Sulphur content in the soil after final harvest (kg ha⁻¹)

The data pertaining to sulphur content in the soil from each plot after final harvest (Table 25) showed that the sulphur content in the soil after final harvest was maximum with wider spacing and increased with increase in fertilizer dosage.

There were significant differences for sulphur content in the soil among different spacings. The highest amount of sulphur in the soil (23.23 kg ha⁻¹) was recorded with a spacing of 60×15 cm followed by 30×15 cm spacing (22.19 kg ha⁻¹). The lowest amount of sulphur in the soil (21.44 kg ha⁻¹) was recorded with a spacing of 45×15 cm.

It was found that there were significant differences for sulphur content in the soil among different fertilizer doses. The highest amount of sulphur in the soil (24.58 kg ha⁻¹) was recorded with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ followed by the fertilizer application of 110 kg N ha⁻¹ + 20 kg S ha⁻¹ (23.21 kg ha⁻¹). The lowest amount of sulphur in the soil (19.43 kg ha⁻¹) was recorded with control treatment.

Among interactions, non-significant influence was observed on the amount of sulphur in soil at all stages of crop growth.

Based on the results obtained it may be concluded that the available nitrogen and sulphur content in the soil was highest at wider spacing due to less nutrient uptake and lowest at optimum spacing due to optimum nutrient uptake. The available nitrogen and sulphur content in the soil was increased with an increase in the level of fertilizer dose applied due to an increase in fixation of nitrogen and sulphur in the soil. Similar results were reported by Chandana *and* Dorajeerao (2014) in gladiolus, Chouhan *et al.* (2014) in gladiolus and Sushma *et al.* (2012) in *Heliconia*.

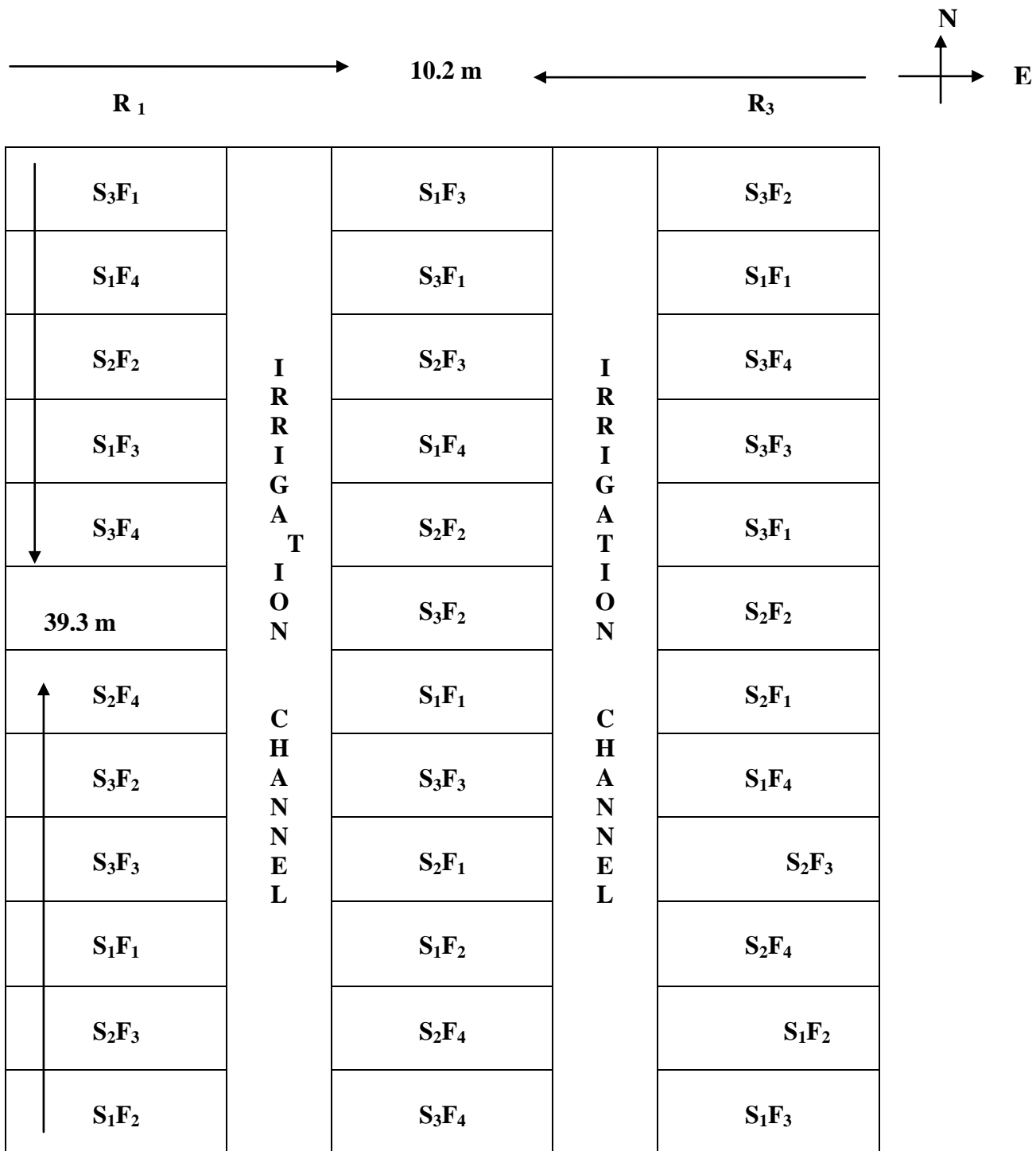


Fig.1 Field layout of the experiment

Table 2. Effect of spacing and fertilizers on plant height at different stages of crop growth in mint

Treatments	Plant height (cm)														
	Days after planting (DAP)														
	30					60					90				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S₁	10.47	10.93	10.91	10.51	10.70	15.10	15.56	15.80	16.11	15.64	18.62	21.16	23.70	25.75	22.30
S₂	10.53	11.09	10.47	11.35	10.86	15.31	15.82	16.20	16.71	16.01	22.81	26.90	28.22	28.56	26.62
S₃	11.02	10.93	10.96	11.07	10.99	15.62	16.30	16.83	17.11	16.46	24.53	27.40	29.95	30.30	28.04
Mean	10.67	10.98	10.78	10.97		15.34	15.89	16.27	16.64		21.98	25.15	27.29	28.20	
	SE m±		CD at 5%			SE m±		CD at 5%			SE m±		CD at 5%		
S	0.093		NS			0.243		NS			0.739		2.170		
F	0.108		NS			0.280		0.823			0.854		2.506		
S×F	0.187		NS			0.485		NS			1.479		NS		

Table 2a. Effect of spacing and fertilizers on plant height at different stages of crop growth in mint

Treatment s	Plant height (cm)														
	Days after planting (DAP)														
	120					150					180				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	29.3 2	31.15	32.6 0	34.41	31.87	34.52	36.46	37.58	39.93	37.12	35.76	38.30	40.53	42.06	39.16
S ₂	30.5 3	34.82	35.5 0	37.36	34.55	34.46	37.31	38.33	40.50	37.65	39.39	41.23	42.42	43.83	41.72
S ₃	33.8 6	36.70	38.1 0	39.34	37.00	35.26	38.50	41.74	44.03	39.88	40.06	44.72	45.15	46.80	44.18
Mean	31.23	34.22	35.4 0	37.03		34.75	37.42	39.22	41.48		38.40	41.41	42.70	44.23	
	SE m±		CD at 5%			SE m±		CD at 5%			SE m±		CD at 5%		
S	0.862		2.531			0.306		0.899			0.900		2.640		
F	0.996		2.922			0.353		1.038			1.039		3.048		
S×F	1.725		NS			0.613		NS			1.800		NS		

Factor-I Spacing (S)

S₁: 30×15 cm

S₂: 45×15 cm

S₃: 60×15 cm

Factor -II Fertilizers (F) (Nitrogen + Sulphur)

F₁: 0 kg ha⁻¹ + 0 kg ha⁻¹ (Control)

F₂: 80 kg ha⁻¹ +20 kg ha⁻¹

F₃: 110 kg ha⁻¹ +20 kg ha⁻¹

F₄: 140 kg ha⁻¹ +20 kg ha⁻¹

Table 3. Effect of spacing and fertilizers on number of branches per plant at different stages of crop growth in mint

Treatments	Number of branches per plant														
	Days after planting (DAP)														
	30					60					90				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	5.38	5.22	5.45	5.23	5.32	11.10	13.70	15.20	16.17	14.04	16.26	19.63	20.73	23.53	20.04
S ₂	5.54	5.47	5.27	5.32	5.40	14.26	16.22	18.00	19.31	16.94	22.30	24.33	25.49	27.63	24.93
S ₃	5.53	5.23	5.53	5.46	5.43	17.20	19.80	20.90	22.27	20.04	25.66	28.00	30.10	33.30	29.26
Mean	5.48	5.31	5.41	5.33		14.18	16.57	18.03	19.25		21.40	23.98	25.44	28.15	
	SE m±		CD at 5%			SE m±		CD at 5%			SE m±		CD at 5%		
S	0.064		NS			0.464		1.363			0.165		0.485		
F	0.075		NS			0.536		1.574			0.190		0.560		
S×F	0.129		NS			0.929		NS			0.330		0.970		

Table 3a. Effect of spacing and fertilizers on number of branches per plant at different stages of crop growth in mint

Treatments	Number of branches per plant														
	Days after planting (DAP)														
	120					150					180				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	19.10	21.62	24.33	28.30	23.33	25.16	26.73	29.26	33.35	28.62	28.15	30.91	33.27	37.30	32.40
S ₂	26.54	29.16	31.83	34.00	30.38	30.13	34.20	37.96	40.70	35.74	34.56	37.80	41.23	45.20	39.69
S ₃	33.41	36.29	38.50	41.20	37.35	39.15	42.60	44.56	47.80	43.52	42.16	46.44	49.06	53.10	47.69
Mean	26.35	29.02	31.55	34.50		31.48	34.51	37.26	40.61		34.95	38.38	41.18	45.20	
	SE m±		CD at 5%			SE m±		CD at 5%			SE m±		CD at 5%		
S	0.075		0.220			0.253		0.743			0.140		0.413		
F	0.086		0.254			0.292		0.858			0.162		0.477		
S×F	0.150		0.440			0.507		1.488			0.281		0.827		

Table 4. Effect of spacing and fertilizers on number of leaves per plant at different stages of crop growth in mint

Treatment s	Number of leaves per plant														
	Days after planting (DAP)														
	30					60					90				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	110.7 6	112.3 3	111.53	112.6 4	111.81	386.1 3	394.03	418.9 3	432.7 4	407.95	724.83	759.06	816.47	883.51	795.96
S ₂	111.8 0	113.2 3	113.20	111.4 0	112.40	510.5 6	542.31	581.4 7	620.6 3	563.74	976.23	1039.1 6	1112.4 6	1194.1 4	1080.4 9
S ₃	110.8 3	112.8 3	115.70	114.1 6	113.38	593.4 3	637.55	676.0 3	710.4 6	654.36	1153.0 6	1236.5 1	1341.9 2	1467.1 1	1299.6 5
Mean	111.13	112.7 9	113.47	112.7 3		496.7 0	524.63	558.8 1	587.9 4		951.37	1011.5 7	1090.2 8	1181.5 8	
	SE m±		CD at 5%			SE m±		CD at 5%			SE m±		CD at 5%		
S	0.621		NS			2.701		3.897			0.701		2.057		
F	0.717		NS			3.119		4.500			0.809		2.375		
S×F	1.242		NS			5.402		7.796			1.402		4.115		

Table 4a. Effect of spacing and fertilizers on number of leaves per plant at different stages of crop growth in mint

Treatments	Number of leaves per plant														
	Days after planting (DAP)														
	120					150					180				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	842.80	894.06	961.40	1038.81	934.26	922.76	1001.15	1095.80	1183.37	1050.77	826.65	887.20	942.71	1018.26	918.70
S ₂	1127.45	1208.33	1291.45	1382.64	1252.46	1253.26	1337.40	1432.84	1546.80	1392.57	1156.81	1224.60	1293.14	1379.73	1263.57
S ₃	1357.06	1446.24	1539.18	1657.97	1500.11	1488.20	1564.35	1659.60	1771.43	1620.89	1363.90	1427.62	1540.74	1638.21	1492.61
Mean	1109.10	1182.87	1264.01	1359.80		1221.40	1300.96	1396.08	1500.53		1115.78	1179.80	1258.86	1345.40	
	SE m±		CD at 5%			SE m±		CD at 5%			SE m±		CD at 5%		
S	1.050		3.081			1.047		3.073			0.355		1.042		
F	1.213		3.558			1.209		3.549			0.410		1.203		
S×F	2.101		6.164			2.095		6.148			0.710		2.085		

Factor-I Spacing (S)

S₁: 30×15 cm

S₂: 45×15 cm

S₃: 60×15 cm

Factor -II Fertilizers (F) (Nitrogen + Sulphur)

F₁: 0 kg ha⁻¹ + 0 kg ha⁻¹ (Control)

F₂: 80 kg ha⁻¹ +20 kg ha⁻¹

F₃: 110 kg ha⁻¹ +20 kg ha⁻¹

F₄: 140 kg ha⁻¹ +20 kg ha⁻¹

Table 5. Effect of spacing and fertilizers on leaf area per plant at different stages of crop growth in mint

Treatments	Leaf area per plant (cm ²)														
	Days after planting (DAP)														
	30					60					90				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	176.29	216.32	239.82	287.3 5	229.9 4	485.43	535.4 7	581.3 7	654.86	564.28	760.54	823.06	919.89	1017.8 0	880.32
S ₂	179.55	236.47	249.33	309.5 1	243.7 1	676.13	758.9 2	791.0 6	854.48	770.14	1111.4 2	1214.70	1355.1 2	1505.5 7	1296.7 0
S ₃	180.17	269.82	299.20	342.7 7	272.9 9	801.64	861.0 4	917.5 1	978.94	889.78	1372.6 4	1522.41	1692.1 7	1872.9 9	1615.0 5
Mean	178.67	240.87	262.78	313.2 1		654.40	718.4 7	763.3 1	829.42		1081.5 3	1186.72	1322.3 9	1465.4 5	
	SE m±		CD at 5%			SE m±		CD at 5%			SE m±		CD at 5%		
S	29.551		NS			17.150		50.312			19.299		56.618		
F	34.123		NS			19.803		58.095			22.285		65.377		
S×F	59.103		NS			34.300		NS			38.599		NS		

Table 5a. Effect of spacing and fertilizers on leaf area per plant at different stages of crop growth in mint

Treatments	Leaf area per plant (cm ²)														
	Days after planting (DAP)														
	120					150					180				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	1356.23	1506.54	1759.81	1996.10	1654.67	1626.29	1789.46	2198.95	2483.99	2024.67	1107.65	1324.35	1587.21	1793.26	1453.11
S ₂	2016.63	2263.64	2473.50	2782.29	2384.01	2499.22	2701.04	3102.26	3512.19	2953.67	1898.83	2035.30	2223.17	2416.02	2143.33
S ₃	2593.71	2997.15	3326.22	3698.43	3153.87	3238.07	3588.50	3888.50	4225.82	3735.22	2315.20	2705.90	3071.41	3328.24	2855.18
Mean	1988.85	2255.77	2519.84	2825.60		2454.52	2693.00	3063.23	3407.33		1773.89	2021.85	2293.93	2512.50	
	SE m±		CD at 5%			SE m±		CD at 5%			SE m±		CD at 5%		
S	70.842		207.825			17.943		52.639			39.568		116.079		
F	81.801		239.976			20.719		60.783			45.689		134.037		
S×F	141.684		NS			35.887		NS			79.136		NS		

Factor-I Spacing (S)

S₁: 30×15 cm

S₂: 45×15 cm

S₃: 60×15 cm

Factor -II Fertilizers (F) (Nitrogen + Sulphur)

F₁: 0 kg ha⁻¹ + 0 kg ha⁻¹ (Control)

F₂: 80 kg ha⁻¹ +20 kg ha⁻¹

F₃: 110 kg ha⁻¹ +20 kg ha⁻¹

F₄: 140 kg ha⁻¹ +20 kg ha⁻¹

Table 6. Effect of spacing and fertilizers on leaf/stem ratio on weight basis at different stages of crop growth in mint

Treatments	Leaf/stem ratio on weight basis														
	Days after planting (DAP)														
	30					60					90				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	2.68	2.71	2.49	2.56	2.61	2.29	2.25	2.12	2.08	2.18	2.12	2.02	1.88	1.81	1.95
S ₂	2.33	2.67	2.25	2.22	2.37	2.03	2.02	1.95	1.86	1.96	1.98	1.96	1.85	1.82	1.90
S ₃	2.49	2.16	2.36	2.40	2.35	1.96	1.90	1.84	1.80	1.87	1.90	1.84	1.80	1.71	1.81
Mean	2.50	2.51	2.37	2.39		2.09	2.05	1.97	1.91		2.00	1.94	1.84	1.78	
	SE m±		CD at 5%			SE m±		CD at 5%			SE m±		CD at 5%		
S	0.072		0.211			0.015		0.045			0.013		0.039		
F	0.083		NS			0.018		0.052			0.015		0.045		
S×F	0.144		NS			0.031		NS			0.027		NS		

Table 6a. Effect of spacing and fertilizers on leaf/stem ratio on weight basis at different stages of crop growth in mint

Treatments	Leaf/stem ratio on weight basis														
	Days after planting (DAP)														
	120					150					180				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	2.00	1.94	1.86	1.78	1.90	1.95	1.90	1.84	1.74	1.86	1.55	1.55	1.50	1.45	1.51
S ₂	1.96	1.90	1.82	1.75	1.86	1.85	1.83	1.78	1.74	1.80	1.50	1.46	1.45	1.43	1.46
S ₃	1.81	1.70	1.66	1.61	1.69	1.80	1.68	1.59	1.59	1.66	1.45	1.44	1.40	1.38	1.42
Mean	1.92	1.85	1.78	1.71		1.87	1.80	1.74	1.69		1.50	1.48	1.45	1.42	
	SE m±		CD at 5%			SE m±		CD at 5%			SE m±		CD at 5%		
S	0.014		0.041			0.012		0.035			0.008		0.024		
F	0.016		0.047			0.013		0.040			0.009		0.028		
S×F	0.027		NS			0.024		NS			0.016		NS		

Factor-I Spacing (S)

∥

S₁: 30×15 cm

S₂: 45×15 cm

S₃: 60×15 cm

Factor -II Fertilizers (F) (Nitrogen + Sulphur)

F₁: 0 kg ha⁻¹ + 0 kg ha⁻¹ (Control)

F₂: 80 kg ha⁻¹ +20 kg ha⁻¹

F₃: 110 kg ha⁻¹ +20 kg ha⁻¹

F₄: 140 kg ha⁻¹ +20 kg ha⁻¹

Table 7. Effect of spacing and fertilizers on fresh weight of leaf per plant at different stages of crop growth in mint

Treatments	Fresh weight of leaf per plant (g)														
	Days after planting (DAP)														
	30					60					90				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S₁	9.56	9.73	9.66	9.76	9.67	29.71	31.84	35.53	40.33	34.35	57.30	59.38	61.34	65.92	60.98
S₂	9.60	9.93	9.75	9.80	9.77	50.45	54.66	58.36	63.45	56.73	93.62	97.49	101.48	107.7 3	100.08
S₃	9.43	9.76	10.43	10.76	10.09	60.37	63.26	65.54	68.02	64.29	105.62	108.91	112.49	117.2 7	111.07
Mean	9.53	9.80	9.94	10.10		46.84	49.92	53.14	57.26		85.51	88.59	91.77	96.97	
	SE m±		CD at 5%			SE m±		CD at 5%			SE m±		CD at 5%		
S	0.152		NS			0.575		1.687			0.241		0.707		
F	0.175		NS			0.664		1.948			0.278		0.816		
S×F	0.304		NS			1.150		NS			0.482		1.414		

Table 7a. Effect of spacing and fertilizers on fresh weight of leaf per plant at different stages of crop growth in mint

Treatments	Fresh weight of leaf per plant (g)														
	Days after planting (DAP)														
	120					150					180				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	68.10	70.12	73.34	76.51	72.01	70.30	72.41	76.11	80.26	74.77	59.61	62.47	64.95	68.46	63.87
S ₂	112.35	114.71	116.58	120.80	116.1 1	115.5 4	119.61	123.2 1	128.2 3	121.64	98.36	103.48	106.3 3	111.24	104.85
S ₃	117.52	126.34	130.11	136.61	127.6 4	124.5 2	129.44	136.2 4	142.0 3	133.05	107.41	115.72	120.5 2	126.43	117.52
Mean	99.32	103.72	106.67	111.30		103.4 5	107.15	111.8 5	116.8 4		88.46	93.89	97.26	102.04	
	SE m±		CD at 5%			SE m±		CD at 5%			SE m±		CD at 5%		
S	0.568		1.667			0.350		1.029			0.449		1.318		
F	0.656		1.925			0.405		1.188			0.519		1.522		
S×F	1.137		3.336			0.701		2.059			0.898		2.637		

Factor-I Spacing (S)

S₁: 30×15 cm

S₂: 45×15 cm

S₃: 60×15 cm

Factor -II Fertilizers (F) (Nitrogen + Sulphur)

F₁: 0 kg ha⁻¹ + 0 kg ha⁻¹ (Control)

F₂: 80 kg ha⁻¹ +20 kg ha⁻¹

F₃: 110 kg ha⁻¹ +20 kg ha⁻¹

F₄: 140 kg ha⁻¹ +20 kg ha⁻¹

Table 8. Effect of spacing and fertilizers on fresh weight of stem per plant at different stages of crop growth in mint

Treatments	Fresh weight of stem per plant (g)														
	Days after planting (DAP)														
	30					60					90				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S₁	3.60	3.62	3.87	3.81	3.72	12.92	14.13	16.71	19.32	15.77	27.01	29.33	32.58	36.32	31.31
S₂	4.13	3.73	4.35	4.40	4.15	24.74	27.02	29.84	33.95	28.88	47.21	49.60	54.84	59.08	52.68
S₃	3.80	4.53	4.43	4.50	4.31	30.71	33.22	35.45	37.73	34.27	55.33	59.12	62.33	68.26	61.26
Mean	3.84	3.96	4.21	4.23		22.79	24.79	27.33	30.33		43.18	46.01	49.91	54.55	
	SE m±		CD at 5%			SE m±		CD at 5%			SE m±		CD at 5%		
S	0.261		NS			1.421		4.169			0.207		0.607		
F	0.301		NS			1.641		4.814			0.239		0.701		
S×F	0.522		NS			2.842		NS			0.414		1.216		

Table 8a. Effect of spacing and fertilizers on fresh weight of stem per plant at different stages of crop growth in mint

Treatments	Fresh weight of stem per plant (g)														
	Days after planting (DAP)														
	120					150					180				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	34.23	36.16	39.44	43.01	38.21	36.01	38.11	41.23	45.96	40.32	38.31	40.06	43.16	47.08	42.15
S ₂	57.12	60.33	64.20	68.87	62.63	62.27	65.11	69.12	73.45	67.48	65.49	70.48	73.12	77.58	71.66
S ₃	64.81	74.40	78.41	84.80	75.60	69.16	76.82	85.40	89.23	80.15	74.01	80.23	85.83	91.20	82.81
Mean	52.05	56.96	60.68	65.56		55.81	60.01	65.25	69.54		59.27	63.59	67.37	71.95	
	SE m±		CD at 5%			SE m±		CD at 5%			SE m±		CD at 5%		
S	0.193		0.566			0.112		0.329			0.083		0.244		
F	0.222		0.653			0.129		0.380			0.096		0.282		
S×F	0.386		1.132			0.224		0.659			0.166		0.489		

Factor-I Spacing (S)

S₁: 30×15 cm

S₂: 45×15 cm

S₃: 60×15 cm

Factor -II Fertilizers (F) (Nitrogen + Sulphur)

F₁: 0 kg ha⁻¹ + 0 kg ha⁻¹ (Control)

F₂: 80 kg ha⁻¹ +20 kg ha⁻¹

F₃: 110 kg ha⁻¹ +20 kg ha⁻¹

F₄: 140 kg ha⁻¹ + 20 kg ha⁻¹

Table 9. Effect of spacing and fertilizers on leaf area index at different stages of crop growth in mint

Treatment s	Leaf area index														
	Days after planting (DAP)														
	30					60					90				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	0.392	0.481	0.533	0.639	0.511	1.079	1.190	1.292	1.455	1.254	1.690	1.829	2.044	2.262	1.956
S ₂	0.266	0.350	0.369	0.459	0.361	1.002	1.124	1.172	1.266	1.141	1.647	1.800	2.008	2.230	1.921
S ₃	0.200	0.300	0.332	0.381	0.303	0.891	0.957	1.019	1.088	0.989	1.525	1.692	1.880	2.081	1.795
Mean	0.286	0.377	0.412	0.493		0.990	1.090	1.161	1.270		1.621	1.773	1.977	2.191	
	SE m±		CD at 5%			SE m±		CD at 5%			SE m±		CD at 5%		
S	0.056		0.164			0.028		0.082			0.037		0.110		
F	0.064		NS			0.032		0.094			0.043		0.127		
S×F	0.112		NS			0.055		NS			0.075		NS		

Table 9a. Effect of spacing and fertilizers on leaf area index at different stages of crop growth in mint

Treatments	Leaf area index														
	Days after planting (DAP)														
	120					150					180				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	3.01 3	3.347	3.91 0	4.435	3.676	3.614	3.977	4.887	5.520	4.499	2.461	2.943	3.52 7	3.98 5	3.229
S ₂	2.98 7	3.363	3.66 4	4.121	3.534	3.703	4.002	4.596	5.203	4.376	2.813	3.015	3.29 3	3.57 9	3.175
S ₃	2.88 1	3.330	3.69 5	4.109	3.504	3.598	3.987	4.321	4.695	4.150	2.572	3.006	3.41 2	3.69 8	3.172
Mean	2.960	3.347	3.75 6	4.222		3.638	3.988	4.601	5.140		2.615	2.988	3.41 1	3.75 4	
	SE m±		CD at 5%			SE m±		CD at 5%			SE m±		CD at 5%		
S	0.008		0.024			0.060		0.176			0.008		0.024		
F	0.009		0.027			0.069		0.203			0.009		0.028		
S×F	0.016		0.048			0.120		0.353			0.016		0.049		

Factor-I Spacing (S)

S₁: 30×15 cm

S₂: 45×15 cm

S₃: 60×15 cm

Factor -II Fertilizers (F) (Nitrogen + Sulphur)

F₁: 0 kg ha⁻¹ + 0 kg ha⁻¹ (Control)

F₂: 80 kg ha⁻¹ +20 kg ha⁻¹

F₃: 110 kg ha⁻¹ +20 kg ha⁻¹

F₄: 140 kg ha⁻¹ +20 kg ha⁻¹

Table 10. Effect of spacing and fertilizers on dry weight of leaf per plant at different stages of crop growth in mint

Treatment s	Dry weight of leaf per plant (g)														
	Days after planting (DAP)														
	30					60					90				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	1.20	1.20	1.22	1.15	1.19	3.27	3.34	3.51	3.71	3.45	6.21	6.77	7.10	7.82	6.97
S ₂	1.20	1.17	1.14	1.17	1.17	5.35	5.50	5.80	6.03	5.67	10.12	12.38	13.0 ₄	13.29	12.20
S ₃	1.30	1.31	1.28	1.32	1.30	5.61	5.89	6.15	6.87	6.13	13.15	13.31	14.2 ₁	14.87	13.88
Mean	1.23	1.22	1.21	1.21		4.74	4.91	5.15	5.53		9.82	10.82	11.4₅	11.99	
	SE m±		CD at 5%			SE m±		CD at 5%			SE m±		CD at 5%		
S	0.139		NS			0.131		0.385			0.178		0.523		
F	0.160		NS			0.151		0.444			0.206		0.604		
S×F	0.278		NS			0.262		NS			0.356		NS		

Table10a. Effect of spacing and fertilizers on dry weight of leaf per plant at different stages of crop growth in mint

Treatment s	Dry weight of leaf per plant (g)														
	Days after planting (DAP)														
	120					150					180				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	11.6 4	12.51	14.2 6	14.76	13.29	12.58	13.37	15.53	16.01	14.37	7.93	9.72	11.0 8	12.4 5	10.29
S ₂	19.2 0	20.76	21.7 1	22.47	21.03	20.45	22.50	23.87	24.24	22.76	16.43	17.93	19.8 8	21.1 1	18.83
S ₃	22.2 9	22.50	23.7 7	24.25	23.20	23.92	24.50	25.15	26.31	24.97	18.28	20.42	21.1 8	22.0 4	20.48
Mean	17.71	18.59	19.9 1	20.49		18.98	20.12	21.51	22.18		14.21	16.02	17.3 8	18.5 3	
	SE m±		CD at 5%			SE m±		CD at 5%			SE m±		CD at 5%		
S	0.125		0.367			0.205		0.603			0.193		0.566		
F	0.144		0.424			0.237		0.697			0.222		0.653		
S×F	0.250		NS			0.411		NS			0.386		NS		

Factor-I Spacing (S)

S₁: 30×15 cm

S₂: 45×15 cm

S₃: 60×15 cm

Factor -II Fertilizers (F) (Nitrogen + Sulphur)

F₁: 0 kg ha⁻¹ + 0 kg ha⁻¹ (Control)

F₂: 80 kg ha⁻¹ +20 kg ha⁻¹

F₃: 110 kg ha⁻¹ +20 kg ha⁻¹

F₄: 140 kg ha⁻¹ +20 kg ha⁻¹

Table 11. Effect of spacing and fertilizers on dry weight of stem per plant at different stages of crop growth in mint

Treatments	Dry weight of stem per plant (g)														
	Days after planting (DAP)														
	30					60					90				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	0.89	0.90	0.90	0.97	0.91	0.96	0.97	1.01	1.11	1.01	2.72	2.94	3.32	3.86	3.21
S ₂	0.90	0.95	0.95	0.98	0.94	0.99	1.21	1.42	1.58	1.30	4.01	4.44	4.60	4.88	4.48
S ₃	0.88	0.88	0.89	0.87	0.88	1.30	1.45	1.60	1.67	1.50	4.16	4.22	4.91	4.95	4.56
Mean	0.89	0.91	0.913	0.94		1.08	1.21	1.34	1.45		3.63	3.86	4.27	4.56	
	SE m±		CD at 5%			SE m±		CD at 5%			SE m±		CD at 5%		
S	1.117		NS			0.036		0.108			0.103		0.304		
F	1.290		NS			0.042		0.124			0.120		0.351		
S×F	2.234		NS			0.073		NS			0.207		NS		

Table 11a. Effect of spacing and fertilizers on dry weight of stem per plant at different stages of crop growth in mint

Treatment s	Dry weight of stem per plant (g)														
	Days after planting (DAP)														
	120					150					180				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	5.24	5.67	6.16	6.73	5.95	6.23	7.02	7.35	8.00	7.15	7.90	8.49	9.26	10.37	9.00
S ₂	9.54	10.20	11.01	11.59	10.58	11.61	12.47	13.11	14.57	12.94	13.15	14.72	15.64	16.78	15.07
S ₃	10.7 2	11.60	12.23	12.91	11.86	12.31	13.96	14.81	15.33	14.10	15.04	15.45	16.83	17.09	16.10
Mean	8.50	9.15	9.80	10.41		10.05	11.15	11.75	12.63		12.03	12.88	13.91	14.74	
	SE m±		CD at 5%			SE m±		CD at 5%			SE m±		CD at 5%		
S	0.126		0.370			0.256		0.751			0.130		0.383		
F	0.145		0.428			0.295		0.868			0.150		0.442		
S×F	0.252		NS			0.512		NS			0.261		NS		

Factor-I Spacing (S)

S₁: 30×15 cm

S₂: 45×15 cm

S₃: 60×15 cm

Factor -II Fertilizers (F) (Nitrogen + Sulphur)

F₁: 0 kg ha⁻¹ + 0 kg ha⁻¹ (Control)

F₂: 80 kg ha⁻¹ +20 kg ha⁻¹

F₃: 110 kg ha⁻¹ +20 kg ha⁻¹

F₄: 140 kg ha⁻¹ +20 kg ha⁻¹

Table 12. Effect of spacing and fertilizers on total dry matter production per plant at different stages of crop growth in mint

Treatment s	Total dry matter production per plant (g)														
	Days after planting (DAP)														
	30					60					90				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	2.09	2.10	2.12	2.12	2.11	4.23	4.31	4.52	4.82	4.47	8.93	9.71	10.42	11.68	10.18
S ₂	2.10	2.12	2.09	2.15	2.11	6.34	6.71	7.22	7.61	6.97	14.13	16.82	17.64	18.17	16.69
S ₃	2.18	2.19	2.17	2.19	2.18	6.91	7.34	7.75	8.54	7.63	17.31	17.53	19.12	19.82	18.44
Mean	2.12	2.13	2.12	2.15		5.82	6.12	6.49	6.99		13.45	14.68	15.72	16.55	
	SE m±		CD at 5%			SE m±		CD at 5%			SE m±		CD at 5%		
S	0.111		NS			0.005		0.014			0.081		0.240		
F	0.128		NS			0.005		0.016			0.094		0.277		
S×F	0.222		NS			0.010		0.029			0.163		0.480		

Table 12a. Effect of spacing and fertilizers on total dry matter production per plant at different stages of crop growth in mint

Treatment s	Total dry matter production per plant (g)														
	Days after planting (DAP)														
	120					150					180				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	16.88	18.18	20.42	21.49	19.24	18.81	20.39	22.68	24.01	21.47	15.83	18.21	20.34	22.82	19.30
S ₂	28.74	30.96	32.72	34.06	31.62	32.06	34.97	36.98	38.81	35.70	29.58	32.65	35.52	37.89	33.91
S ₃	33.01	34.10	36.00	37.16	35.06	36.23	38.46	39.96	41.64	39.07	33.32	35.87	38.01	39.13	36.58
Mean	26.21	27.74	29.71	30.90		29.03	31.27	33.20	34.82		26.24	28.91	31.29	33.28	
	SE m±		CD at 5%			SE m±		CD at 5%			SE m±		CD at 5%		
S	0.083		0.244			0.112		0.329			0.152		0.445		
F	0.096		0.282			0.129		0.380			0.175		0.514		
S×F	0.166		0.489			0.224		0.659			0.304		0.892		

Factor-I Spacing (S)

S₁: 30×15 cm

S₂: 45×15 cm

S₃: 60×15 cm

Factor-II Fertilizers (F) (Nitrogen + Sulphur)

F₁: 0 kg ha⁻¹ + 0 kg ha⁻¹ (Control)

F₂: 80 kg ha⁻¹ +20 kg ha⁻¹

F₃: 110 kg ha⁻¹ +20 kg ha⁻¹

F₄: 140 kg ha⁻¹ +20 kg ha⁻¹

Table 13. Effect of spacing and fertilizers on crop growth rate at different stages of crop growth in mint

Treatments	Crop growth rate (g m ⁻² d ⁻¹)														
	Days after planting (DAP)														
	30-60					60-90					90-120				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	1.585	1.637	1.777	1.993	1.748	3.481	4.000	4.370	5.081	4.233	5.889	6.274	7.407	7.267	6.709
S ₂	2.093	2.266	2.533	2.696	2.398	3.847	4.993	5.146	5.215	4.800	7.215	6.983	7.447	7.847	7.373
S ₃	1.751	1.907	2.066	2.351	2.019	3.852	3.774	4.211	4.178	4.004	5.815	6.137	6.252	6.422	6.156
Mean	1.810	1.937	2.125	2.347		3.727	4.256	4.576	4.825		6.306	6.465	7.035	7.179	
	SE m±		CD at 5%			SE m±		CD at 5%			SE m±		CD at 5%		
S	0.975		NS			0.113		0.333			0.142		0.419		
F	1.126		NS			0.131		0.384			0.165		0.484		
S×F	1.951		NS			0.227		NS			0.285		NS		

Factor-I Spacing (S)

S₁: 30×15 cm

S₂: 45×15 cm

S₃: 60×15 cm

Factor -II Fertilizers (F) (Nitrogen + Sulphur)

F₁: 0 kg ha⁻¹ + 0 kg ha⁻¹ (Control)

F₂: 80 kg ha⁻¹ +20 kg ha⁻¹

F₃: 110 kg ha⁻¹ +20 kg ha⁻¹

F₄: 140 kg ha⁻¹ +20 kg ha⁻¹

Table 13a. Effect of spacing and fertilizers on crop growth rate at different stages of crop growth in mint

Treatments	Net assimilation rate (mg cm ⁻² d ⁻¹)														
	Days after planting (DAP)														
	30-60					60-90					90-120				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	0.23 3	0.209	0.207	0.201	0.213	0.256	0.269	0.267	0.278	0.267	0.257	0.249	0.25 7	0.22 5	0.247
S ₂	0.37 7	0.341	0.364	0.339	0.355	0.296	0.348	0.331	0.306	0.320	0.320	0.279	0.27 0	0.25 4	0.281
S ₃	0.37 8	0.336	0.337	0.349	0.350	0.327	0.293	0.299	0.273	0.298	0.272	0.253	0.23 2	0.21 5	0.243
Mean	0.329	0.295	0.303	0.296		0.293	0.303	0.299	0.286		0.283	0.260	0.25 3	0.23 1	
	SE m±		CD at 5%			SE m±		CD at 5%			SE m±		CD at 5%		
S	1.502		NS			0.024		NS			0.008		0.024		
F	1.734		NS			0.028		NS			0.009		0.028		
S×F	3.004		NS			0.049		NS			0.016		NS		

Table 14a. Effect of spacing and fertilizers on net assimilation rate at different stages of crop growth in mint

Treatments	Net assimilation rate (mg cm ⁻² d ⁻¹)									
	Days after planting (DAP)									
	120-150					150-180				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	0.054	0.045	0.038	0.038	0.044	-0.074	-0.047	-0.042	-0.019	-0.045
S ₂	0.053	0.054	0.051	0.051	0.052	-0.038	-0.033	-0.018	-0.010	-0.025
S ₃	0.037	0.044	0.037	0.038	0.039	-0.035	-0.028	-0.019	-0.022	-0.026
Mean	0.048	0.048	0.042	0.042		-0.049	-0.036	-0.026	-0.017	
	SE m±		CD at 5%			SE m±		CD at 5%		
S	0.001		0.004			1.417		NS		
F	0.001		0.004			1.637		NS		
S×F	0.002		NS			2.835		NS		

Factor-I Spacing (S)

S₁: 30×15 cm

S₂: 45×15 cm

S₃: 60×15 cm

Factor -II Fertilizers (F) (Nitrogen + Sulphur)

F₁: 0 kg ha⁻¹ + 0 kg ha⁻¹ (Control)

F₂: 80 kg ha⁻¹ +20 kg ha⁻¹

F₃: 110 kg ha⁻¹ +20 kg ha⁻¹

F₄: 140 kg ha⁻¹ +20 kg ha⁻¹

Table 15. Effect of spacing and fertilizers on herbage yield per plant at different stages of crop growth in mint

Treatments	Herbage yield per plant (g)									
	Days after planting (DAP)									
	90					120				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	84.31	88.71	93.92	102.24	92.29	102.43	106.31	112.92	119.55	110.30
S ₂	140.83	147.09	156.32	166.81	152.76	169.67	175.24	180.82	189.71	178.86
S ₃	160.95	168.03	174.82	185.53	172.33	182.33	200.82	208.56	221.52	203.30
Mean	128.69	134.61	141.68	151.52		151.47	160.79	167.43	176.92	
	SE m±		CD at 5%			SE m±		CD at 5%		
S	0.897		2.634			0.474		1.392		
F	1.036		3.041			0.548		1.608		
S×F	1.795		NS			0.949		2.785		

Table 15a. Effect of spacing and fertilizers on herbage yield per plant at different stages of crop growth in mint

Treatments	Herbage yield per plant (g)									
	Days after planting (DAP)									
	150					180				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S₁	106.35	110.72	117.34	126.22	115.15	97.92	102.53	108.11	115.54	106.02
S₂	177.81	184.64	192.43	201.68	189.14	164.25	174.62	179.45	188.82	176.78
S₃	193.71	210.15	221.75	235.58	215.29	181.62	196.16	206.75	217.93	200.61
Mean	159.29	168.50	177.17	187.82		147.93	157.77	164.77	174.09	
	SE m±		CD at 5%			SE m±		CD at 5%		
S	0.529		1.553			0.472		1.384		
F	0.611		1.793			0.545		1.599		
S×F	1.058		3.106			0.944		2.770		

Factor-I Spacing (S)

S₁: 30×15 cm

S₂: 45×15 cm

S₃: 60×15 cm

Factor -II Fertilizers (F) (Nitrogen + Sulphur)

F₁: 0 kg ha⁻¹ + 0 kg ha⁻¹ (Control)

F₂: 80 kg ha⁻¹ +20 kg ha⁻¹

F₃: 110 kg ha⁻¹ +20 kg ha⁻¹

F₄: 140 kg ha⁻¹ + 20 kg ha⁻¹

Table 16. Effect of spacing and fertilizers on herbage yield per plot at different stages of crop growth in mint

Treatments	Herbage yield per plot (kg)									
	Days after planting (DAP)									
	90					120				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	13.72	14.32	15.35	16.40	14.95	16.51	17.07	18.23	19.30	17.78
S ₂	15.88	16.58	17.62	18.80	17.22	19.05	19.67	20.37	21.48	20.14
S ₃	12.92	13.36	14.07	14.89	13.81	14.66	16.06	16.75	17.96	16.36
Mean	14.18	14.75	15.68	16.70		16.74	17.60	18.45	19.58	
	SE m±		CD at 5%			SE m±		CD at 5%		
S	0.087		0.257			0.046		0.134		
F	0.101		0.297			0.053		0.155		
S×F	0.175		NS			0.091		0.270		

Table 16a. Effect of spacing and fertilizers on herbage yield per plot at different stages of crop growth in mint

Treatment s	Herbage yield per plot (kg)									
	Days after planting (DAP)									
	150					180				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	17.33	17.77	18.96	19.94	18.50	15.96	16.51	17.70	18.71	17.22
S ₂	19.82	20.67	21.54	22.57	21.15	18.49	19.56	20.26	21.20	19.88
S ₃	15.57	16.98	17.85	18.88	17.32	14.45	15.78	16.57	17.59	16.09
Mean	17.57	18.47	19.45	20.46		16.30	17.28	18.18	19.17	
	SE m±		CD at 5%			SE m±		CD at 5%		
S	0.028		0.082			0.030		0.089		
F	0.032		0.095			0.035		0.103		
S×F	0.056		0.164			0.061		0.179		

Factor- I Spacing (S)

S₁: 30×15 cm

S₂: 45×15 cm

S₃: 60×15 cm

Factor -II Fertilizers (F) (Nitrogen + Sulphur)

F₁: 0 kg ha⁻¹ + 0 kg ha⁻¹ (Control)

F₂: 80 kg ha⁻¹ +20 kg ha⁻¹

F₃: 110 kg ha⁻¹ +20 kg ha⁻¹

F₄: 140 kg ha⁻¹ + 20 kg ha⁻¹

Table 17. Effect of spacing and fertilizers on herbage yield per hectare at different stages of crop growth in mint

Treatments	Herbage yield per hectare (q)									
	Days after planting (DAP)									
	90					120				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	152.54	159.14	170.61	182.32	166.15	183.53	189.70	202.64	214.53	197.60
S ₂	176.50	184.29	195.84	208.93	191.39	211.71	218.56	226.33	238.68	223.82
S ₃	143.64	148.45	156.35	165.53	153.49	162.96	178.53	186.11	199.63	181.80
Mean	157.56	163.96	174.26	185.59		186.06	195.59	205.02	217.61	
	SE m±		CD at 5%			SE m±		CD at 5%		
S	0.976		2.865			0.510		1.498		
F	1.127		3.308			0.589		1.729		
S×F	1.953		NS			1.021		2.996		

Table 17a. Effect of spacing and fertilizers on herbage yield per hectare at different stages of crop growth in mint

Treatments	Herbage yield per hectare (q)									
	Days after planting (DAP)									
	150					180				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S₁	192.56	197.53	210.71	221.62	205.60	177.36	183.53	196.73	207.90	191.38
S₂	220.22	229.70	239.43	250.88	235.05	205.45	217.36	225.21	235.64	220.91
S₃	173.07	188.67	198.36	209.79	192.47	160.55	175.33	184.11	195.51	178.87
Mean	195.28	205.30	216.16	227.43		181.12	192.07	202.01	213.01	
	SE m±		CD at 5%			SE m±		CD at 5%		
S	0.309		0.908			0.339		0.997		
F	0.357		1.049			0.392		1.151		
S×F	0.619		1.818			0.679		1.994		

Factor-I Spacing (S)

S₁: 30×15 cm

S₂: 45×15 cm

S₃: 60×15 cm

Factor -II Fertilizers (F) (Nitrogen + Sulphur)

F₁: 0 kg ha⁻¹ + 0 kg ha⁻¹ (Control)

F₂: 80 kg ha⁻¹ +20 kg ha⁻¹

F₃: 110 kg ha⁻¹ +20 kg ha⁻¹

F₄: 140 kg ha⁻¹ +20 kg ha⁻¹

Table 18. Effect of spacing and fertilizers on essential oil content at different stages of crop growth in mint

Treatments	Essential oil content (%)									
	Days after planting (DAP)									
	90					120				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	0.272	0.413	0.423	0.413	0.380	0.398	0.690	0.683	0.702	0.618
S ₂	0.272	0.413	0.412	0.423	0.380	0.402	0.679	0.701	0.710	0.623
S ₃	0.272	0.422	0.423	0.423	0.385	0.401	0.679	0.691	0.695	0.616
Mean	0.272	0.416	0.419	0.420		0.401	0.683	0.692	0.702	
	SE m±		CD at 5%			SE m±		CD at 5%		
S	0.0082		NS			0.0083		NS		
F	0.0094		0.0277			0.0096		0.0282		
S×F	0.0164		NS			0.0167		NS		

Factor-I Spacing (S)

S₁: 30×15 cm

S₂: 45×15 cm

S₃: 60×15 cm

Factor -II Fertilizers (F) (Nitrogen + Sulphur)

F₁: 0 kg ha⁻¹ + 0 kg ha⁻¹ (Control)

F₂: 80 kg ha⁻¹ +20 kg ha⁻¹

F₃: 110 kg ha⁻¹ +20 kg ha⁻¹

F₄: 140 kg ha⁻¹ +20 kg ha⁻¹

Table 18a. Effect of spacing and fertilizers on essential oil content at different stages of crop growth in mint

Treatments	Essential oil content (%)									
	Days after planting (DAP)									
	150					180				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	0.506	0.701	0.725	0.714	0.662	0.512	0.742	0.757	0.757	0.692
S ₂	0.501	0.729	0.737	0.740	0.677	0.502	0.763	0.773	0.781	0.705
S ₃	0.506	0.725	0.737	0.748	0.679	0.507	0.756	0.767	0.773	0.701
Mean	0.504	0.718	0.733	0.734		0.507	0.754	0.766	0.770	
	SE m±		CD at 5%			SE m±		CD at 5%		
S	0.0083		NS			0.0084		NS		
F	0.0096		0.0282			0.0097		0.0284		
S×F	0.0167		NS			0.0168		NS		

Table 19. Effect of spacing and fertilizers on essential oil yield at different stages of crop growth in mint

Treatments	Essential oil yield (kg ha ⁻¹)									
	Days after planting (DAP)									
	90					120				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	41.42	65.69	72.21	75.26	63.65	73.04	130.89	138.46	150.60	123.25
S ₂	48.04	76.03	80.62	88.44	73.28	85.19	148.44	158.54	169.46	140.41
S ₃	39.29	62.67	66.18	70.06	59.55	65.36	121.16	128.54	138.80	113.47
Mean	42.92	68.13	73.00	77.92		74.53	133.50	141.85	152.95	
	SE m±		CD at 5%			SE m±		CD at 5%		
S	0.791		2.321			1.075		3.155		
F	0.913		2.680			1.241		3.643		
S×F	1.582		NS			2.150		NS		

Table 19a. Effect of spacing and fertilizers on essential oil yield at different stages of crop growth in mint

Treatments	Essential oil yield (kg ha ⁻¹)									
	Days after planting (DAP)									
	150					180				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	97.43	138.40	152.82	158.23	136.72	90.82	136.12	148.98	157.44	133.34
S ₂	110.37	167.38	176.38	185.65	159.94	103.11	165.84	174.08	183.96	156.75
S ₃	87.60	136.84	146.25	156.86	131.89	81.41	132.60	141.26	151.12	126.60
Mean	98.47	147.54	158.48	166.91		91.78	144.85	154.77	164.17	
	SE m±		CD at 5%			SE m±		CD at 5%		
S	1.666		4.889			1.604		4.705		
F	1.924		5.645			1.852		5.434		
S×F	3.333		NS			3.208		NS		

Factor-I Spacing (S)

S₁: 30×15 cm

S₂: 45×15 cm

S₃: 60×15 cm

Factor -II Fertilizers (F) (Nitrogen + Sulphur)

F₁: 0 kg ha⁻¹ + 0 kg ha⁻¹ (Control)

F₂: 80 kg ha⁻¹ +20 kg ha⁻¹

F₃: 110 kg ha⁻¹ +20 kg ha⁻¹

F₄: 140 kg ha⁻¹ +20 kg ha⁻¹

Table 20. Effect of spacing and fertilizers on nitrogen content in plant sample at different stages of crop growth in mint

Treatment s	Nitrogen content in plant sample (%)									
	Days after planting (DAP)									
	90					120				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	0.870	0.980	1.022	1.022	0.974	0.910	1.020	1.040	1.047	1.004
S ₂	0.880	1.029	1.036	1.039	0.996	0.920	1.050	1.053	1.055	1.020
S ₃	0.880	1.034	1.038	1.040	0.998	0.930	1.055	1.057	1.060	1.026
Mean	0.877	1.014	1.032	1.034		0.920	1.042	1.050	1.054	
	SE m±		CD at 5%			SE m±		CD at 5%		
S	0.003		0.010			0.004		0.013		
F	0.004		0.012			0.005		0.016		
S×F	0.007		NS			0.009		NS		

Factor-I Spacing (S)

S₁: 30×15 cm

S₂: 45×15 cm

S₃: 60×15 cm

Factor -II Fertilizers (F) (Nitrogen + Sulphur)

F₁: 0 kg ha⁻¹ + 0 kg ha⁻¹ (Control)

F₂: 80 kg ha⁻¹ +20 kg ha⁻¹

F₃: 110 kg ha⁻¹ +20 kg ha⁻¹

F₄: 140 kg ha⁻¹ +20 kg ha⁻¹

Table 20a. Effect of spacing and fertilizers on nitrogen content in plant sample at different stages of crop growth in mint

Treatment s	Nitrogen content in plant sample (%)									
	Days after planting (DAP)									
	150					180				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	0.920	1.030	1.045	1.049	1.011	0.921	1.032	1.048	1.050	1.013
S ₂	0.940	1.052	1.055	1.059	1.027	0.950	1.053	1.057	1.061	1.030
S ₃	0.960	1.062	1.065	1.069	1.039	0.970	1.063	1.066	1.070	1.042
Mean	0.940	1.048	1.055	1.059		0.947	1.049	1.057	1.060	
	SE m±		CD at 5%			SE m±		CD at 5%		
S	0.002		0.006			0.002		0.006		
F	0.002		0.007			0.002		0.007		
S×F	0.004		NS			0.004		NS		

Table 21. Effect of spacing and fertilizers on sulphur content in plant sample at different stages of crop growth in mint

Treatments	Sulphur content in plant sample (%)									
	Days after planting (DAP)									
	90					120				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	0.320	0.405	0.415	0.418	0.390	0.340	0.413	0.414	0.416	0.396
S ₂	0.330	0.411	0.415	0.419	0.394	0.340	0.415	0.416	0.417	0.397
S ₃	0.330	0.412	0.418	0.419	0.395	0.350	0.416	0.420	0.420	0.402
Mean	0.327	0.409	0.416	0.419		0.343	0.415	0.417	0.418	
	SE m±		CD at 5%			SE m±		CD at 5%		
S	0.002		NS			0.008		NS		
F	0.002		0.007			0.009		0.027		
S×F	0.004		NS			0.016		NS		

Table 21a. Effect of spacing and fertilizers on sulphur content in plant sample at different stages of crop growth in mint

Treatment s	Sulphur content in plant sample (%)									
	Days after planting (DAP)									
	150					180				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	0.350	0.416	0.419	0.418	0.401	0.360	0.417	0.420	0.420	0.404
S ₂	0.360	0.418	0.419	0.420	0.404	0.370	0.420	0.421	0.423	0.409
S ₃	0.370	0.419	0.422	0.424	0.409	0.390	0.422	0.423	0.424	0.415
Mean	0.360	0.418	0.420	0.421		0.373	0.420	0.421	0.422	
	SE m±		CD at 5%			SE m±		CD at 5%		
S	0.001		0.004			0.010		NS		
F	0.001		0.004			0.012		0.036		
S×F	0.002		NS			0.021		NS		

Factor-I Spacing (S)

S₁: 30×15 cm

S₂: 45×15 cm

S₃: 60×15 cm

Factor -II Fertilizers (F) (Nitrogen + Sulphur)

F₁: 0 kg ha⁻¹ + 0 kg ha⁻¹ (Control)

F₂: 80 kg ha⁻¹ +20 kg ha⁻¹

F₃: 110 kg ha⁻¹ +20 kg ha⁻¹

F₄: 140 kg ha⁻¹ +20 kg ha⁻¹

Table 22. Effect of spacing and fertilizers on nitrogen uptake at different stages of crop growth in mint

Treatments	Nitrogen uptake (kg ha ⁻¹)									
	Days after planting (DAP)									
	90					120				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	17.26	21.15	23.66	26.53	22.15	34.14	41.12	47.19	50.00	43.11
S ₂	18.42	25.64	27.07	27.91	24.76	39.17	48.16	51.04	53.23	47.90
S ₃	16.93	20.14	22.05	22.90	20.50	34.11	39.97	42.28	43.77	40.03
Mean	17.53	22.31	24.26	25.78		35.80	43.08	46.83	49.00	
	SE m±		CD at 5%			SE m±		CD at 5%		
S	0.978		2.869			1.946		5.709		
F	1.129		3.312			2.247		6.592		
S×F	1.956		NS			3.892		NS		

Table 22a. Effect of spacing and fertilizers on nitrogen uptake at different stages of crop growth in mint

Treatments	Nitrogen uptake (kg ha ⁻¹)									
	Days after planting (DAP)									
	150					180				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	38.46	46.67	52.67	55.97	48.44	32.40	41.76	47.37	53.25	43.69
S ₂	44.65	54.50	57.80	60.89	54.46	41.63	50.93	55.62	59.48	51.91
S ₃	38.65	45.38	47.29	49.46	45.19	35.91	42.37	45.02	46.52	42.45
Mean	40.58	48.85	52.58	55.44		36.64	45.02	49.33	53.08	
	SE m±		CD at 5%			SE m±		CD at 5%		
S	1.486		4.360			1.880		5.516		
F	1.716		5.035			2.171		6.369		
S×F	2.972		NS			3.760		NS		

Factor-I Spacing (S)

S₁: 30×15 cm

S₂: 45×15 cm

S₃: 60×15 cm

Factor -II Fertilizers (F) (Nitrogen + Sulphur)

F₁: 0 kg ha⁻¹ + 0 kg ha⁻¹ (Control)

F₂: 80 kg ha⁻¹ +20 kg ha⁻¹

F₃: 110 kg ha⁻¹ +20 kg ha⁻¹

F₄: 140 kg ha⁻¹ +20 kg ha⁻¹

Table 23. Effect of spacing and fertilizers on sulphur uptake at different stages of crop growth in mint

Treatment s	Sulphur uptake (kg ha ⁻¹)									
	Days after planting (DAP)									
	90					120				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S₁	6.35	8.74	9.61	10.85	8.88	12.75	16.69	18.79	19.87	17.02
S₂	6.91	10.24	10.85	11.28	9.82	14.48	19.03	20.17	21.04	18.68
S₃	6.35	8.02	8.88	9.23	8.12	12.84	15.76	16.80	17.34	15.68
Mean	6.53	9.00	9.78	10.45		13.35	17.16	18.58	19.41	
	SE m±		CD at 5%			SE m±		CD at 5%		
S	0.230		0.675			0.763		2.239		
F	0.265		0.780			0.881		2.585		
S×F	0.460		NS			1.526		NS		

Table 23a. Effect of spacing and fertilizers on sulphur uptake at different stages of crop growth in mint

Treatment s	Sulphur uptake (kg ha ⁻¹)									
	Days after planting (DAP)									
	150					180				
	F ₁	F ₂	F ₃	F ₄	Mean	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	14.63	18.85	21.12	22.30	19.22	12.66	16.87	18.98	21.30	17.45
S ₂	17.10	21.66	22.95	24.15	21.46	16.21	20.32	22.15	23.71	20.59
S ₃	14.89	17.91	18.74	19.62	17.79	14.44	16.82	17.86	18.43	16.88
Mean	15.54	19.47	20.93	22.02		14.43	18.00	19.66	21.14	
	SE m±		CD at 5%			SE m±		CD at 5%		
S	0.287		0.843			0.633		1.857		
F	0.332		0.974			0.731		2.144		
S×F	0.575		NS			1.266		NS		

Factor-I Spacing (S)

S₁: 30×15 cm

S₂: 45×15 cm

S₃: 60×15 cm

Factor -II Fertilizers (F) (Nitrogen + Sulphur)

F₁: 0 kg ha⁻¹ + 0 kg ha⁻¹ (Control)

F₂: 80 kg ha⁻¹ +20 kg ha⁻¹

F₃: 110 kg ha⁻¹ +20 kg ha⁻¹

F₄: 140 kg ha⁻¹ +20 kg ha⁻¹

Table 24. Effect of spacing and fertilizers on nitrogen content in the soil after final harvest in mint

Treatments	Nitrogen content in the soil after final harvest (kg ha ⁻¹)				
	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	83.60	104.50	108.68	121.22	104.50
S ₂	50.16	87.78	96.14	100.32	83.60
S ₃	87.78	117.04	150.48	158.84	128.53
Mean	73.84	103.10	118.43	126.79	
	SE m±		CD at 5%		
S	8.077		23.696		
F	9.327		27.362		
S×F	16.154		NS		

Factor-I Spacing (S)

S₁: 30×15 cm

S₂: 45×15 cm

S₃: 60×15 cm

Factor -II Fertilizers (F) (Nitrogen + Sulphur)

F₁: 0 kg ha⁻¹ + 0 kg ha⁻¹ (Control)

F₂: 80 kg ha⁻¹ +20 kg ha⁻¹

F₃: 110 kg ha⁻¹ +20 kg ha⁻¹

F₄: 140 kg ha⁻¹ +20 kg ha⁻¹

Table 25. Effect of spacing and fertilizers on sulphur content in the soil after final harvest in mint

Treatments	Sulphur content in the soil after final harvest (kg ha ⁻¹)				
	F ₁	F ₂	F ₃	F ₄	Mean
S ₁	19.29	22.08	23.26	24.13	22.19
S ₂	19.18	20.94	21.78	23.89	21.44
S ₃	19.82	22.78	24.61	25.74	23.23
Mean	19.43	21.93	23.21	24.58	
	SE m±		CD at 5%		
S	0.188		0.551		
F	0.217		0.636		
S×F	0.376		NS		

Factor-I Spacing (S)

S₁: 30×15 cm

S₂: 45×15 cm

S₃: 60×15 cm

Factor -II Fertilizers (F) (Nitrogen + Sulphur)

F₁: 0 kg ha⁻¹ + 0 kg ha⁻¹ (Control)

F₂: 80 kg ha⁻¹ +20 kg ha⁻¹

F₃: 110 kg ha⁻¹ +20 kg ha⁻¹

F₄: 140 kg ha⁻¹ +20 kg ha⁻¹

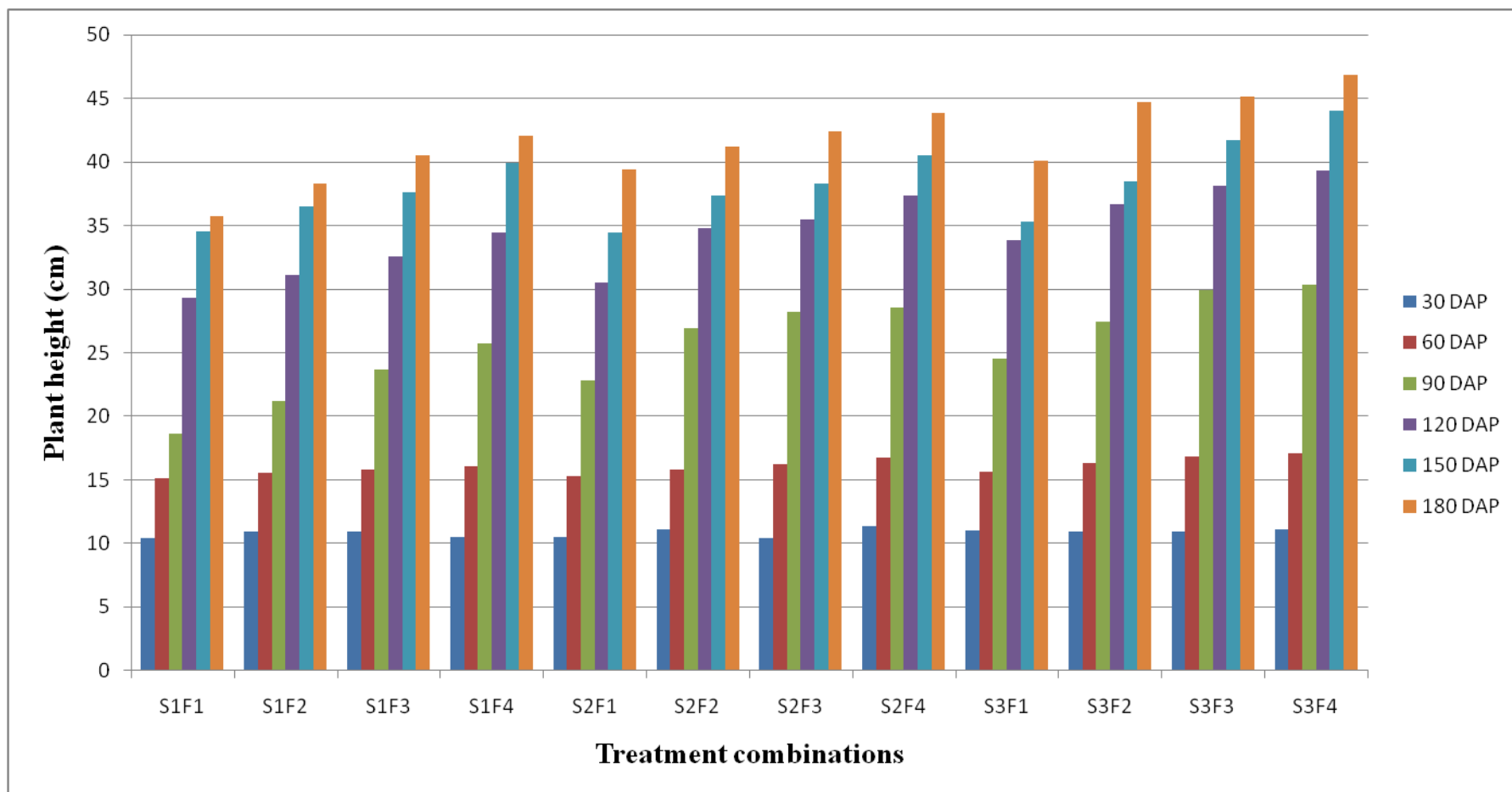


Fig. 2: Effect of spacing and fertilizers on plant height at different stages of crop growth in mint

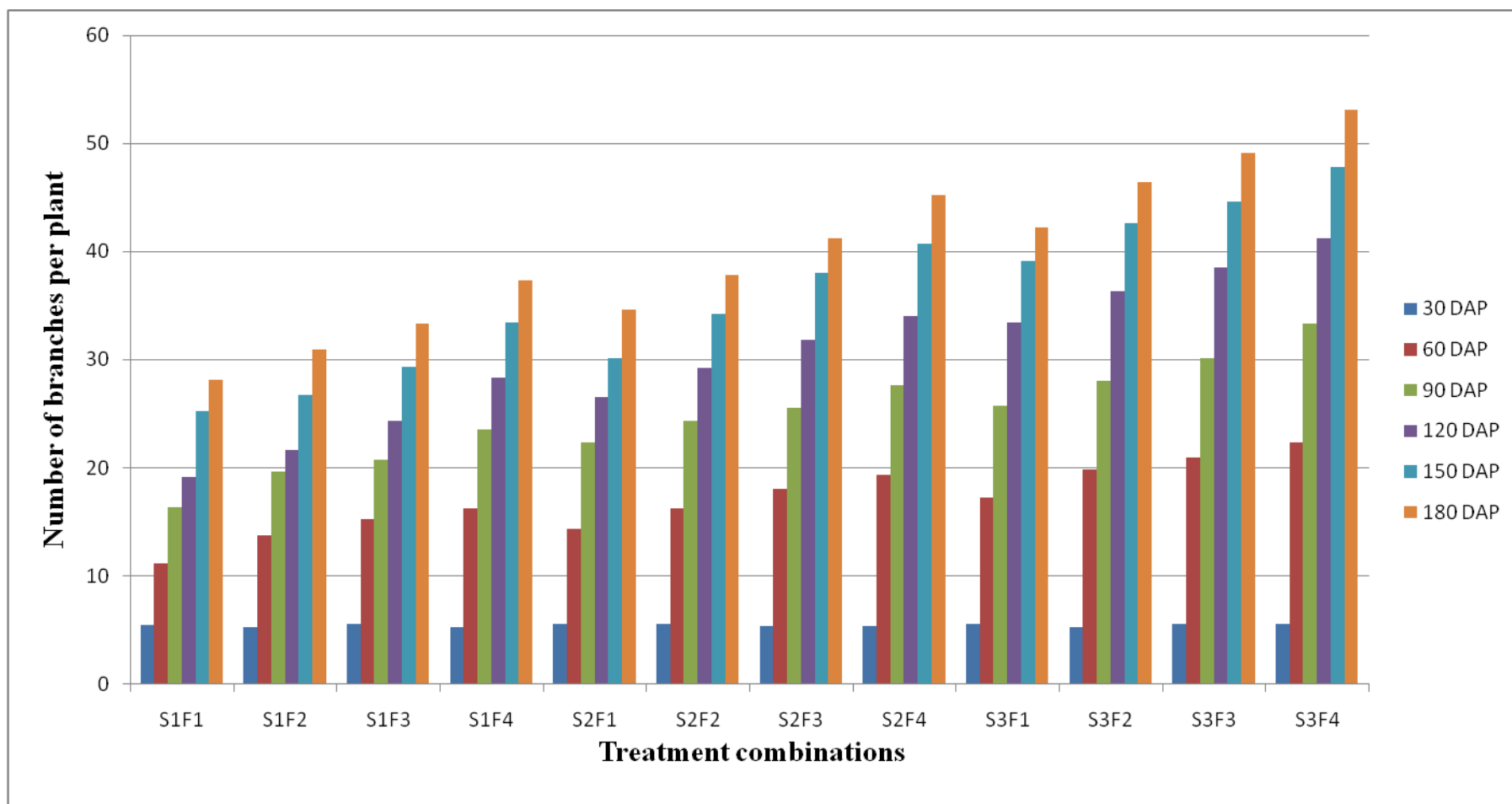


Fig. 3: Effect of spacing and fertilizers on number of branches per plant at different stages of crop growth in mint

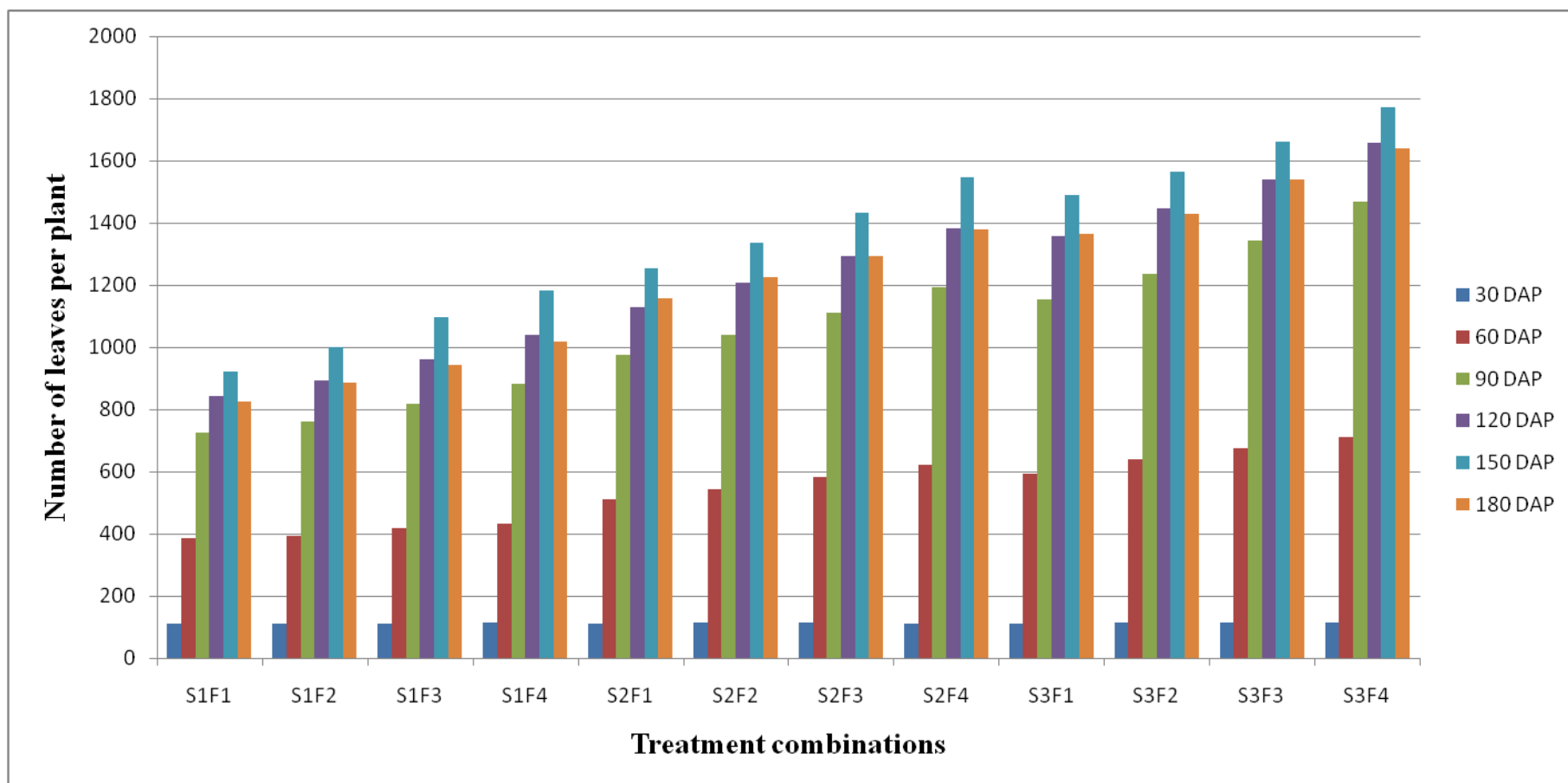


Fig. 4: Effect of spacing and fertilizers on number of leaves per plant at different stages of crop growth in mint

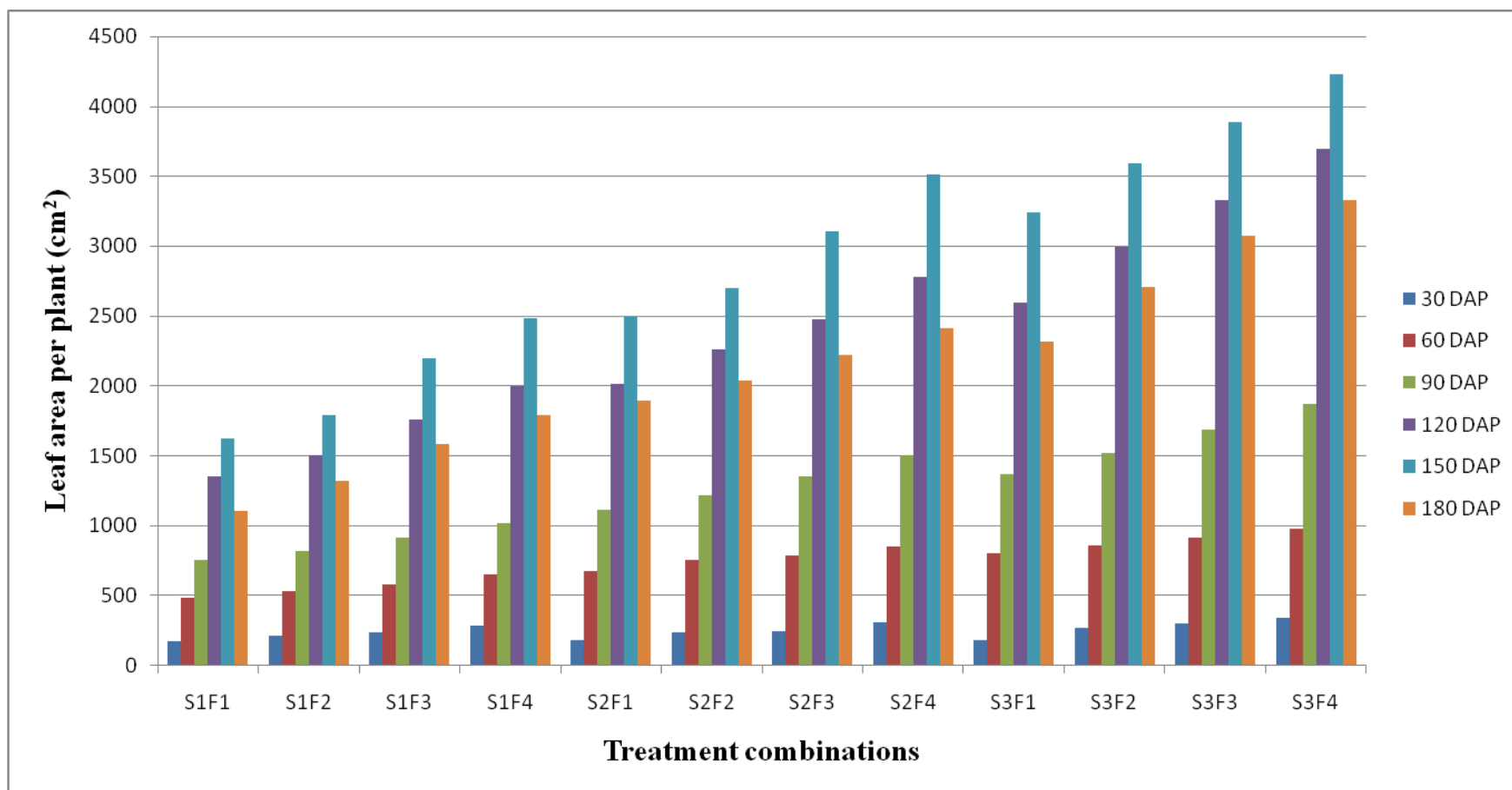


Fig. 5: Effect of spacing and fertilizers on leaf area per plant at different stages of crop growth in mint

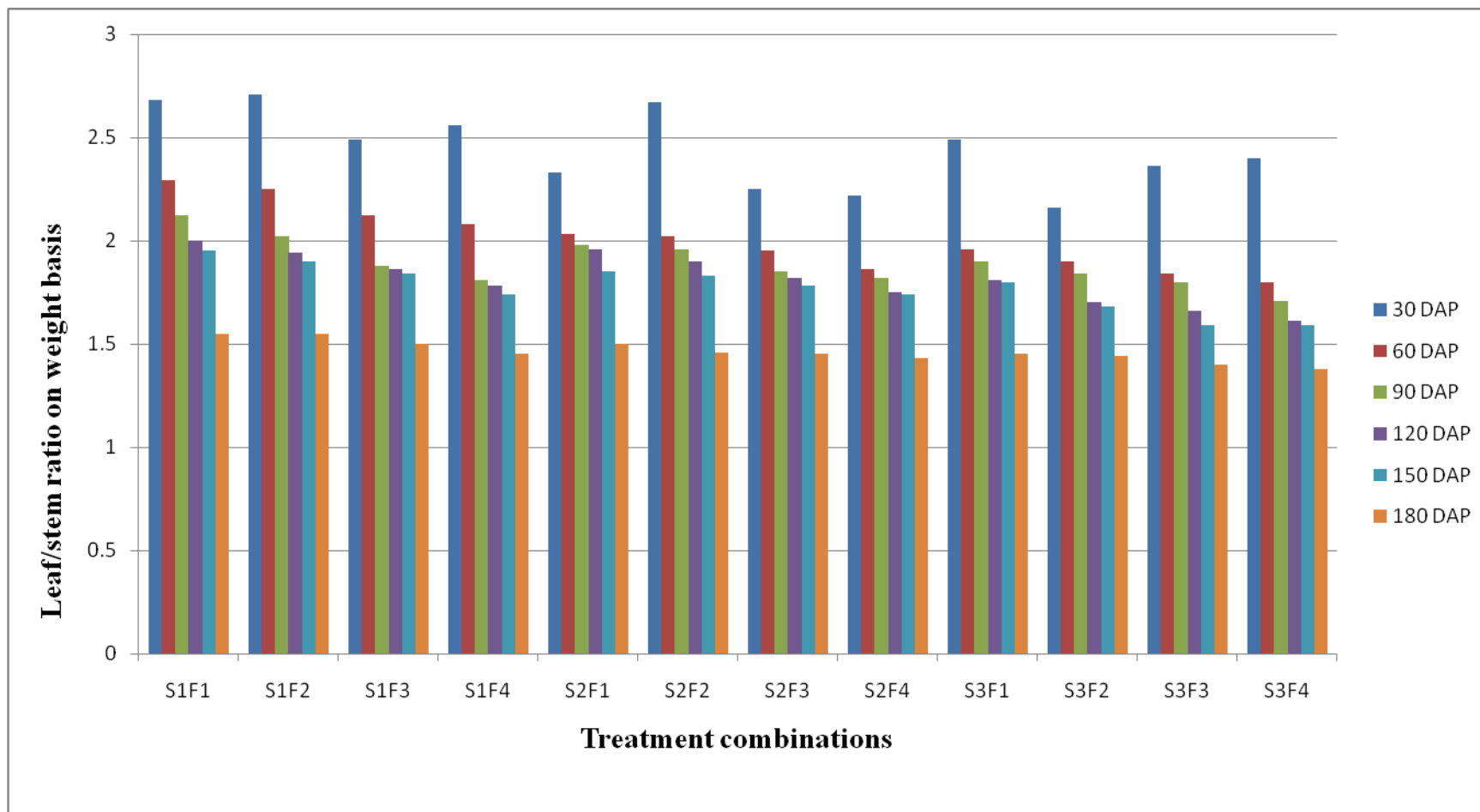


Fig. 6: Effect of spacing and fertilizers on leaf/stem ratio on weight basis at different stages of crop growth in mint

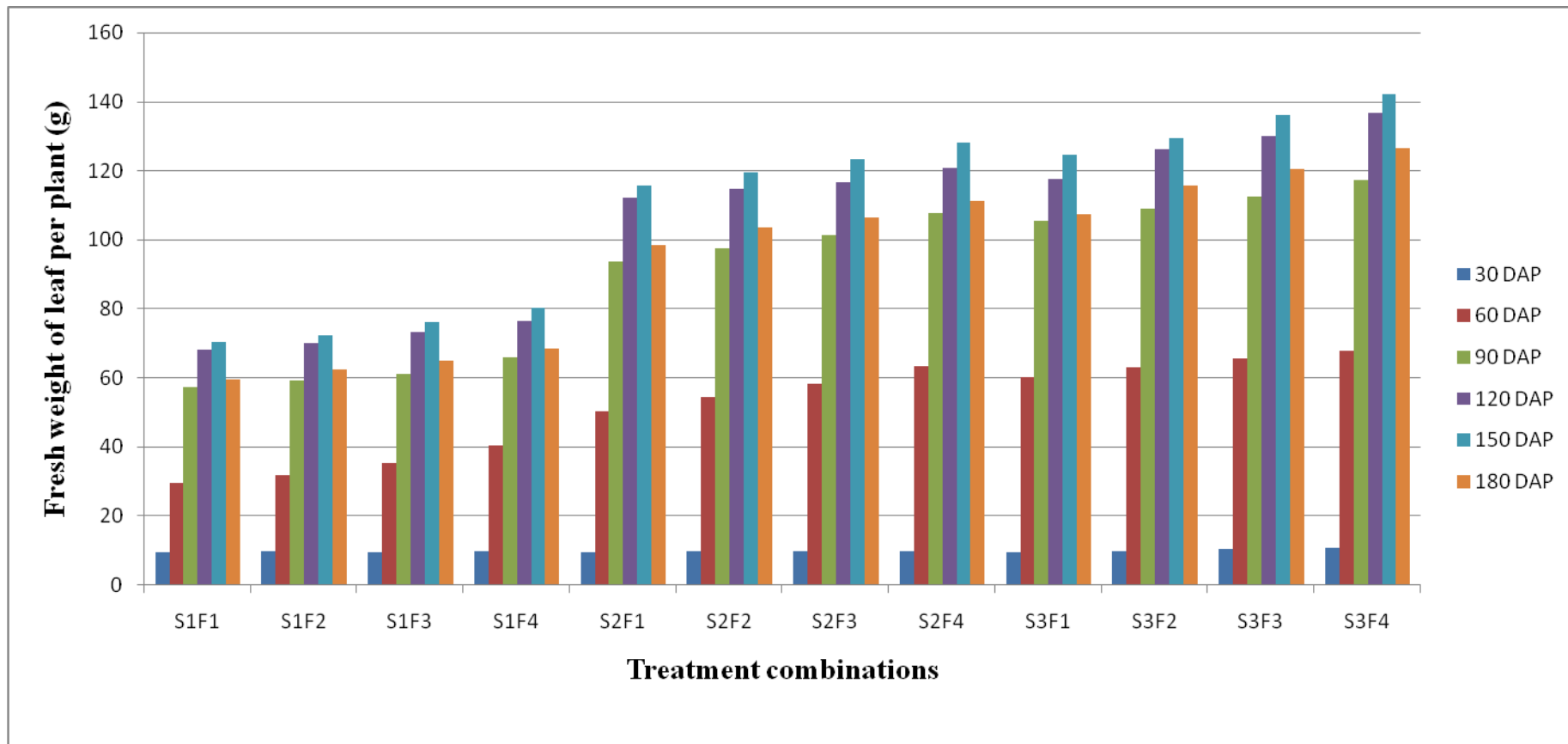


Fig. 7: Effect of spacing and fertilizers on fresh weight of leaf per plant at different stages of crop growth in mint

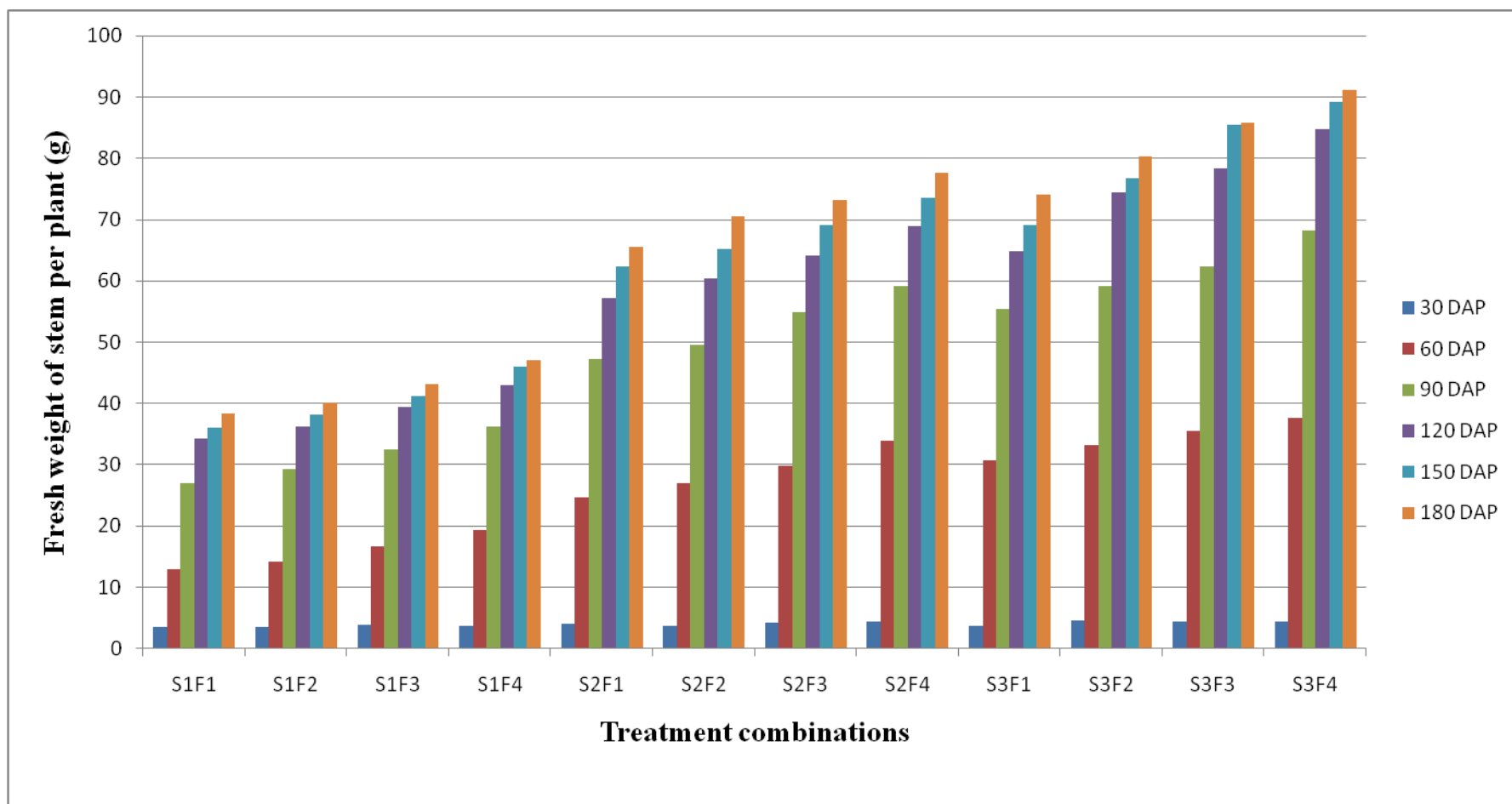


Fig. 8: Effect of spacing and fertilizers on fresh weight of stem per plant at different stages of crop growth in mint

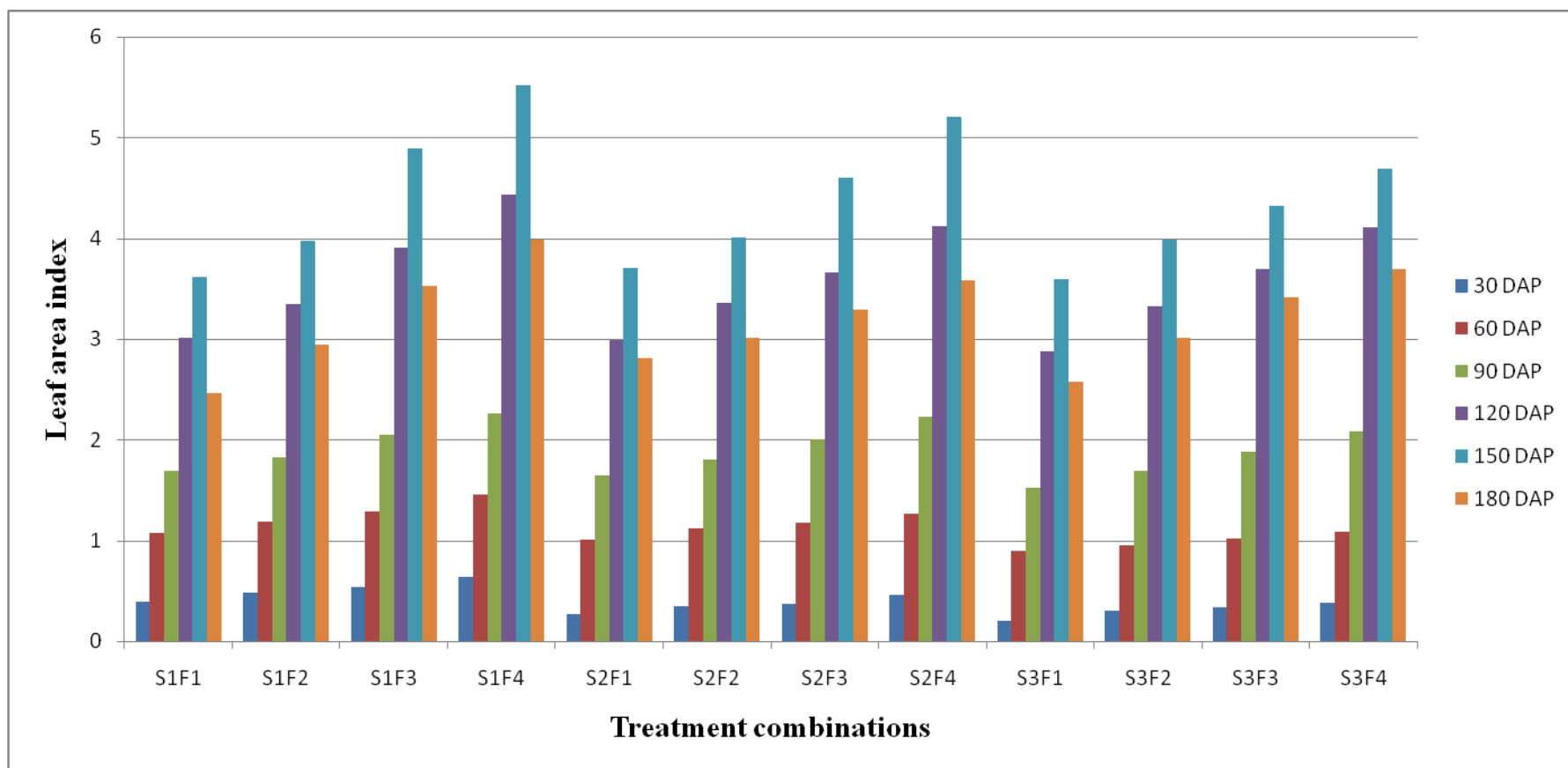


Fig. 9: Effect of spacing and fertilizers on leaf area index at different stages of crop growth in mint

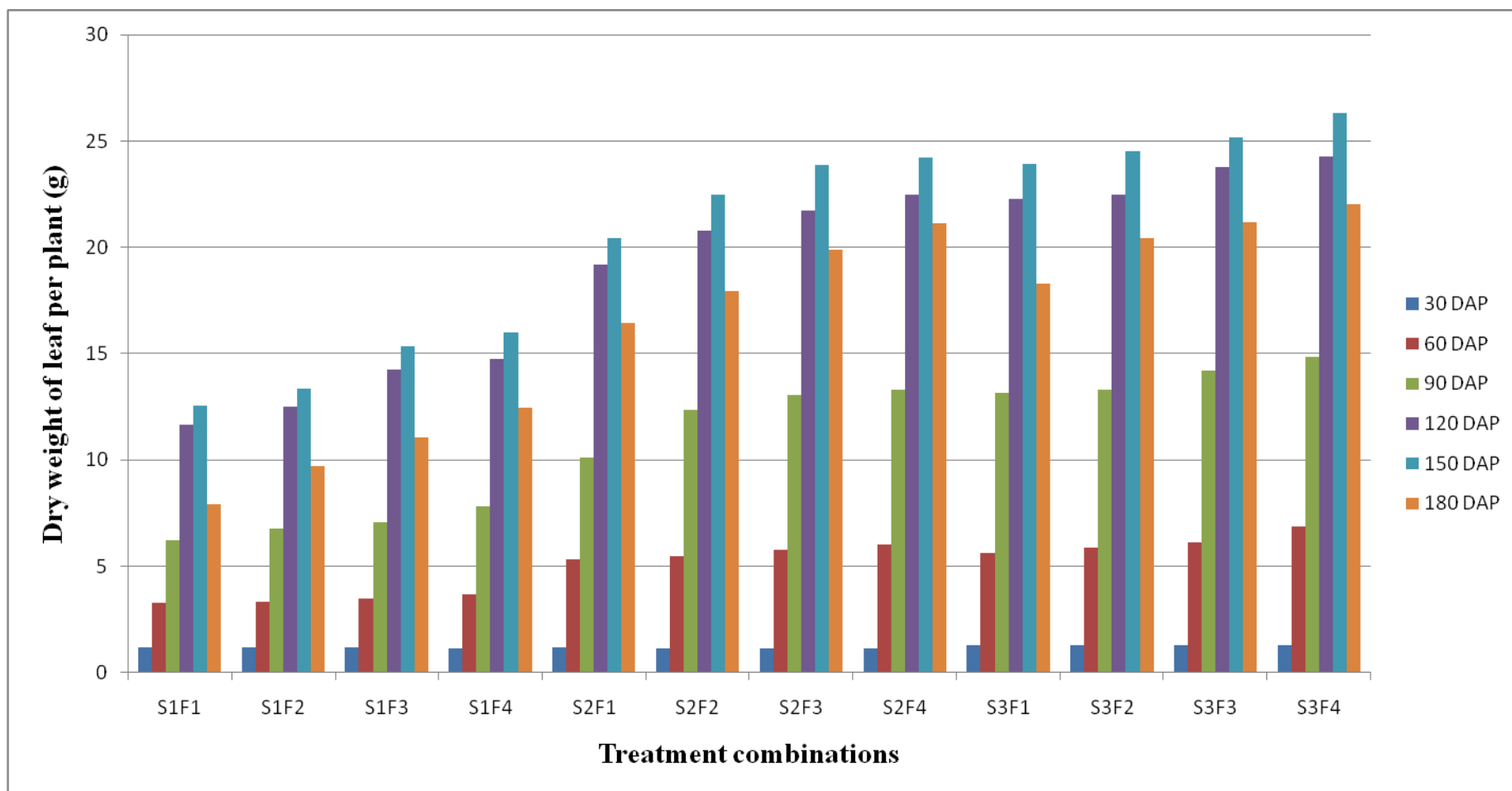


Fig. 10: Effect of spacing and fertilizers on dry weight of leaf per plant at different stages of crop growth in mint

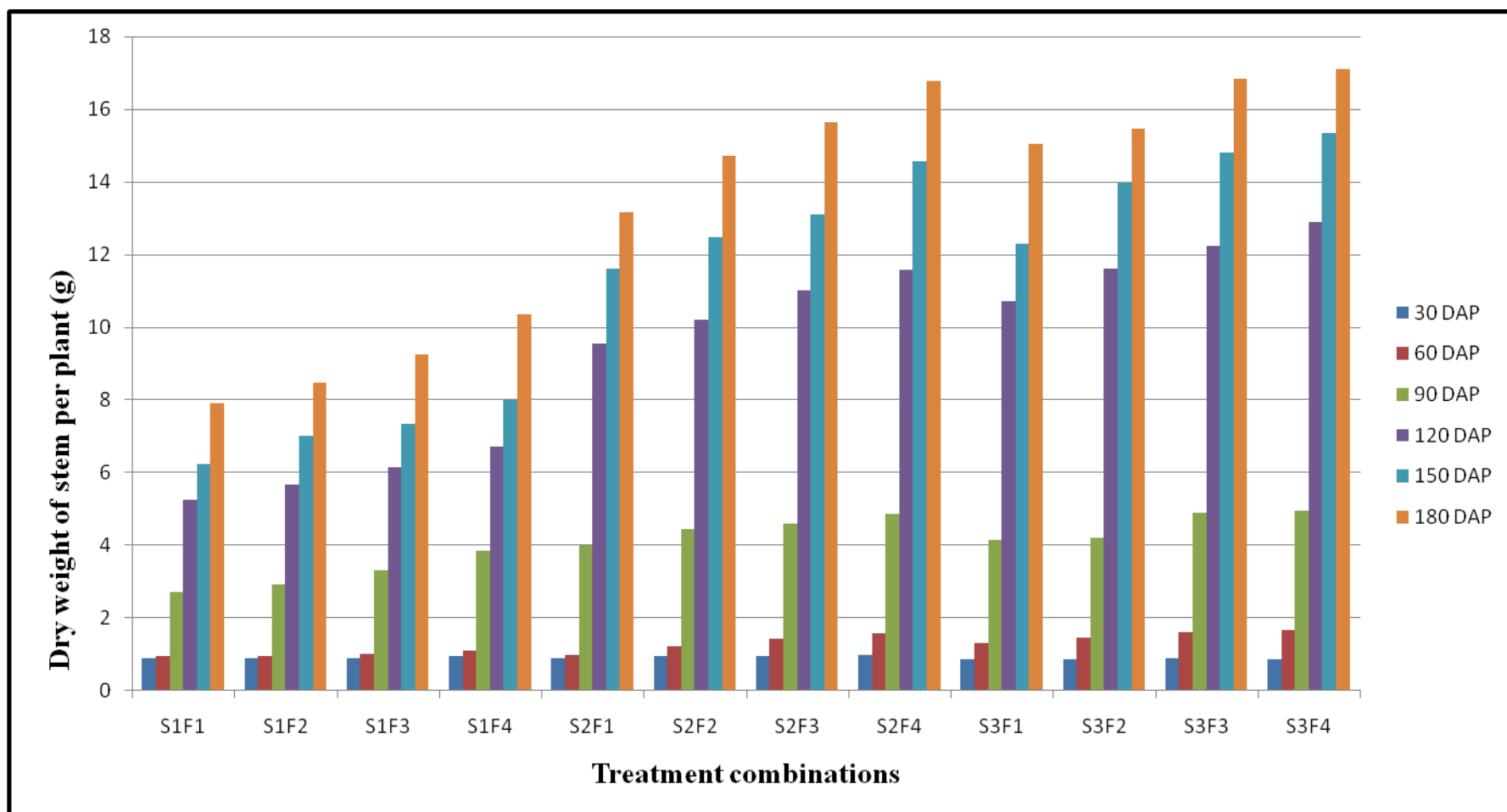


Fig. 11: Effect of spacing and fertilizers on dry weight of stem per plant at different stages of crop growth in mint

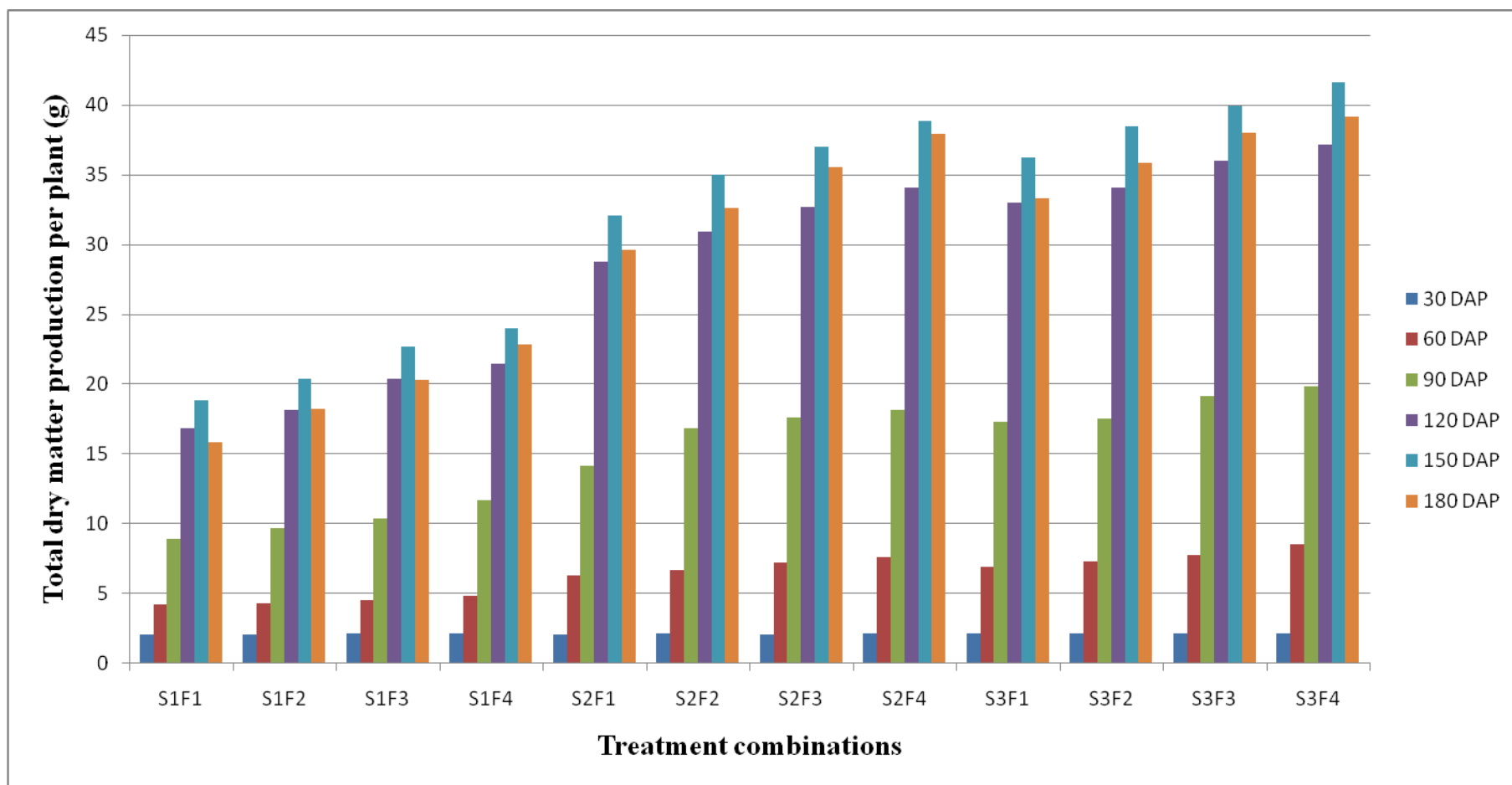


Fig. 12: Effect of spacing and fertilizers on total dry matter production per plant at different stages of crop growth in mint

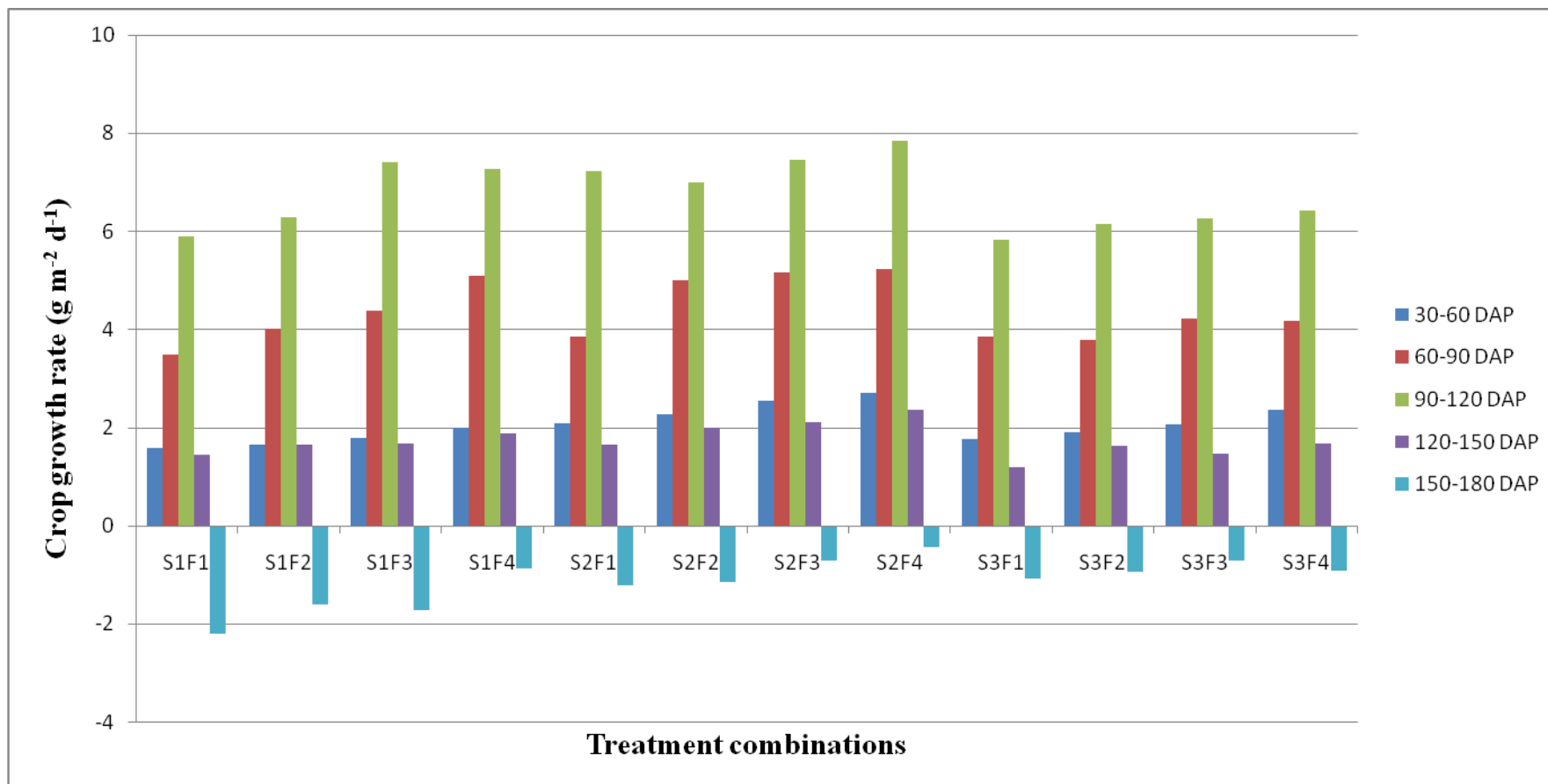


Fig. 13: Effect of spacing and fertilizers on crop growth rate at different stages of crop growth in mint

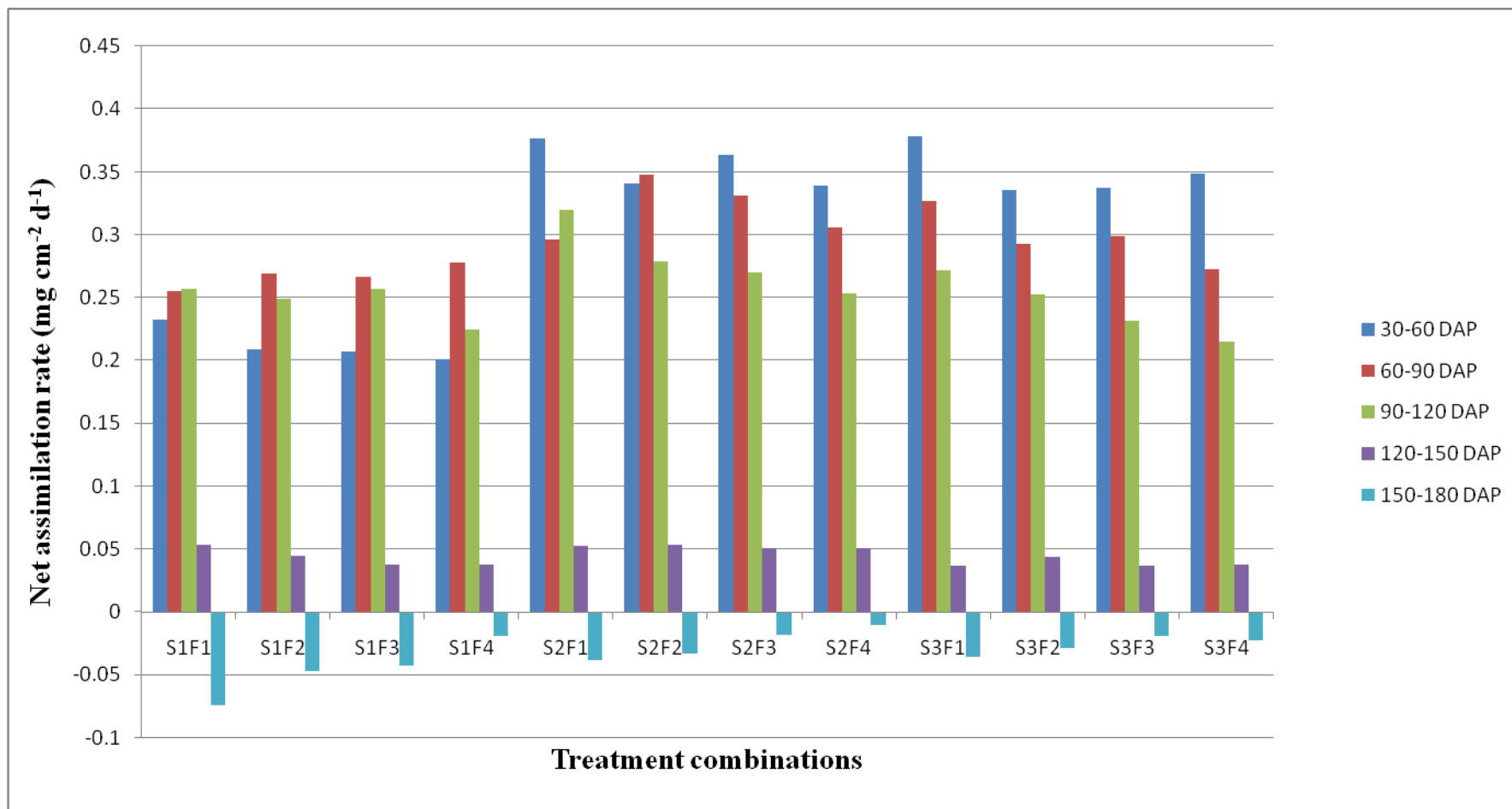


Fig. 14: Effect of spacing and fertilizers on net assimilation rate at different stages of crop growth in mint

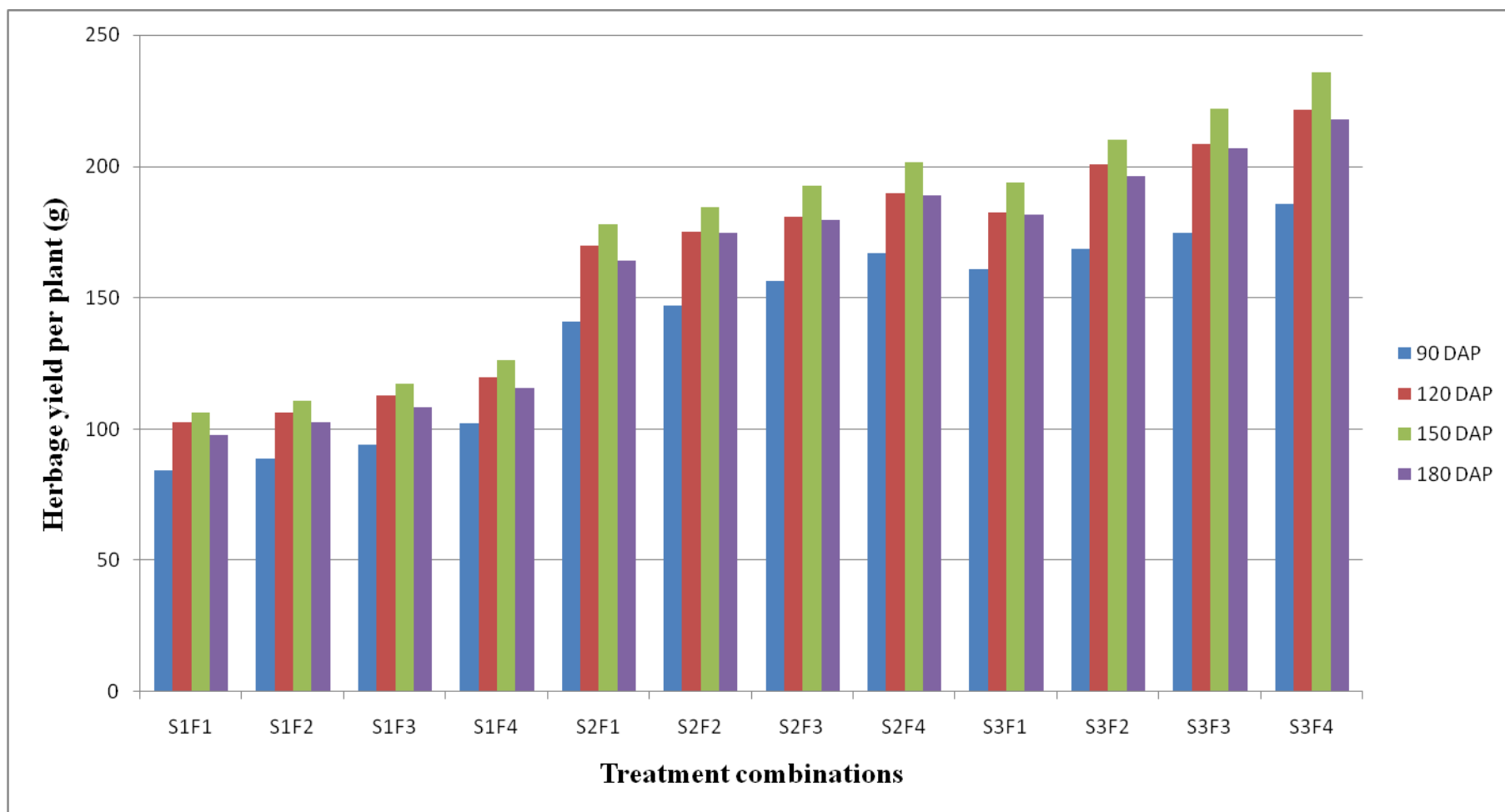


Fig. 15: Effect of spacing and fertilizers on herbage yield per plant at different stages of crop growth in mint

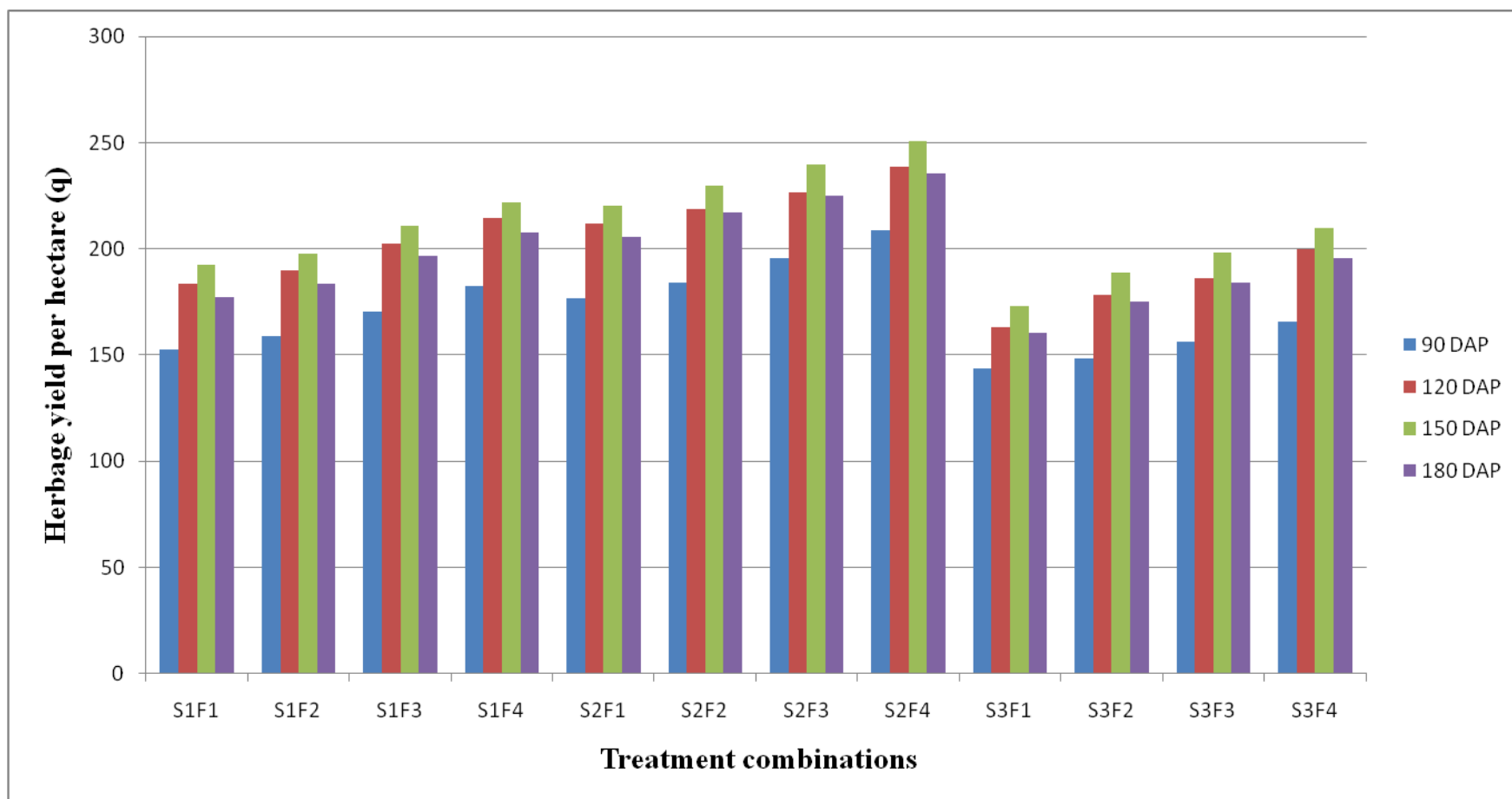


Fig. 17: Effect of spacing and fertilizers on herbage yield per hectare at different stages of crop growth in mint

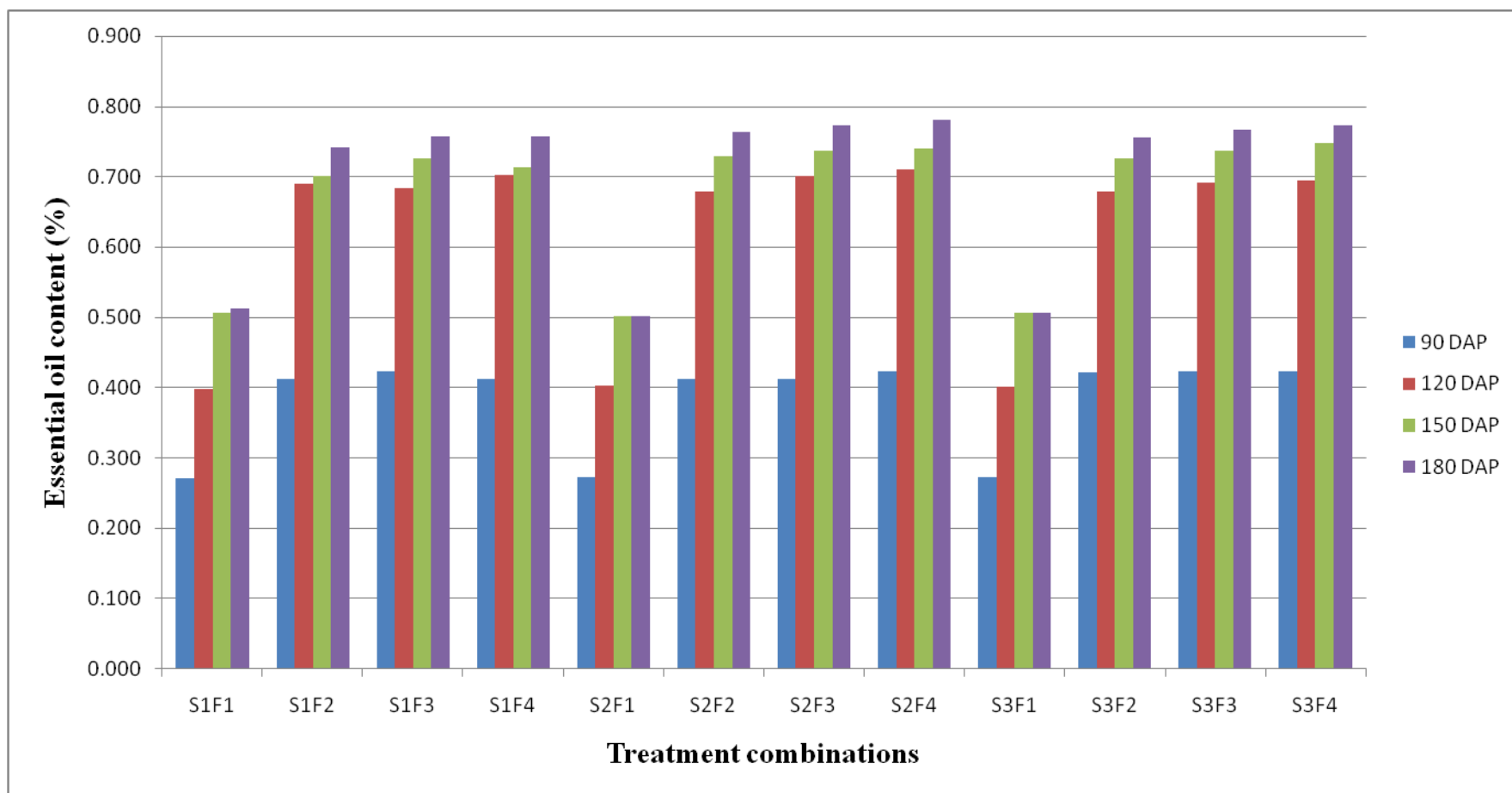


Fig. 18: Effect of spacing and fertilizers on essential oil content at different stages of crop growth in mint

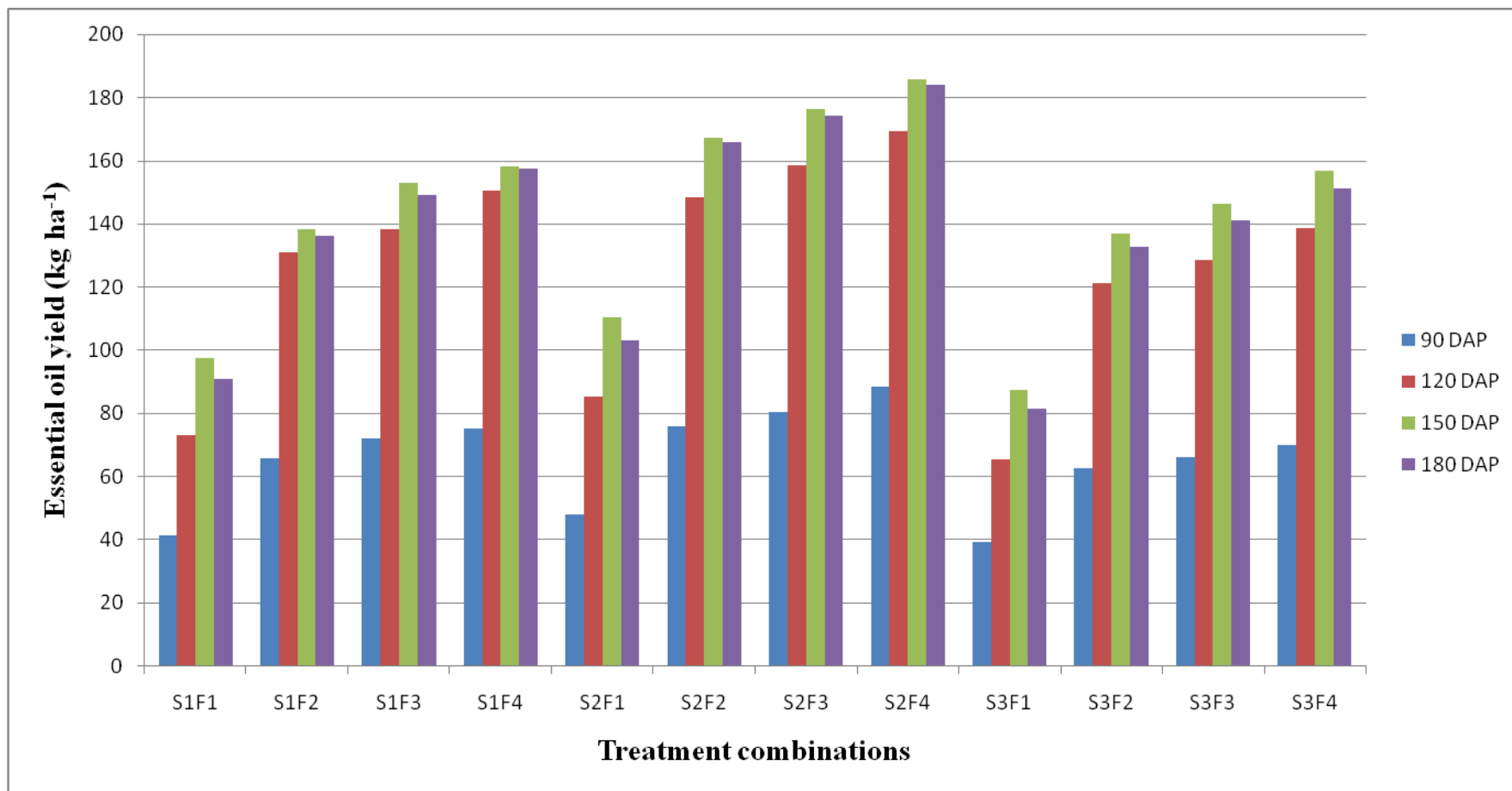


Fig. 19: Effect of spacing and fertilizers on essential oil yield at different stages of crop growth in mint

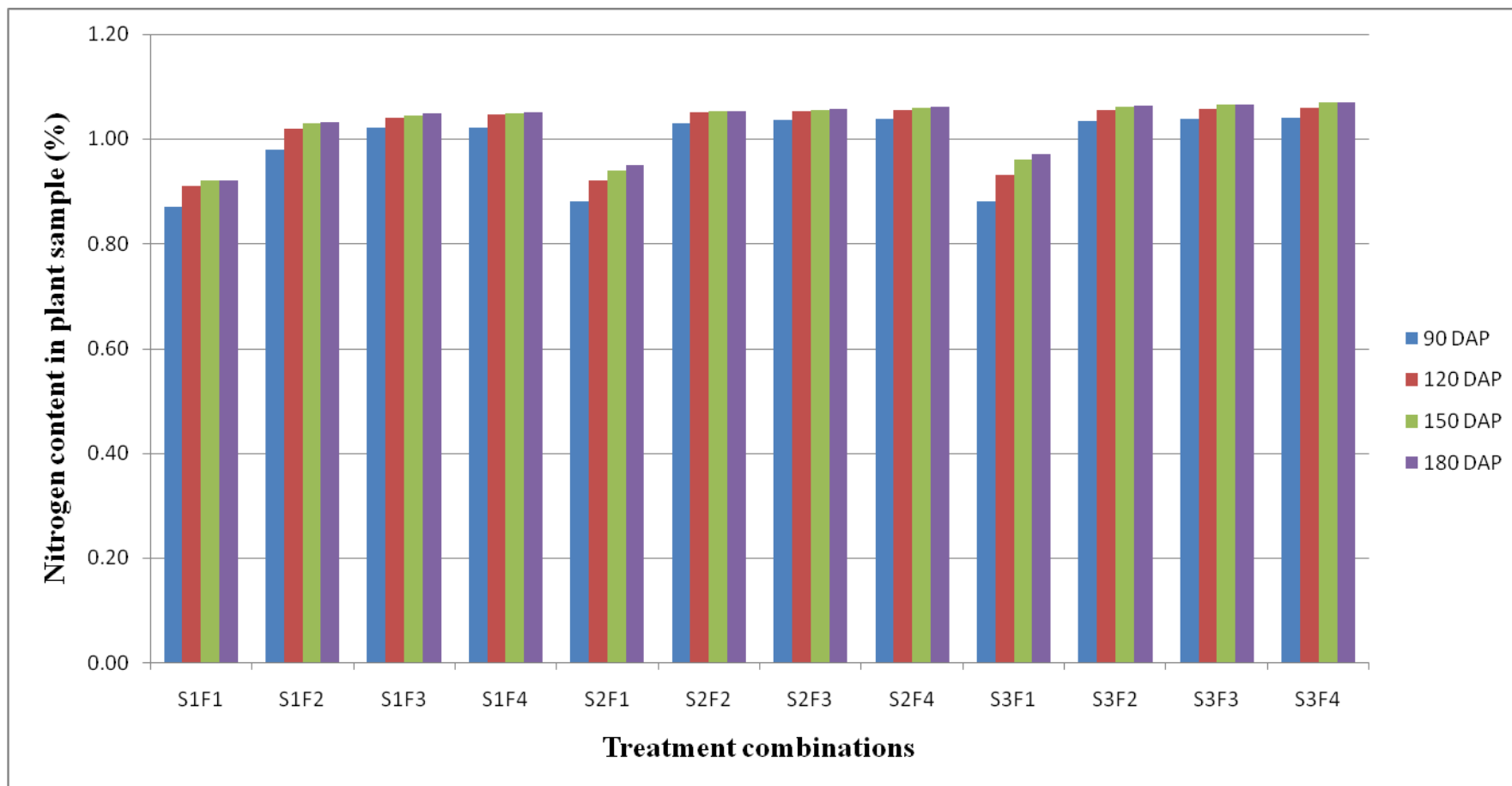


Fig. 20: Effect of spacing and fertilizers on nitrogen content in plant sample at different stages of crop growth in mint

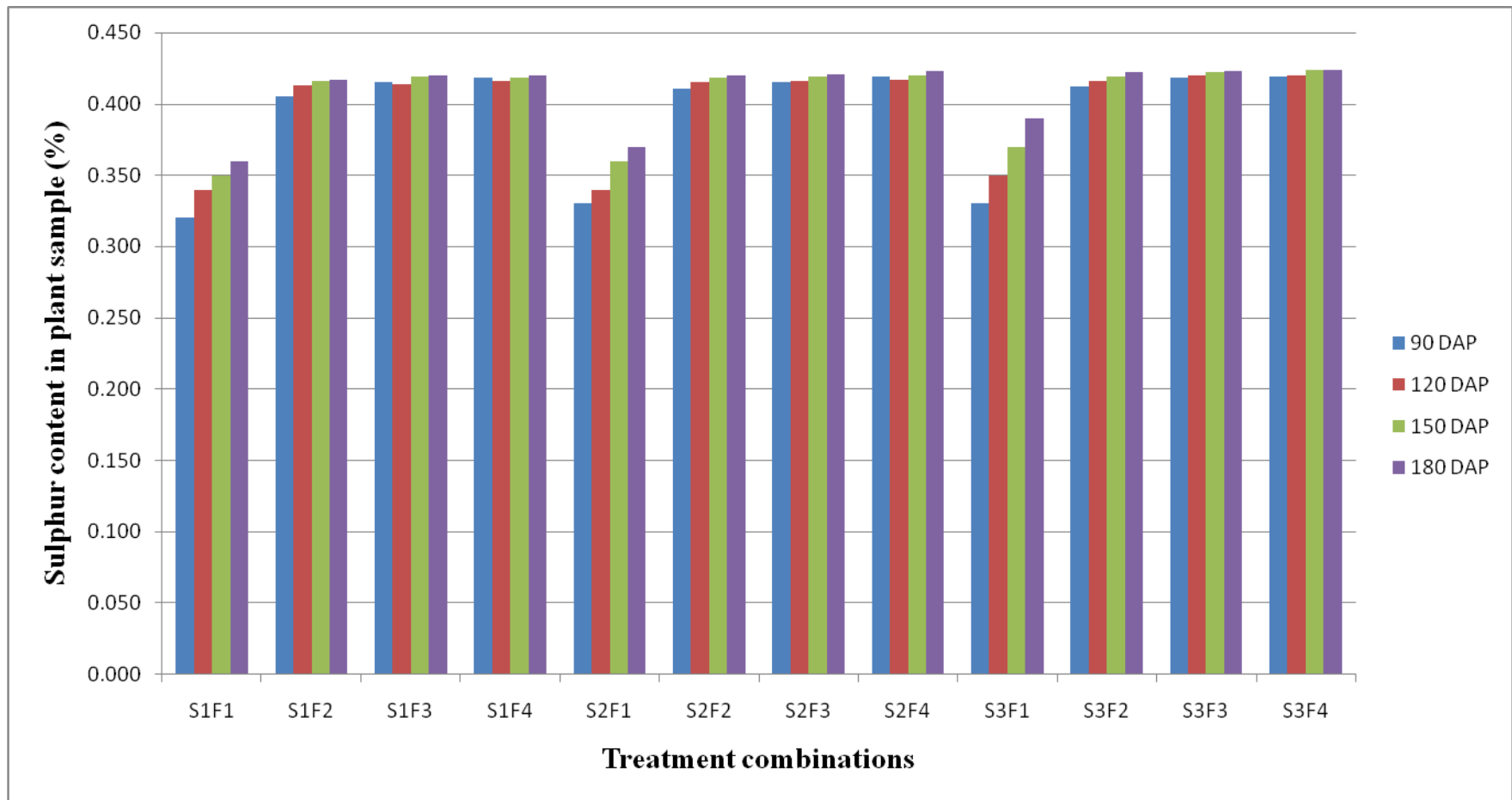


Fig. 21: Effect of spacing and fertilizers on sulphur content in plant sample at different stages of crop growth in mint

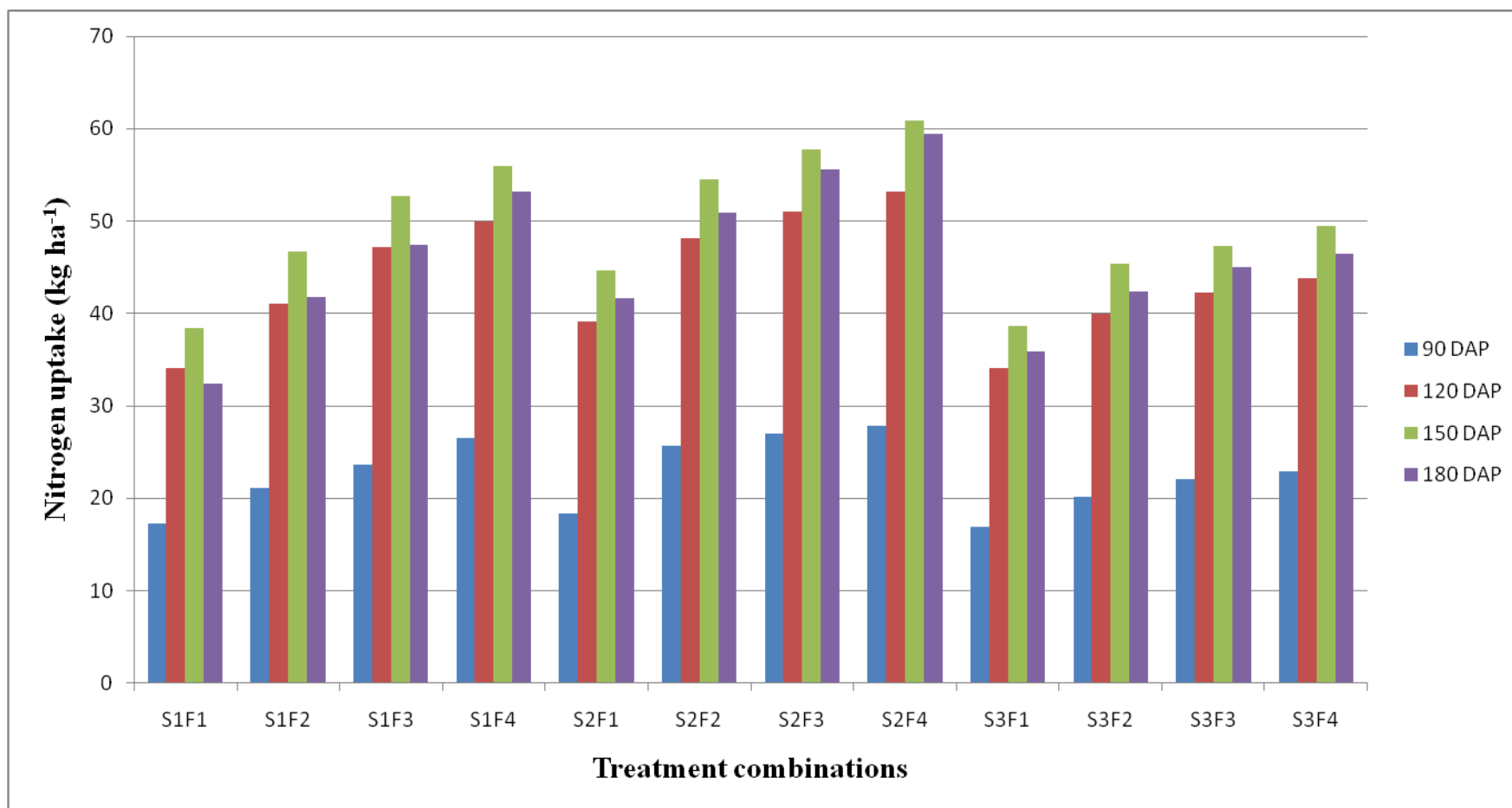


Fig. 22: Effect of spacing and fertilizers on nitrogen uptake at different stages of crop growth in mint

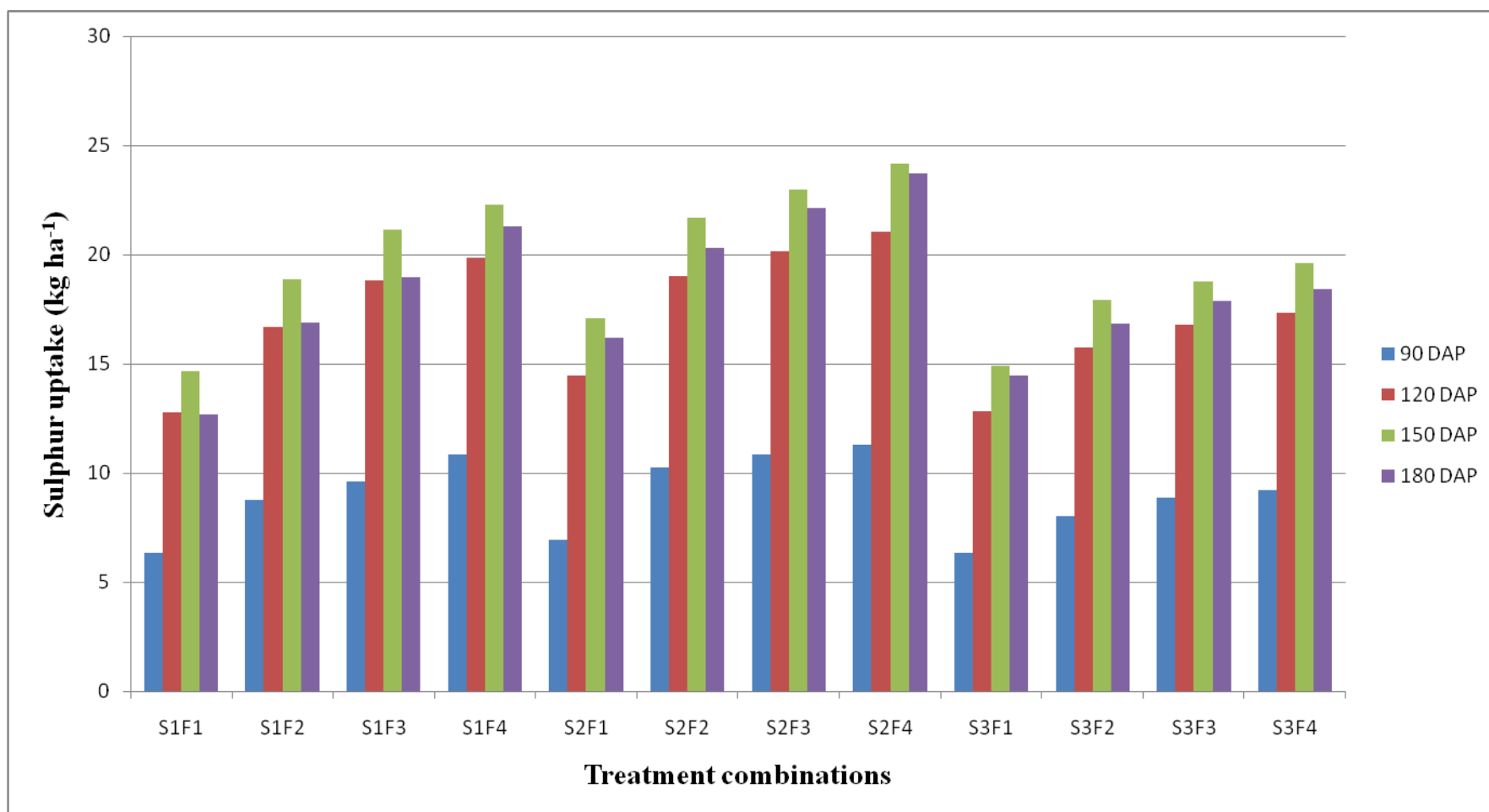


Fig. 23: Effect of spacing and fertilizers on sulphur uptake at different stages of crop growth in mint

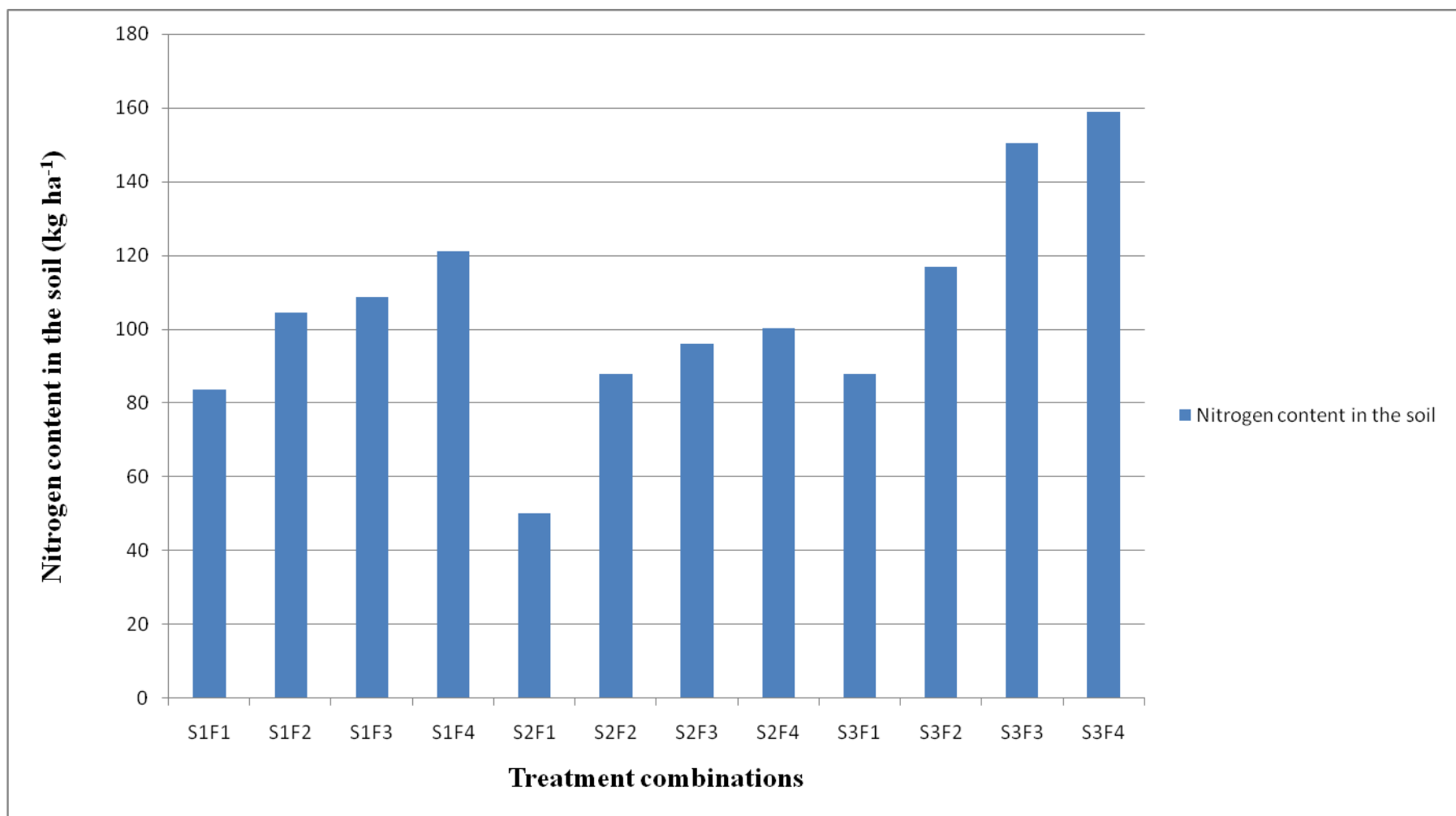


Fig. 24: Effect of spacing and fertilizers on nitrogen content in the soil after final harvest in mint

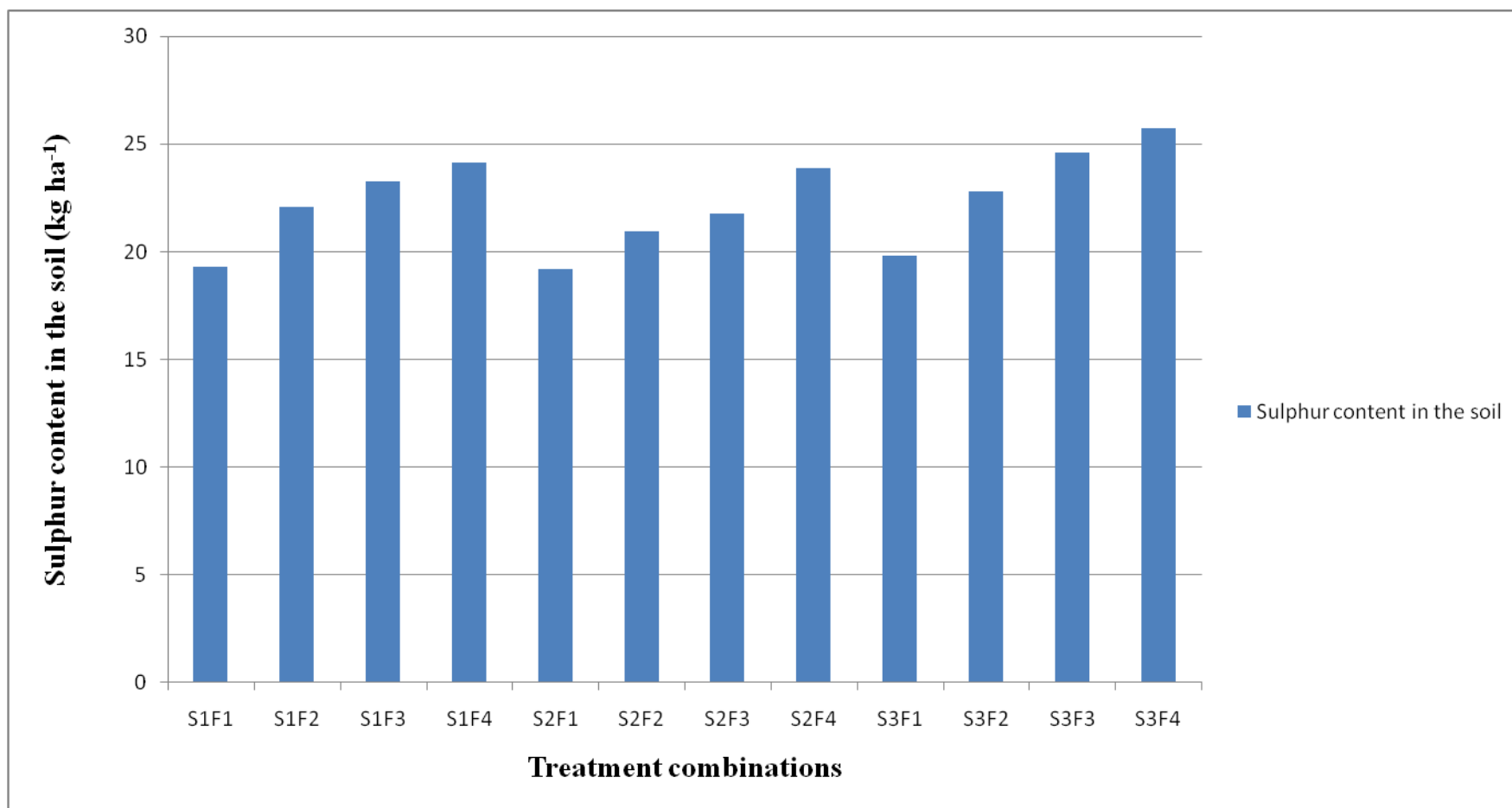


Fig. 25: Effect of spacing and fertilizers on sulphur content in the soil after final harvest in mint

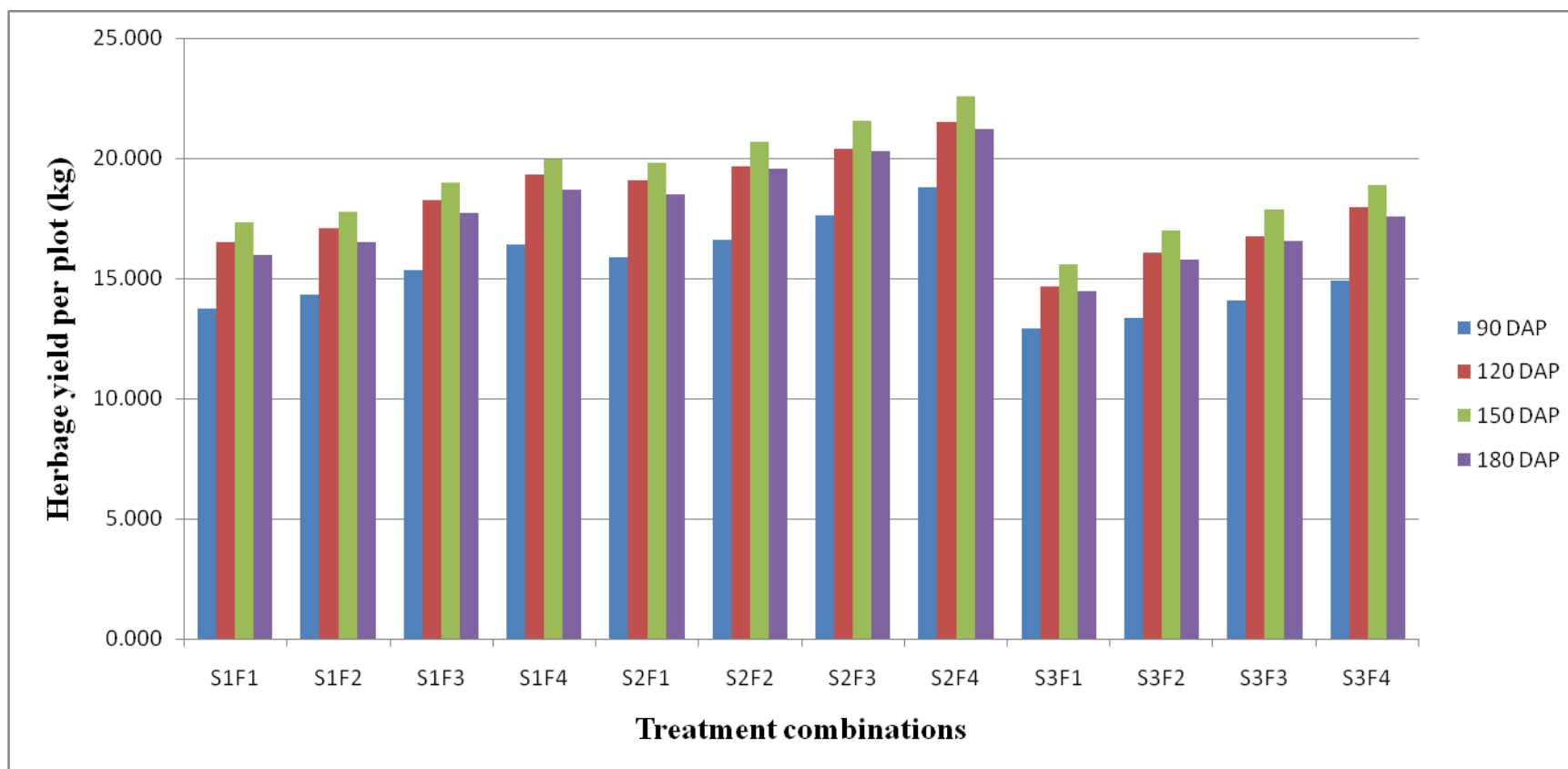


Fig. 16: Effect of spacing and fertilizers on herbage yield per plot at different stages of crop growth in mint

Chapter-V

Summary and Conclusions

CHAPTER V

SUMMARY AND CONCLUSIONS

The present investigation entitled **“Effect of spacing and fertilizers on growth, herbage and oil yield of mint (*Mentha viridis* L.) in red sandy loam soils of coastal Andhra Pradesh”** was carried out at Horticultural College and Research Institute, Venkataramannagudem, West Godavari District of Andhra Pradesh, during *rabi*, 2015-2016. The experiment was laid out with 12 different treatment combinations in a randomized block design with factorial concept (FRBD) each replicated thrice. The data was recorded on various parameters *viz.*, growth, physiological, yield, biochemical and nutrient status of plant at each harvest and soil after final harvest. The data was statistically analyzed and summarised as below.

Among the treatments, wider spacing of 60×15 cm showed significantly the highest values with respect to most of the growth parameters *viz.*, plant height (39.88 cm), number of branches per plant (43.52), number of leaves per plant (1620.89), leaf area per plant (3735.22 cm²), fresh weight of leaf per plant (133.05 g) and fresh weight of stem per plant (80.15 g), whereas the fertilizer application at the rate of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ significantly recorded the highest values for plant height (41.48 cm), number of branches per plant (40.61), number of leaves per plant (1500.53), leaf area per plant (3407.33 cm²), fresh weight of leaf per plant (116.84 g) and fresh weight of stem per plant (69.54 g) at 150 DAP when compared to the other treatments.

Among the treatment combinations, 60×15 cm spacing with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ showed significantly the highest values with respect to most of the growth parameters *viz.*, number of branches per plant (47.80), number of leaves per plant (1771.43), fresh weight of leaf per plant (142.03 g) and fresh weight of stem per plant (89.23 g) at 150 DAP when compared to other treatment combinations.

Among the treatments, closer spacing of 30×15 cm showed significantly the highest values for leaf area index (4.499), 45×15 cm spacing for crop growth

rate (7.373) and net assimilation rate (0.355). A spacing of 60×15 cm showed significantly the highest values for dry weight of leaf per plant (24.97 g), dry weight of stem per plant (14.10 g) and total dry matter production per plant (39.07 g), whereas the fertilizer application at the rate of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ significantly recorded the highest values for leaf area index (5.140), crop growth rate (7.179), dry weight of leaf per plant (22.18 g), dry weight of stem per plant (12.63 g) and total dry matter production per plant (34.82 g) when compared to the other treatments. The dry matter partitioning was high in leaves compared to stem at 60×15 cm spacing with the application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹.

The significant highest herbage yield per plant (215.29 g) was recorded with a spacing of 60×15 cm at 150 DAP. The highest herbage yield per plot (21.15 kg), herbage yield per hectare (235.05 q) and essential oil yield per hectare (159.94 kg) was recorded with the optimum spacing of 45×15 cm when compared to 60×15 cm of spacing, whereas the fertilizer dose of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ recorded the highest herbage yield per plant (187.82 g), herbage yield per plot (20.46 kg), herbage yield per hectare (227.43 q) and essential oil yield per hectare (166.91 kg) compared to the control treatment at 150 DAP. The highest essential oil content (0.734 %) was recorded with the application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ at 150 DAP.

Among the interactions, 60×15 cm spacing with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ showed significantly the highest values for herbage yield per plant (235.58 g), whereas 45×15 cm spacing with the fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ showed significantly the highest values for herbage yield per plot (22.57 kg) and herbage yield per hectare (250.88 q) at 150 DAP.

Based on the nutrient uptake studies it is concluded that the available nitrogen content in plant (1.039 %) and soil samples (128.53 kg ha⁻¹) and sulphur content in plant (0.409 %) and soil samples (23.23 kg ha⁻¹) were maximum with a wider spacing of 60×15 cm whereas the uptake of nitrogen (54.46 kg ha⁻¹) and sulphur (21.46 kg ha⁻¹) were maximum with an optimum spacing of 45×15 cm. The fertilizer application of 140 kg N ha⁻¹ + 20 kg S ha⁻¹ recorded significantly

the high values with respect to nitrogen content in plant (1.059 %) and soil samples (126.79 kg ha⁻¹), sulphur content in plant (0.421 %) and soil samples (24.58 kg ha⁻¹) and uptake of nitrogen (55.44 kg ha⁻¹) and sulphur (22.02 kg ha⁻¹).

Based on the results obtained, it is concluded that the optimum spacing of 45×15 cm supplied with 140 kg N ha⁻¹ + 20 kg S ha⁻¹ of fertilizer was found best for many of the growth, physiological, yield and biochemical parameters in enhancing the herbage and oil yields of mint which can be recommended for cultivation of mint in red sandy loam soils of coastal Andhra Pradesh. The appropriate stage of harvest of mint (*Mentha viridis* L.) in red sandy loam soils of coastal Andhra Pradesh is at 150 days after planting.

Future line of work:

1. In order to increase the oil yield in *Mentha viridis*, the critical time of nutrient uptake and its correlation with oil content should be studied.
2. Effect of different levels of micronutrients with special reference to sulphur and zinc on herbage and oil yields of mint should be studied.
3. Effect of nutrients in the form of organic sources on growth, herbage and oil yields of mint should be studied.
4. Effect of bio fertilizers on growth, herbage and oil yields of mint should be studied.

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The pattern of “Literature Cited” presented above is in accordance with the “Guidelines” for thesis presentation for Dr. Y.S.R. Horticultural University, Venkataramannagudem.

Appendices



Appendix I
Weekly meteorological data recorded at College Farm, HCRI,
Venkataramannagudem, West Godavari District during the period of the
experiment in the year 2015-16

S. No.	Standard weeks	Period	Temperature (° C)		Relative Humidity (%)		Rain fall (mm)	Rainy days
			Max.	Min.	8.00 h	14.00 h		
1	42	12 th - 18 th Oct	33.1	23.1	94.0	85.0	2.8	1
2	43	19 th - 25 th Oct	33.5	22.5	92.0	81.0	3.5	1
3	44	25 th - 1 st Nov	32.0	23.3	91.0	82.0	0	0
4	45	2 nd - 8 th Nov	32.5	23	92.9	87.5	35.4	2
5	46	9 th - 15 th Nov	25.7	21.1	92.3	92.7	0	0
6	47	16 th - 22 nd Nov	27.2	19.4	93.3	92.4	17.2	1
7	48	23 rd - 29 th Nov	31.1	20.7	91.8	92.5	0	0
8	49	30 th Nov- 6 th Dec	31.1	21.5	92.0	92.8	0	0
9	50	6 th - 13 th Dec	31	19.5	91.4	89.0	0	0
10	51	14 th - 20 th Dec	30.3	19.8	92.1	92.8	0	0
11	52	21 st - 27 th Dec	30.7	19.1	91.6	92.7	0	0
12	53	28 th Dec - 3 rd Jan	30.3	19.1	91.3	92.8	0	0
13	1	4 th - 10 th Jan	29.6	19.4	91.8	91.0	0	0
14	2	11 th - 17 th Jan	29.6	18.7	91.0	93.0	0	0
15	3	18 th - 24 th Jan	29.1	20.1	91.7	89.0	0	0
16	4	25 th - 31 st Jan	30.1	19.5	91.4	92.8	0	0
17	5	1 st - 7 th Feb	30.7	19.7	91.6	92.0	0	0
18	6	8 th - 14 th Feb	30.9	20.3	92.0	92.7	0	0
19	7	15 th - 21 st Feb	32.5	18.1	91.3	92.0	0	0
20	8	22 nd - 28 th Feb	31.7	21.1	92.0	92.8	0	0
21	9	1 st - 7 th Mar	31.9	21.3	91.9	92.3	0	0

Appendix I contd....

S. No.	Standard weeks	Period	Temperature (° C)		Relative Humidity (%)		Rain fall (mm)	Rainy days
			Max.	Min.	8.00 h	14.00 h		
22	10	8 th - 14 th Mar	31.2	20.3	92.0	92.2	0	0
23	11	15 th - 21 st Mar	31.7	23.3	91.8	92.5	0	0
24	12	22 nd - 28 th Mar	31.8	22.2	91.6	92.7	0	0
25	13	29 th Mar - 4 th Apr	34.0	21.8	92.1	89.0	0	0
26	14	5 th - 11 th Apr	33.1	23.0	92.4	92.8	0	0
27	15	12 th - 18 th Apr	34.3	22.6	91.2	92.6	0	0