EFFECT OF CROP GEOMETRY AND NITROGEN LEVELS ON HERB AND OIL YIELD AND QUALITY OF SPEARMINT (*Mentha spicata* L.)

Thesis

Submitted to Punjab Agricultural University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE
in
AGRONOMY
(Minor Subject: Botany)

By

Anshmeet
(L-2018-A-1-M)

Department of Agronomy
College of Agriculture

LUDHIANA – 141004

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CERTIFICATE - I

This is to certify that the thesis entitled **"Effect of crop geometry and nitrogen levels on herb and oil yield and quality of spearmint (*Mentha spicata* L.)"** submitted for the degree of **Master of Science** in the subject of **Agronomy** (Minor subject: **Botany**) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Anshmeet (L-2018-A-1-M)** under my supervision and that no part of this thesis has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

Dr. Rajender Kumar
(Major Advisor)
Principal Agronomist
School of Organic Farming
Punjab Agricultural University
Ludhiana

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Sometimes, Not Getting What You Want Is A Wonderful Stroke of Luck!

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Drive Further, Ride Higher, Live Better!

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ABSTRACT

The present investigation entitled 'Effect of crop geometry and nitrogen levels on herb and oil yield and quality of spearmint (*Mentha spicata* L.)' was carried out at Research Area, School of Organic Farming, Punjab Agricultural University, Ludhiana during two successive years 2019 and 2020.The experiment was laid out in split plot design, keeping combinations of two varieties (MSS-5 and Local) of spearmint and two row spacing's (45 cm and 60 cm) in main plots and four nitrogen levels (0, 50, 75 and 100 kg ha^{-1}) in sub plots. The treatments were replicated three times. The soil of the experimental site was sandy loam in texture with slightly alkaline soil reaction (pH- 7.9), low in organic carbon and available nitrogen, medium in available phosphorus and potassium. Spearmint variety 'MSS-5' performed significantly superior than 'Local' variety in plant growth attributes (stool population, plant height, dry matter accumulation, leaf area index) and produced higher (9.3 and 14.1 per cent) fresh herb yield than 'Local' (155.3 q ha^{-1} and 145 q ha^{-1}) during 2019 and 2020, respectively. 'MSS-5' variety produced significantly higher oil yield than the 'Local'. Planting of spearmint at 45 cm row spacing produced significantly higher fresh herb yield (5.1 and 10.6 per cent) than 60 cm (158.8 q ha^{-1} and 147.4 q ha^{-1}) during 2019 and 2020, respectively. Application of 75 kg N ha^{-1} produced significantly higher fresh herb and oil yield than 0 kg N ha^{-1} and 50 kg N ha^{-1} while the response beyond 75 kg N ha^{-1} was non-significant during both the years.

Keywords: Crop geometry, *Mentha spicata*, Nitrogen levels, Spearmint, Spearmint oil

Signature of Major Advisor

Signature of the Student

ਖੋਜ ਦਾ ਸਿਰਲੇਖ	:	ਜੜ੍ਹੀ-ਬੂਟੀਆਂ ਅਤੇ ਤੇਲ ਦੀ ਉਪਜ ਅਤੇ ਸਪੇਅਰਮਿੰਟ ਦੀ ਗੁਣਵੱਤਾ (*ਮੈਂਥਾ ਸਪਾਈਕਾਟਾ* ਐੱਲ.) 'ਤੇ ਫ਼ਸਲ ਦੀ ਜਿਓਮੈਟਰੀ ਅਤੇ ਨਾਈਟ੍ਰੋਜਨ ਦੇ ਪੱਧਰਾਂ ਦਾ ਪ੍ਰਭਾਵ
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ਸਾਰ ਅੰਸ਼

'ਜੜ੍ਹੀ-ਬੂਟੀਆਂ ਅਤੇ ਤੇਲ ਦੀ ਉਪਜ ਅਤੇ ਸਪੇਅਰਮਿੰਟ ਦੀ ਗੁਣਵੱਤਾ (*ਮੈਂਥਾ ਸਪਾਈਕਾਟਾ* ਐੱਲ.) 'ਤੇ ਫ਼ਸਲ ਦੀ ਜਿਓਮੈਟਰੀ ਅਤੇ ਨਾਈਟ੍ਰੋਜਨ ਦੇ ਪੱਧਰਾਂ ਦਾ ਪ੍ਰਭਾਵ' ਸਿਰਲੇਖ ਵਾਲੀ ਮੌਜੂਦਾ ਜਾਂਚ ਖੋਜ ਖੇਤਰ, ਸਕੂਲ ਆਫ ਆਰਗੈਨਿਕ ਫਾਰਮਿੰਗ, ਪੰਜਾਬ ਐਗਰੀਕਲਚਰਲ ਯੂਨੀਵਰਸਿਟੀ, ਲੁਧਿਆਣਾ ਵਿਖੇ 2019-20 ਦੋ ਸਾਲ ਲਗਾਤਾਰ ਕੀਤੀ ਗਈ । ਪ੍ਰਯੋਗ ਵਿੱਚ ਸਪਿਰਮਿੰਟ ਦੀਆਂ ਦੋ ਕਿਸਮਾਂ (ਐੱਮ ਐੱਸ ਐੱਸ 5 ਅਤੇ ਲੋਕਲ) ਦੇ ਸੁਮੇਲ ਅਤੇ ਮੁੱਖ ਪਲਾਟਾਂ ਵਿੱਚ ਦੋ ਕਤਾਰਾਂ ਦੀ ਦੂਰੀ (45 ਅਤੇ 60 ਸੈਂਟੀਮੀਟਰ) ਅਤੇ ਚਾਰ ਨਾਈਟ੍ਰੋਜਨ ਪੱਧਰਾਂ (0, 50, 75 ਅਤੇ 100) ਦੇ ਸੁਮੇਲ ਨੂੰ ਧਿਆਨ ਵਿੱਚ ਰੱਖਦੇ ਹੋਏ, ਸਪਲਿਟ ਪਲਾਟ ਡਿਜ਼ਾਈਨ ਵਿੱਚ ਰੱਖਿਆ ਗਿਆ ਸੀ। ਟ੍ਰੀਟਮੈਂਟ ਨੂੰ ਤਿੰਨ ਵਾਰ ਦੁਹਰਾਇਆ ਗਿਆ। ਪ੍ਰਯੋਗਾਤਮਕ ਸਥਾਨ ਦੀ ਮਿੱਟੀ ਥੋੜ੍ਹੀ ਜਿਹੀ ਖਾਰੀ ਪ੍ਰਤੀਕਿਰਿਆ (pH 7.9), ਵਾਲੀ ਬਣਤਰ ਵਿੱਚ ਰੇਤਲੀ ਦੋਮਟ ਸੀ, ਜੈਵਿਕ ਕਾਰਬਨ ਅਤੇ ਉਪਲਬਧ ਨਾਈਟ੍ਰੋਜਨ ਵਿੱਚ ਘੱਟ ਅਤੇ ਉਪਲਬਧ ਫਾਸਫੋਰਸ ਅਤੇ ਪੋਟਾਸ਼ੀਅਮ ਵਿੱਚ ਮੱਧਮ ਸੀ। ਕਿਸਮ 'ਐਮ ਐੱਸ ਐੱਸ-5' ਨੇ ਪੌਦਿਆਂ ਦੇ ਵਾਧੇ ਦੇ ਗੁਣਾਂ (ਸਟੂਲ ਦੀ ਆਬਾਦੀ, ਪੌਦਿਆਂ ਦੀ ਉਚਾਈ, ਸੁੱਕੇ ਪਦਾਰਥਾਂ ਦਾ ਸੰਚਵ, ਪੱਤਾ ਖੇਤਰ ਸੂਚਕਾਂਕ) ਵਿੱਚ 'ਸਥਾਨਕ' ਕਿਸਮ ਨਾਲੋਂ ਕਾਫ਼ੀ ਉੱਤਮ ਪ੍ਰਦਰਸ਼ਨ ਕੀਤਾ। ਐੱਮ ਐੱਸ ਐੱਸ-5 ਨੇ (9.5 ਅਤੇ 14.8 ਪ੍ਰਤੀਸ਼ਤ) ਵਧੇਰੀ ਤਾਜ਼ੀ ਜੜ੍ਹੀ-ਬੂਟੀ ਦੀ ਪੈਦਾਵਾਰ ਕੀਤੀ ਸਥਾਨਕ ਨਾਲੋਂ 2019 ਅਤੇ 2020 ਦੇ ਦੌਰਾਨ (155.3 ਅਤੇ 145 ਕੁਇੰਟਲ / ਹੈਕਟੇਅਰ)। 45 ਸੈਂਟੀਮੀਟਰ ਕਤਾਰਾਂ ਦੀ ਦੂਰੀ ਵਾਲੀ ਬਿਜਾਈ ਨੇ 60 ਸੈਂਟੀਮੀਟਰ (158.8 ਅਤੇ 147.4 ਕੁਇੰਟਲ/ਹੈਕਟੇਅਰ) ਵਾਲੀ ਦੂਰੀ ਤੋਂ 5.1 ਅਤੇ 10.6 ਪ੍ਰਤੀਸ਼ਤ ਵਧੇਰੀ ਤਾਜ਼ੀ ਜੜ੍ਹੀ-ਬੂਟੀ ਦੀ ਪੈਦਾਵਾਰ ਕੀਤੀ। 75 ਕਿਲੋ ਨਾਈਟ੍ਰੋਜਨ ਦੀ ਵਰਤੋਂ 0 ਅਤੇ 50 ਕਿਲੋ ਨਾਈਟ੍ਰੋਜਨ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਨਾਲੋਂ ਵਧੇਰੀ ਤਾਜ਼ੀ ਜੜ੍ਹੀ-ਬੂਟੀਆਂ ਅਤੇ ਤੇਲ ਦੀ ਪੈਦਾਵਾਰ ਕੀਤੀ ਜਦੋਂ ਕਿ ਇਸ ਤੋਂ ਵੱਧ ਪ੍ਰਤੀਕਿਰਿਆ ਦੋਵਾਂ ਸਾਲਾਂ ਦੌਰਾਨ ਗ਼ੈਰ-ਮੁਹੱਤਵਪੂਰਨ ਰਹੀ ।

ਮੁੱਖ ਸ਼ਬਦ: ਫ਼ਸਲੀ ਜਿਓਮੈਟਰੀ, ਮੈਂਥਾ ਸਪਾਈਕਾਟਾ, ਨਾਈਟ੍ਰੋਜਨ ਪੱਧਰ, ਸਪੀਅਰਮਿੰਟ, ਸਪੀਅਰਮਿੰਟ ਤੇਲ।

ਪ੍ਰਮੁੱਖ ਸਲਾਹਕਾਰ ਦੇ ਹਸਤਾਖਰ **ਵਿਦਿਆਰਥੀ ਦੇ ਹਸਤਾਖਰ**

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CHAPTER I

INTRODUCTION

Aromatic plants are known since times immemorial and the earliest mention of medicinal use of plants is found in '*Rig Veda*'. These plants have been used for therapeutic, religious, cosmetic, nutritional, and beautification purposes since ancient times and humanity of all civilizations and culture are familiar with their usage. They have brought many benefits, such as food flavoring, medicines, preservatives, decorations, beauty and personal pleasure.

There exists unknown and uncountable potential of aromatic plants, although long history for their use since prehistoric times can be traced back. These wonderful resources should not be lost in future; therefore, the coexistent balance among plants, animal, and human need not be upset. The role of medicinal and aromatic plants is evolving in revelation to the time. They play a vital role in disease management i.e. from prevention to cure. The accumulated massive knowledge, information, and materials need to be distributed among the whole world and that to further generations. The blessings of medicinal and aromatic plants (MAPs) are treasures that belong to all lives (Inoue *et al* 2019).

The international market is quite worthy for MAPs and essential oils. The increasing environment friendly consumers lead producers to produce high quality essential oils leading to growing preference for organic and herbal based products in the world market. These plants will have a special role for humans in the future as their benefits are recognized all over.

The *Mentha* genus is categorized as 5 sections: *Audibertia*, *Eriodontes*, *Mentha*, *Preslia* and *Pulegium* (Bunsawat *et al* 2004). Mentha genus connotes 25-30 species of aromatic perennial herbs belonging to the family Lamiaceae (Ali *et al* 2002). India is a prominent leader of mint production in the world supplying 80 per cent of mints globally, followed by China and Japan. Indian state Uttar Pradesh contributes around 90 per cent of Indian mint production, while remaining 10 per cent comes from areas of Punjab, Rajasthan etc. (Mahantesh *et al* 2017). Japanese mint (*M. arvensis*), peppermint (*M. piperita* L.) and spearmint (*M. spicata* L.) are the most common species cultivated in the western hemisphere (Ullah *et al* 2012).

Spearmint (*Mentha Spicata*) oil is rich in carvone (65 per cent) content and emits caraway like odour. The oil is useful in dentifrice, confectionery and pharmaceutical products. It bears lanceolate stalkless, light green leaves and narrow, long, terminal flowering spikes with lilac flowers, attaining a height of up to 60 cm. Two commercial varieties have been evolved in India. Of them, 'Punjab Spearmint' is an erect growing with quadrangular purple-green, hairy stem and average production 20 q ha^{-1} of fresh herb. It contains 0.57 per cent oil, the oil yield being 120 l ha^{-1} containing 68 per cent carvone. The other variety 'MSS-5' is relatively vigorous in growth, yielding 250-300 q ha^{-1} of fresh herb or 150 kg of oil from commercial plantations and it is cultivated in a small area in Punjab and foothills of Uttar Pradesh. It fetches quite a higher price.

Mentha genus encompasses several species already used at industrial scale and with well-developed cultivation techniques. Extracts are traditionally used as food due to their remarkable antioxidant properties *i.e*. phenolic compounds. Many essential oil chemo types show distinct aromatic flavor conferred by different terpenoids. Both extract and essential oil depict activities on a broad spectrum of microorganisms tested *in vitro* and utilizing various food matrices. Due to its natural origin, antioxidant and antimicrobial activities, mint-derived products could become a great alternative to artificial preservatives, and to find a wide range of applications for shelf-life extension of fruits and vegetables, beverages, dairy products, baking or meat and fish products. Nevertheless, industrial implementation depends on efficacy, ease of use and profitability of such natural additive over synthetic preservatives.

Spearmint is a recognized source of essential oils and recently has been used as a valuable source of the potent antioxidants for the nutraceuticals. It is a rich source of polyphenols and posesses strong antioxidant properties that are characterized by its volatile oil which is of economic importance and in widely cultivated all around the world for production of its essential oil. It is believed to be the oldest of the mints and has derived its name from spear-shaped flowers that distinguishes it from other mint varieties. It is a hybrid between *M. longifolia* and *M. rotundifolia*. Commonly used plant parts are leaves (fresh or dried) and essential oil. Spearmint has a fresh, minty and woody aroma providing a cooling effect, slightly pungent with lemony and sweetish notes (Lawrence 2007).

The essential oil, having carvone as a principal constituent, is obtained by steam distillation of newly flowering tops constituting a pale yellow color (Charles D J 2013). The various components of oil are carvone (51.7 per cent) and cis carveol (24.3 per cent), succeeded by limonene (5.3 per cent), 1,8-cineol (4.0 per cent), cis dihydrocarvone (2.2 per cent), carvyl acetate (2.1 per cent) and cis sabinene hydrate (1.0 per cent) as reported by Hussain *et al* (2010). Carvone with range of 48.6 - 57.9 per cent, ρ-cymene with range of 9.6 - 20.5 per cent and 1, 8-cineole with 14.6 - 19.3 per cent were the major components of spearmint essential oil (Süleyman and Özlem 2006).

Members of the genus *Mentha* promise a great variability in chemical composition, both intra and inter species. The reports on chemical composition of various *Mentha* species depicted that various factors interfere with essential oil composition, which includes environmental factors (growth location, soil characteristics, moisture presence, temperature etc.), phenological factors (phase of the plant collection), plant parts used for essential oil extraction (flowers, stems, leaves, entire aerial parts or inflorescences), type of material (fresh or dry) and even methods used for essential oil analysis (de Sousa Barros *et al* 2015).

Spearmint herb is anti-spasmodic, anti-inflammatory, restorative, carminative, diuretic, stomachic and stimulant (Pearson *et al* 2010). Its oil exhibits anti-microbial properties against *Staphylococcus aureus* and *Escherichia coli* (Torres *et al* 1996). *M. piperita* and *M. spicata* essential oils were found to be active against pathogenic bacteria (Sivropoulou *et al* 1995, Soković *et al* 2010). The medicinal uses involve cure against indigestion, heartburn, colds and flu, congestion and headaches etc. The oil is used mostly as a flavoring agent in toothpastes and food flavoring agent in pickles and spices, chewing gum and confectionery, soaps, mouth wash and sauces (Park *et al* 2002). *M. spicata* extract exhibits high antioxidant properties which can be credited for its metal chelating ability and strong hydrogen donating ability. Therefore, it can be used both as food supplement and in pharmaceutical industry (Elmastaş *et al* 2005).

Cultural practices and environmental conditions affect the plant productivity and oil content. The successful production of mint plants depends on establishment of good stand and intensive care throughout its growth cycle. The impact of environmental factors such as temperature, relative humidity, irradiance, photoperiod, fertilizer application and cultivation practices influence the growth and yield of mint plants which result in change in composition of essential oil. Furthermore, type and amount of fertilizer such as nitrogen, have more pronounced effect on mint plants growth and yield and quality of oil. Cultural practices and appropriate utilization of inputs along with environmental conditions largely influence the crop productivity. Crop geometry is a major non-monetary factor in mint cultivation which affects productivity both in terms of herbage and oil yield directly or indirectly (Rissanen *et al* 2002). Plant productivity and oil quality could be influenced directly or indirectly by the changes in environmental conditions such as light intensity, day length, concentration of carbon dioxide, air temperature and air humidity (Lee and Lee 2002). Unlike other mint species, spearmint has relatively smaller leaf size and spreading growth habit, therefore optimum crop geometry plays a major role in harnessing solar radiation interception uniformly exposing leaves and shoots resulting in enhanced vegetative growth and herb yield by nutrient and moisture uptake. It has been observed that moisture content, leaf to stem ratio and fresh leaf weight elevated significantly with the narrower inter row spacing (Kassahun *et al* 2011) whereas wider row spacing increased branching without changes in oil content (Salim *et al* 2014).

Plant nutrition is of primal focus in the management of crop plant cultivation especially medicinal plants. Adequate nutrient and water supply into the soil is essential towards healthy growth thus producing more effective materials for aromatic and essence-bearing plants like spearmint.

Since the herb yield and its oil content is of commercial importance in case of spearmint, the factor like nitrogen application which promotes photosynthesis thereby number of leaves, leaf area, plant height and plant biomass leads to higher productivity. Besides being a crucial element of nucleic acids and enzymes, nitrogen is also an integral constituent of chlorophyll, which encourages photosynthesis and production of photosynthates from which the vegetative parts are developed and finally contribute in enhancing the productivity (Nigussie *et al* 2017). Variable response of spearmint to nitrogen levels have been reported by various studies depending upon crop geometry, plant density and soil fertility (Nigussie *et al* 2017, Randhawa *et al* 1984, Jha and Singh 1979). Therefore, the selection of species which perform well over a wider range of environments can enhance quantity and quality yields of mint. The essential oil composition of aromatic plants is largely affected by the genotype and agronomic factors. Yesil and Kara (2016) observed a decreasing trend of carvone content with higher doses of nitrogen application. Among various factors affecting mint plant, type and amount of fertilizers, such as nitrogen, have more pronounced effect on mint plants growth and quantity and quality of oil.

Too narrow or wider row spacing and inappropriate nitrogen application may lead to imbalances in vegetative growth, herb and oil yield (Randhawa *et al* 1984). Over application of N causes mint to grow rapidly producing many new shoots which arise from the base of the plant. Vigorous growths combined with newly growing shoots contribute to a markedly inferior type of oil. Over vegetative growth can cause reduction in oil content and thereby suboptimal oil yield.

Varietal response in terms of herb and oil yield may also vary with crop geometry and nitrogen doses. Hence, considering the interaction of crop geometry and nitrogen application, the present studies have been conducted with the following objectives:

1. To optimize crop geometry and nitrogen requirement for higher herb and oil yield and quality of different varieties of *Mentha Spicata*.
2. To study the interactive effects of crop geometry and nitrogen on herb and oil yield and quality of *Mentha Spicata*.

CHAPTER II

REVIEW OF LITERATURE

The literature relating to the study entitled ‘Effect of crop geometry and nitrogen levels on herb and oil yield and quality of spearmint (*Mentha Spicata* L.)’ has been reviewed under the following sub headings:

2.1 Effect of crop geometry

Crop geometry is of vital importance in harnessing solar radiation and its interception which results in better exposure to leaves and shoots. It also provides efficient utilization of nutrient and moisture thereby giving enhanced vegetative growth and herb yield. Although wider or narrower spacing is dependent on environmental conditions, below or above a certain level can either result in mutual shading and poor growth or can display lower yields as compared to optimum spacing in mint crop. This also effect on crop leaf stem ratio and oil yields (Prasad and Saxena 1980).

Row spacing plays major role in determining the microenvironment in the mint field. The optimization of this factor can lead to a higher yield in the crop by favorably affecting the absorption of nutrients and exposure of the shoot canopy to the light (Gowan *et al* 1991).

Salim *et al* (2014) reported that among row spacing of 20, 30 and 40 cm, narrow row spacing of 20 cm resulted in the maximum growth in terms of plant height, leaf count and herb yield in spearmint (*M. spicata*), while in contrast, wider row spacing of 30 and 40 cm improved branching without any change in oil content.

El-Gammassy *et al* (1975) reported that 20 cm row spacing resulted in highest mint yield compared to other wider spacing. Also it was noted that narrow spacing (20 cm) for mint production increased the plant density and consequently influenced the plant population. They postulated that the highest yield was obtained from the crop planted at narrow spacing and lowest ones obtained from wider spacing.

Ghosh and Chatterjee (1978) reported that *M. spicata* exhibited highest oil content when planted at a spacing of 30 × 60 cm. In another study, it was also observed that herb and oil yield increased with increased row spacing from 30 to 45 cm while further increase in row spacing to 60 cm resulted in declining of the herb and oil yields. Crop growth rate (CGR) was also found to be maximum (126.60 kg ha^{-1} day^{-1}) at 45 cm row spacing, followed by 30 cm (122.70) and 60 cm (110.01) row spacing.

Randhawa and Kaur (1996) concluded that at optimum nitrogen, cost to benefit ratio was maximum at 60 cm row spacing in spearmint (*M. spicata*). Oil content did not show much variation with different row spacing. Similarly, the stool population was not significantly altered by different row spacings, however, leaf-stem ratio decreased with increase in row spacing from 30 to 60 cm but the differences were non-significant.

Sarma and Sarma (2014) studied the effect of different row spacing (40 × 25 cm, 40 × 30 cm, 40 × 35 cm, 40 × 40 cm and 40 × 45 cm) on herbage yield and oil content of Bergamot mint (*M. citrata*) with or without irrigation. It was reported that herb and oil yield were enhanced when the crop was planted in 40 × 35 cm spacing with irrigation in comparison to other treatments. While the herbage yield varied with irrigation and without irrigation, no variation in oil content was recorded. Mean oil content was observed as 0.61-0.63 per cent with or without irrigation.

Mansoori (2014) studied the effect of plant density and harvesting time on growth and essential oil of peppermint (*M. piperita*) and concluded that fresh biomass yield, plant height, dry biomass yield and fresh leaf weight had a significant increase with the decreasing plant density while the fresh biomass and essential oil yield increased by increasing plant density (from 8 plants m^{-2} to 20 plants m^{-2}).

Singh *et al* (1999) reported maximum herbage yield of 270.5 q ha^{-1} at 45 cm row spacing in case of menthol mint (*M. arvensis*). Kattimani *et al* (2001) revealed that highest biomass (28.36 t ha^{-1}) and essential oil yield (176.11 kg ha^{-1}) were obtained through cultivation of menthol mint (*M. arvensis*) at row spacing of 60 cm.

Randhawa *et al* (1984) revealed that a closer row spacing of 30 × 45 cm gave significantly higher yield over wider row spacing of 60 × 70 cm in spearmint (*M. spicata*). It was observed that herb yield decreased as the spacing increased from 30 to 60 cm.

Sharma and Kanjilal (1999) reported maximum fresh herbage yield and oil yield in case of 45 cm row spacing as compared to the wider row spacing of 60 cm and 75 cm and the closer spacing of 30 cm in peppermint (*M. piperita*). However, the quality of oil as measured by the menthol content (71 to 72.3 per cent) was not affected by planting time as well as spacing. It was advocated that this might be due to optimum plant population, proper utilization of moisture and nutrients by the plants which resulted in more leaf growth per plant leading to higher herbage yield.

Solomon and Beemnet (2011) reported significantly higher fresh biomass weight (113.25 q ha^{-1}) and maximum essential oil yield (39.7 kg ha^{-1}) at row spacing of 30 cm in comparison to 40 cm, 50 cm and 60 cm while studying the influence of row spacing on agronomic characteristics and essential oil yields of Japanese mint (*M. arvensis*).

Saini *et al* (2003) found that planting of bergamot mint (*M. citrara*) in end January at a row spacing of 60 cm produced maximum herb and oil yield as compared to other row spacing's of 45 and 75 cm.

Singh and Kewala (1979) recorded the maximum oil yield percentage of *M. spicata* (28.78 kg ha^{-1}) when planted at row spacing of 40 × 40 cm. It was also observed that with the widening in row to row distance among plants, herbage yield decreased.

Nithin *et al* (2018) studied the effect of different methods of planting and crop geometry on agronomic parameters of menthol mint (*M. arvensis*). It was revealed that raised bed method of planting with 60 × 30 cm spacing recorded maximum plant height and number of branches. Whereas, maximum fresh herbage yield was reported from raised bed method of planting with 45 × 30 cm spacing.

Raman and Vasudevan (1976) while studying row spacing effect on mentha oil parameters in case of *M. piperita*, *M. spicata* and *M. citrata* revealed that 40 × 40 cm row spacing resulted in maximum essential oil content of 0.27, 0.22 and 0.36 per cent, respectively.

Singh *et al* (1986) concluded that Japanese mint (*M. arvensis*) imparted crop smothering effect on weeds and highest oil concentration was found when it was planted at 40 cm row spacing as compared to other row spacing treatments of 60 and 80 cm.

Kassahun *et al* (2011) while studying the effects of different inter row spacing (30, 45 and 60 cm) on the fresh herb and essential oil yield of spearmint observed significantly higher fresh biomass (8,169 kg ha^{-1} to 14,995 kg ha^{-1}) and essential oil yield (16.18 kg ha^{-1} to 25.70 kg ha^{-1}) with decrease in row spacing from 60 cm to 30 cm. Therefore it was advised that narrower inter row spacing of 30 cm incurred superior yield returns.

2.2 Effect of nitrogenous fertilizers

Mentha, a leafy crop shows good response to nitrogen application. Besides being a crucial component of enzymes and nucleic acids, nitrogen is an important constituent of chlorophyll, which encourages photosynthesis and production of photosynthates from which the vegetative parts are developed and finally contribute in enhancing the crop productivity. Nitrogen application enhanced plant height and leaf area index while a decreasing trend was seen in leaf-stem ratio and oil concentration, irrespective of row spacing (Nigussie *et al* 2017). By manipulating irrigation, nitrogen and harvest date, a substantial increase in oil yield was possible. Also such increases in oil yield did not adversely affect oil quality (Clark and Menary 1980).

Saxena and Singh (1995) studied the effects of irrigation, mulch and nitrogen on yield and composition of Japanese mint (*M. arvensis*) and found that significantly higher dry matter and essential oil yields were obtained through application of Mulch and Nitrogen @ 215 kg ha^{-1}. It also increased the consumptive use; water use efficiency and moisture use rate.

Shivajiprasad and Saxena (1980) while studying effect of different row spacing (30, 45, 60 and 75 cm) on peppermint (*M piperita*) concluded that cultivating mint at narrow spacing of 30 cm, nitrogen uptake by crop was significantly higher than other spacing. Also there was decrease in dry matter production at all stages of crop growth with increase in row spacing from 30 to 75 cm.

Piccaglia *et al* (1994) reported that nitrogen application to mint crop enhanced essential oil yield by changing a variety of growth parameters such as the total plant dry weight, tillers per plant and the Leaf Area Index (LAI). The green herbage and oil yields increased simultaneously with increasing levels of nitrogen application up to 200 kg ha^{-1} at 45 or 60 cm row spacing.

Alkire and Simon (1996) evaluated response of peppermint (*M. piperita*) and spearmint (*M. spicata*) to nitrogen rates and its different forms (Ammonium Sulfate, Calcium Nitrate and Urea). It was reported that Calcium Nitrate gave the highest essential oil yields with 93.0 kg ha^{-1}, compared to Urea (87.1 kg ha^{-1}) and Ammonium Sulfate (85.0 kg ha^{-1}). Oil yields were lower in plots with the highest Nitrogen rates because of overgrowth and lodging.

Randhawa and Kaur (1996) led study on spearmint (*M. spicata*) and revealed that the oil concentration and its composition in green herb are related to leaf area index and nitrogen concentration in the plant. Both the oil and the carvone content in oil decreased, while the limonene content increased with increase in leaf area index and N concentration.

Yesil and Kara (2016) observed decreasing trend of the carvone content with higher doses of nitrogen application in spearmint (*M. spicata*).

Ahmad *et al* (2020) recommended the use of 25 per cent shadow and the application of 120 mg/kg Nitrogen to obtain the highest concentration and performance of essential oil in peppermint (*M. piperita*), as well as to increase the number of leaves per plant and leaf surface area for marketable and edible consumption. Shade nets of certain type can be used to induce shadow on crop.

Bhardwaj and Kaushal (1989) compared essential oil parameters for two varieties of Japanese mint (*M. arvensis*) and found that the oil content and physio-chemical properties were significantly superior in 'Russia' (V1) as compared to 'Haldwani' (V2). The oil content increased significantly with the application of 150 kg N ha^{-1}. Free menthol, an important constituent of essential oil showed minor decrease with the increase in nitrogen level, whereas menthone and methyl acetate contents in oil increased with increasing the dosage of nitrogen.

Ram *et al* (2006) recommended that Japanese mint (*M. arvensis*) could be grown profitably by providing 16 irrigations, *i.e.* 80 cm water (based on 1.2 IW:CPE ratio) and Nitrogen (200 kg) in the sugarcane trash mulched plots, which gave highest B:C ratio from menthol mint cropping and also provided maximum essential oil of better quality.

Kattimani *et al* (2001) studied the effect of nitrogen and phosphorus on biomass and essential oil yield, nutrient uptake and essential oil quality of Japanese mint (*M. arvensis*) cv. MAS-1. It was reported that the combined application of 225 kg N and 40 kg P_2O_5 ha^{-1} recorded highest biomass yield, essential oil yield and nutrient uptake compared to other treatment combinations. The N use efficiency and apparent N recovery were highest with the application of 75 kg N ha^{-1} and decreased with further increases in N level. Similar effects were also recorded by the application of 40 kg P_2O_5 ha^{-1}. Physiological efficiency of N was highest with the application of 225 kg N and lowest with 75 kg N ha^{-1}.

Rajeswara *et al* (1984) studied row spacing effect on Bergamot mint (*M. citrata*) and revealed that 45 cm row spacing produced much higher fresh biomass and essential oil yield as compared to the row spacing of 60 and 30 cm.

Vedivel *et al* (1981) reported that Bergamot mint (*M. citrata*) planted at row spacing of 40 × 40 cm produced maximum herbage yield of 197.27 q ha^{-1} while the yield percent declined in case of wider row spacing.

Singh and Kewala (1979) and Rajeswara *et al* (1983) reported that the Nitrogen application increased the fresh herb yield significantly over the control and each successive increment in nitrogen resulted in significant increase of fresh herb yield up to 160 kg N ha^{-1} in *M. citrata*.

Munsi (1992) evaluated response of Japanese mint (*M. arvensis*) to nitrogen and phosphorus application on its yield, essential oil content and quality. It was reported that for improvement in production of essential oil, judicious application of nitrogen and phosphorus is necessary. The combined effect of Nitrogen and Phosphorus at 100 kg ha^{-1} and 60 kg ha^{-1} respectively had maximum beneficial effect.

Mohmoud and Younis (2009) reported that application of N (75 kg ha^{-1}) along with P_2O_5 (50 kg ha^{-1}) in *M. longifolia* resulted in increased oil and herb yield.

Randhawa and Kaur (1996) reported that herb yield increased with successive increase in Nitrogen levels from 0 to 100 kg ha^{-1} $cutting^{-1}$. At harvest, the yields obtained at 75 and 100 kg N ha^{-1} were at par but both significantly better than 0 and 50 kg N ha^{-1}. Maximum herb yield (341 q ha^{-1} $cutting^{-1}$) was obtained with application of 100 kg N ha^{-1} $cutting^{-1}$ but the highest oil content was observed at 75 kg N ha^{-1} $cutting^{-1}$. Total oil yield increased with increase in Nitrogen level up to 100 kg ha^{-1} and up to 120 days after planting.

Ram *et al* (1995) concluded that the bergamot mint should be irrigated at 1.2 IW : CPE ratio with an application of 160 kg N ha^{-1} in the sub-tropical climate of India.

Nigussie *et al* (2017) reported that combined application of N and P fertilizers at the rate of 30 kg ha^{-1} and 20 kg ha^{-1}, respectively, increased spearmint above ground biomass by 29 per cent and essential oil yield by 12 per cent while being compared to the control treatment.

Sheykholeslami *et al* (2015) examined the effect of chemical and organic fertilizers on yield components and essence content of peppermint (*M. piperita*). Treatments were: control, sheep manure, vermicompost and basic chemical fertilizer doses at different rates at (N-60, P-50, K-60 kg ha^{-1}), (N-60, P-80, K-60 kg ha^{-1}), (N-90, P-50, K-80 kg ha^{-1}) and (N-90, P-80, K-80 kg ha^{-1}). Agronomic and quantitative traits of peppermint like plant height stem and leaves total wet and dry weight were obtained at the maximum values when basic chemical fertilizer dose of NPK was applied at the rate of 90-80-80 kg ha^{-1}. To prevent soil, plant and environment pollution, application of sheep manure along with chemical fertilizer was recommended.

Ram and Kumar (1997) reported that application of N significantly increased plant height, leaf: stem ratio, leaf area index, dry matter production, herbage yield and essential oil yield when applied at rate of 120 kg ha^{-1} N as neem coated urea. Basal application of N gave higher herbage and oil yields in the first harvest whereas split application gave higher yields in the second harvest. The total yields of the 2 harvests were higher with split application of N.

Court *et al* (1993) conducted an experiment at Ontario, Canada to study the effects of different rates (0, 60, 120, 180, 240 and 300 kg ha^{-1}) of N fertilizer on yield and chemical characteristics of the essential oil of peppermint. It was reported that oil yield increased with N fertilization up to 180 kg ha^{-1}, thereafter increased fertilizer application had no influence on yield. Chemical constituents of essential oil were not affected by N fertilization.

Muhammad *et al* (2015) observed that dose of fertilizer N P K at 175:50:50 kg ha^{-1} along with FYM 6 t ha^{-1} produced higher number of leaves, leaf area, herb yield and oil yield and menthol content in Japanese mint (*M. arvensis*). However, Anwar *et al* (2001) reported maximum menthol content (84 per cent) obtained by combined application of Nitrogen at 100 kg ha^{-1} and Sulphur at 25 kg ha^{-1}.

Mahmoud ad A-Hasson (2009), in a study to determine the effect of different rates of application of N and P fertilizers at different time intervals on the growth and essential oil yield of indigenous mint (*M. longifolia*), found that application of N (75 kg ha^{-1}) and P (50 kg ha^{-1}) significantly increased the total dry matter and essential oil yield. Essential oil yield increased with the corresponding increase in the total number of leaves/plant and leaf area. Application of nitrogen and phosphorus fertilizers at different time intervals significantly affected the plant growth and the essential oil yield.

Verma (2017) studied the effect of combined doses of nitrogen and phosphorus (N_0P_0, $N_{50}P_{20}$, $N_{100}P_{40}$, $N_{150}P_{60}$, $N_{200}P_{80}$) on plant growth and oil yield of menthol mint (*M. arvensis*) in western Himalayan region and found that the maximum fresh herb yield (t ha^{-1}), oil content (per cent) and oil yield (l ha^{-1}) was observed with the application of N_{200} P_{80} followed by N_{150} P_{60}.

Keshavarz *et al* (2018) investigated the effect of different organic and chemical fertilizer treatments in peppermint (*M. piperita*) and Japanese mint (*M. arvensis*). It was reported in this study that regardless of the mint species, plants treated with chemical and organic fertilizers together displayed greater plant height, higher oil content and oil yield. Peppermint provided higher plant height, number of internodes, number of leaves and oil percentage as compared to Japanese mint. Oil percentage and essential oil yield of mint increased significantly under the treatment with 25 per cent urea (23.75 kg ha^{-1} N) + 75 per cent vermicompost (10.1 t ha^{-1}). Plant height and number of leaves increased along with the replacement of organic fertilizer with chemical fertilizers. The results showed a positive and significant correlation with leaf number and essential oil yield. Application of vermicompost in combination with chemical fertilizer increased plant height, oil percentage and essential oil in both species, suggesting that organic and chemical fertilizer combination improves performance and environmental sustainability.

Deepak *et al* (2019) reported that Japanese mint treated with 100 per cent of recommended dose of fertilizer (NPK @ 150:60:40 kg ha^{-1} + Zn @ 25 kg ha^{-1} + S @ 25 kg ha^{-1}) showed maximum oil yield parameters. Plants treated with 100 per cent recommended dose of fertilizer proved better as compared to 75 per cent dose, with or without sulphur and/or zinc. Apart from this, recommended dose of fertilizer alone showed lowest performance in all parameters in almost all stages of plant growth when compared with zinc and/or sulphur combinations. Control treatments displayed lowest performance.

Chand *et al* (2004) reported that combined application of fertilizer and organic residues have greater effect on improved mint herb and oil yield. Herb and essential oil yield of mint were found to be significantly higher with combined application of organic and inorganic sources of nutrients as compared to single applications. Recycling of crop residues helps in sustaining and restoring soil fertility and also provides a significant effect to the succeeding crop. A significant improvement was noticed in soil respiration, soil microbial biomass and available soil carbon and nitrogen compared to inorganic fertilizer alone.

Singh *et al* (1989) reported that herbage and oil yields of Japanese mint (*M. arvensis*), peppermint (*M. piperita*) and spearmint (*M. spicata*) increased significantly with N fertilization up to 100 kg ha^{-1} and those of bergamot mint (*M. citrata*) up to 150 kg ha^{-1}. Plant height, leaf-stem ratio and leaf area index increased with Nitrogen application, but essential oil content decreased in all the species. Economic optimum doses of N for *M. arvensis*, *M. piperita*, *M. spicata* and *M. citrata* were 167, 153, 145 and 225 kg N ha^{-1}, respectively and their oil yield expected from the response equation were 190, 103, 50 and 193 kg oil ha^{-1}, respectively. Oil quality did not vary with N fertilization.

Zheljazkov and Margina (1996) studied the effect of increasing doses of fertilizer application on quantitative and qualitative characters of mint and reported that the plant height and branching increased with the increasing fertilizer rates up to N at 533.6 kg ha^{-1}, P_2O_5 at 182 kg ha^{-1} and K_2O at 240 kg ha^{-1}. However, plant leafiness was not significantly affected by the increase of fertilizer rates. It was emphasized that enhanced fertilizer rates led to increase in the fresh herbage yield from 13 to 72 per cent and that from the second harvest by 23 to 78 per cent compared to the control. Essential oil content displayed increase of 16 to 119 per cent in essential oil yield of different cultivars over the control treatment. Level of fertilization did not significantly affect the main chemical compounds in the oil as the chemical compound variations among different cultivars were mainly due the differences in their genotypes.

Zheljazkov *et al* (2010) studied the effect of nitrogen, location, and harvesting stage on peppermint productivity, oil content, as well as oil composition and concluded that the overall oil content and yields were unaffected by nitrogen application rates (0 kg ha^{-1} and 80 kg ha^{-1}) while oil yields were higher at bud formation than at flowering.

Shormin *et al* (2009) investigated Japanese mint (*M. arvensis*) to different levels of nitrogen and water stress. It was found that the higher dose of Nitrogen (240 kg ha^{-1}) applied at 100 per cent field capacity, resulted in maximum plant height and fresh herbal yield compared to other lower doses of nitrogen treatments.

Abbass J A (2009) reported that the application of N at 100 kg ha^{-1} along with 150 kg P_2O_5 ha^{-1}, resulted in significantly more branches per plant, more leaves per plant, better plant height (64.26 cm), herb yield (10.45 t ha^{-1}) and oil yield (53.72 kg ha^{-1}) in spearmint (*M. spicata*) as compared to control treatment (no N and P_2O_5 application).

Behera *et al* (2015) conducted study to optimize the use of water and nutrients by Japanese mint (*Mentha arvensis* L.) with three moisture regimes [I^1 drip irrigation at 100%, I^2 at 80% and I^3 at 60% pan evaporation (PE)] and three fertility levels (F^1 100%, F^2 75% and F^3 50% recommended dose of NPK) with an extra (control) treatment having surface irrigation and soil application of fertilizer. It was inferred that Japanese mint could be grown with drip irrigation at 100 per cent PE with 100 per cent recommended dose of fertilizer to give the highest oil yield of 260 kg ha^{-1}. It required 777mm of water and saved 29 per cent of water. It absorbed 120 kg N ha^{-1} and produced high quality oil.

Chattopadhyay and Gupta (1999) concluded that addition of mint residue fertilizer (3.35 t ha^{-1} in combination with N) reduced the requirements for NPK fertilizer without affecting essential oil yield.

Poshtdar *et al* (2016) investigated the effect of source and rate of nitrogen fertilizer on yield, water use efficiency and essential oil of peppermint (*Mentha piperita* L.) including sources; Urea, Ammonium Sulfate and Urea Ammonium Nitrate (UAN) at the rates; 0, 70, 140, 210 and 280 kg N ha^{-1} were applied. Results showed that application of UAN fertilizer led to higher essential oil yield and maximum relative essential oil yield. Water use efficiency was greater in UAN (1.9 gm^{-3}) folloewe by Urea (1.4 gm^{-3}) and Ammonium Sulfate (1.3 gm^{-3}). Physiological efficiency of nitrogen in the Ammonium Sulfate fertilizer was similar in the two years and showed slightly higher than Urea and UAN fertilizers. Results showed that application of higher rates of UAN fertilizer in peppermint in Khouzestan had higher efficiency, while nitrogen use efficiency in Urea and Ammonium Sulfate fertilizers was greater at the lower rates.

2.3 Effect of varieties

The performance of different varieties in terms of growth and yield can be attributed for their different inherited traits and different agronomic practices that is crop geometry, rates of nitrogen application and time of planting and harvesting.

Currently four main varieties of spearmint (developed by CIMAP) are 'Neera', 'Arka', 'Neerkalka' and 'MSS-5'. 'Neerkalka' being an interspecific hybrid of *M. arvensis* cv Kalka and *M. spicata* cv Neera retains the profuse growth habit of *M. arvensis* simultaneously expressing the "carvone type" mint oil characteristics of *M. spicata* and is more commercially acceptable due to its more favorable agronomic traits (Patra 2008).

Singh *et al* (2001) found that 'MSS-5' showed more promising plant growth characteristics than variety 'Arka' and 'Neera' in controlled nutrient conditions therefore being most suitable variety for cultivation. Carvone content was not affected by irrigation frequency in case of 'MSS-5' which was 68 per cent.

2.4 Combined effect of row spacing and nitrogen

Vinod kumar (2009) found that the crop transplanted on 15 February at 30 × 45 cm spacing and with NPK dose of 120:50:40 kg ha^{-1} gave maximum plant height (43.39 cm), maximum herb yield (271.96 q ha^{-1}), maximum oil content of 0**.**42 per cent and maximum oil yield of 81.38 kg ha^{-1} as compared to row spacing of 30 × 30, 30 × 40 cm and NPK dosage compared to bio fertilizer application.

Shekhar *et al* (2018) found that the total fresh and dry herbage yield was observed better in spacing 60 × 60 cm with fertilizer doses of NPK at 100:140:80 kg ha^{-1} and the oil yield (kg ha^{-1}) was found maximum in spacing 30 × 30 cm with fertilizer doses of NPK at 25:35:20 kg ha^{-1}. Many studies have reported that mint oil yield become reduced at higher rate of N application.

Kothari and Singh (1995) reported that the spearmint crop planted at 60 cm rows and supplied with 200 kg ha^{-1} nitrogen gave the best performance among the various combinations of row spacing (45, 60 and 75 cm) and N (0, 100, 200 and 300 kg ha^{-1}) levels. Total herbage or oil yield was not increased significantly with further increase in N supply and row spacing. Oil concentration and composition were found related to leaf area index and N concentration in the plant. Both the oil concentration and the carvone concentration in oil decreased, while the limonene concentration increased with increasing leaf area index and N concentration. The oil concentration decreased with higher N levels regardless of row spacing.

Kumar *et al* (2015) studied the performance of spearmint under varying dates of planting, row spacing and fertilizers. It was reported that crop transplanted on 15 February gave maximum values for plant height (36.82 cm), herb yield (173.15 q ha^{-1}), oil content (0.24 per cent) and oil yield (50.89 kg ha^{-1}) as compared to January and March transplanted crop. The 30 × 45 cm spacing registered maximum plant height (38.26 cm), herbage yield (188.30 q ha^{-1}), oil content (0.25 per cent) and oil yield (48.72 kg ha^{-1}) among different spacing.

Kumar and Sood (2011) reported that 15th February planting and 30 × 45 cm spacing coupled with application of NPK fertilizer recorded maximum herb yield (204.42 q ha^{-1}) and maximum oil content (0.36 per cent) and essential oil yield (62.57 kg ha^{-1}) in peppermint.

Degala and Swami (2016) reported that the combination of 45 × 15 cm spacing along with combined application of Nitrogen (140 kg ha^{-1}) and Sulphur (20 kg ha^{-1}) recorded higher herbage yield and essential oil yield of mint (*M. viridis*) whereas plant height, number of branches, leaves, leaf area, leaf 1fresh weight and fresh weight of stem per plant were found maximum with 60 × 15 cm spacing along with combined application of N at 140 kg ha^{-1}and S at 20 kg ha^{-1} at 150 DAP. Also maximum leaf area index was recorded with 30 × 15 cm spacing at 150 DAP.

Sarma and Sarma (2014) reported that the herbage and oil yield in bergamot mint (*M. citrata*) were enhanced when the crop was planted in 40 × 35 cm spacing with irrigation.

Anwar *et al* (2010) reported that essential oil yield increased with increasing levels of NPK with highest oil yield in cultivar Saksham followed by Kosi when compared to Himalaya, Kalka, Kushal and Shivalik varieties. The oil yield was maximum with N at 150 kg ha^{-1}, P at 60 kg ha^{-1}and K at 60 kg ha^{-1} with non-significant effect of NPK on oil quality.

Kumar *et al* (2010) reported that application of Zinc at 25 kg ha^{-1} and Sulphur at 20 kg ha^{-1} along with recommended dose of NPK at 150:60:40 kg ha^{-1} provided maximum oil yield (446.9 l ha^{-1}) in menthol mint (*M. arvensis*) cv Kosi.

Mahantesh *et al* (2017) studied the effect of row spacing (30, 45 and 60 cm) and Nitrogen levels (50, 100, 150 and 200 kg ha^{-1}) on growth and yield of Japanese Mint (*M. arvensis*). Maximum plant height, plant spread, branches, leaves per plant and higher fresh herbage yield per plant was reported at 60 cm spacing while the highest fresh herbage yield per plot and per hectare were reported at closer row spacing of 30 cm.

Ahsan (1999) reported that the increasing levels of nitrogen fertilization from 0 to 150 kg ha^{-1} lead to increase in the quantity of dry matter production in spearmint.

Jha and Singh (1979) reported that application of nitrogen at 160 kg ha^{-1} resulted in significantly higher herbage yield (177.7 q ha^{-1}) and essential oil yield (33.1 kg ha^{-1}) of spearmint over other N treatments (0, 40 and 80 kg ha^{-1}). It was also reported that row spacing of 40 cm recorded maximum yield, while wider spacing resulted in lowering of yield.

Adamovic *et al* (1982) reported similar results in case of peppermint with respect of herbage and oil yield had been recorded in row spacing of 50 × 15 cm.

CHAPTER III

MATERIALS AND METHODS

The field experiment entitled, "Effect of crop geometry and nitrogen levels on herb and oil yield and quality of spearmint (*Mentha Spicata* L.)" was conducted at Research Area, School of Organic Farming, Punjab Agricultural University (Ludhiana) during spring seasons of 2019 and 2020. The details of materials used and methods employed during the course of investigation have been presented in this chapter**.**

LOCATION AND CLIMATE

Ludhiana is situated at 30°54' N latitude and 75° 48' E longitude with an altitude of 247 m above the mean sea level. It is located in the central plain region of Punjab state under Trans-Gangetic agro-climatic zone of India. The climate of the region is designated as sub-tropical and semi-arid with very hot and dry summer from April to June, hot and humid conditions from July to September, cold winters from November to January and mild climate during February and March. The mean minimum and maximum temperature shows wide fluctuation during both seasons. The temperature starts decreasing rapidly after November and continues till January. The lowest temperature goes up to 1 or 2°C accompanied by frost or foggy conditions during these months. Temperature starts rising by the end of February and continues till June that may go as high as 45 °C during summer season. The annual rainfall of region is 755 mm, of which about 75 per cent is received during monsoon from July to September. During winter, the rains are scanty but a few showers of cyclonic rains are received during December-January or late spring.

WEATHER DURING CROP SEASON

The weekly mean maximum air temperature ranged from 19.0-39.4°C and 17.6-41.3 °C, while weekly mean minimum temperature ranged from 6.2-22.1 °C and 4.9-22.9 °C during 2019 and 2020, respectively. The maximum and minimum weekly mean temperature of 39.4 °C, 41.3 °C and 6.2 °C, 4.9 °C were recorded during 19th, 21st and 5th, 6th methodological week of crop season 2019 and 2020 respectively. The maximum 77 per cent and 77.5 per cent of weekly mean relative humidity was recorded during 7th and 5th week of 2019 and 2020. The minimum 29 per cent and 30.1 per cent of weekly mean relative humidity was recorded during 18th and 21st week of crop season 2019 and 2020. The maximum weekly rainfall was recorded (68.4 and 28.6 mm) during 6th and 11th week of crop season 2019 and 2020, respectively. The total rainfall of 154.6 mm 138.4 mm was recorded during 2019 and 2020 and evaporation recorded was low during January and then increased up to May. However, relative humidity recorded was the highest during January and then it decreased. Rainfall was unevenly distributed throughout the crop season.

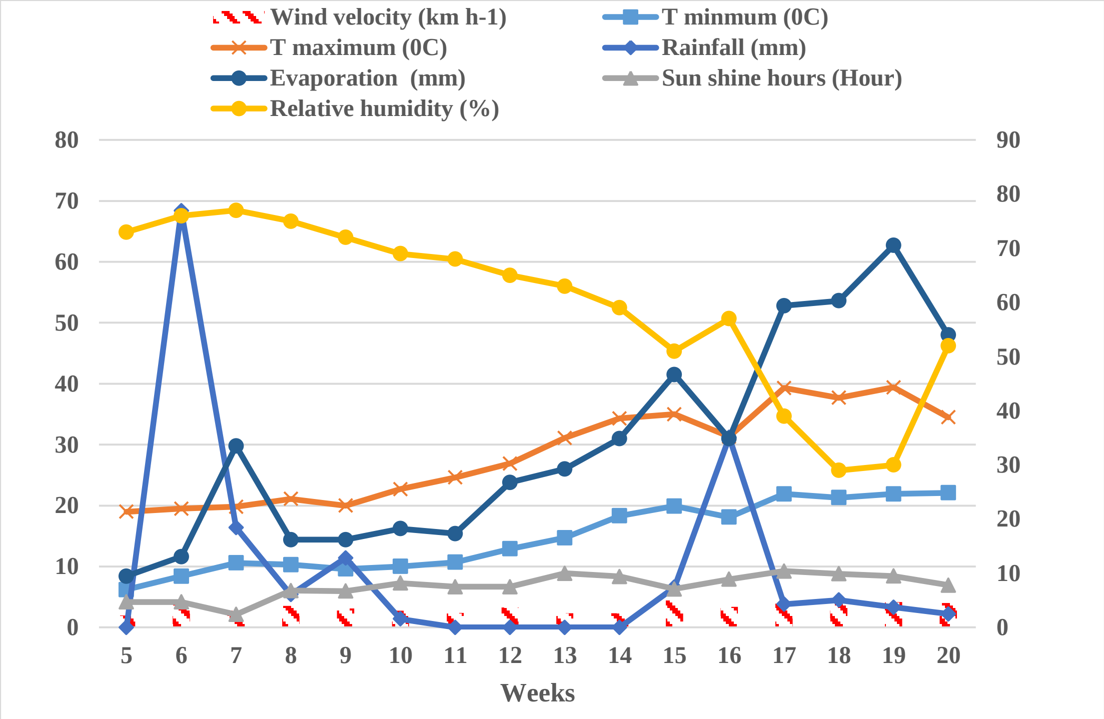

Fig. 3.1: Weekly mean meteorological data recorded during the crop season (2019) at Meteorological-Observatory, PAU, Ludhiana

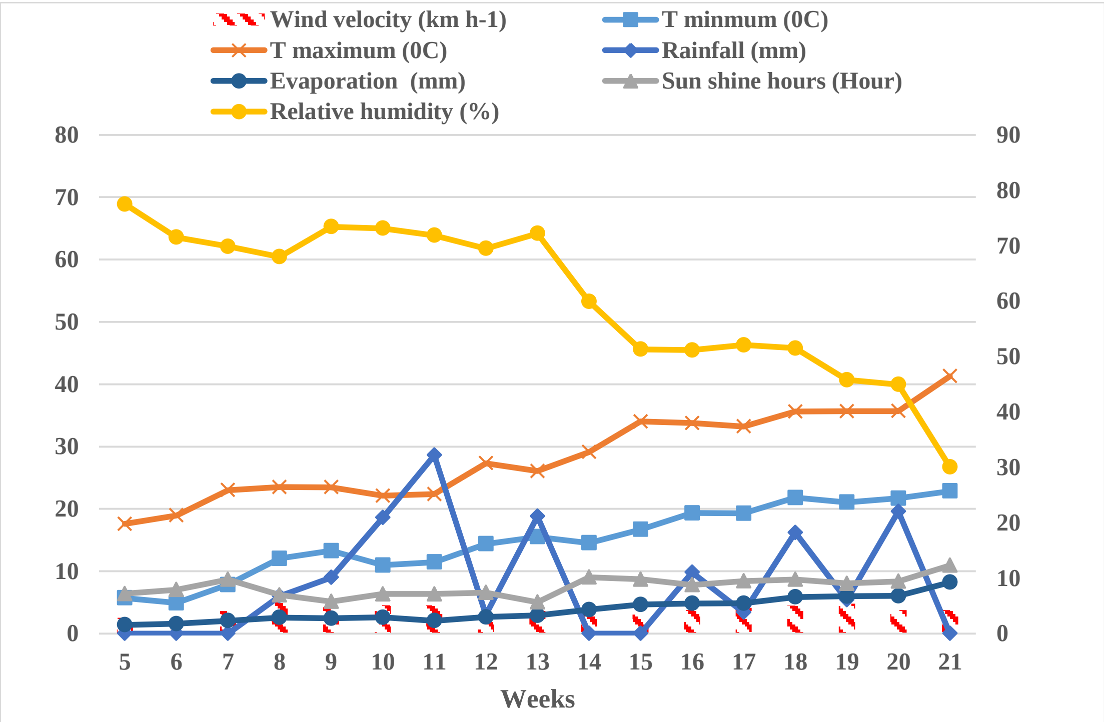

Fig. 3.2: Weekly mean meteorological data recorded during the crop season (2020) at Meteorological-Observatory, PAU, Ludhiana

3.3 Cropping history

Cropping history of the experimental field is given below in Table 3.1:

Table 3.1: Cropping history of field under experiment

Year	Crop
2017-18	Turmeric
2018-19	Fenugreek

SOIL CHARACTERISTICS

Composite soil samples were taken for top 15 cm soil layer from randomly selected places in the experimental field before planting of the experimental crop. The soil samples were dried in the shade, ground and sieved through 2 mm sieve. The mechanical and chemical analyses were done to determine the texture and chemical properties of experimental field. The details of the soil properties are described as follows:

Mechanical and chemical properties

The soil of the experimental site was sandy loam in texture (Table 3.2) with slightly alkaline soil reaction and electrical conductivity (Table 3.3), low in organic carbon and available nitrogen, medium in available phosphorus and potassium.

Table 3.2: Mechanical properties of the soil

Soil properties	Depth (0-15 cm)	Analytical method
Mechanical properties		
Sand (per cent)	65.3	International pipette method (Piper 1966)
Silt (per cent)	15.7	
Clay (per cent)	18.3	
Textural class	Sandy loam	

Table 3.3: Chemical properties of the soil

pH	7.9	Beckman's glass electronic pH meter in 1:2 soil : water suspension (Jackson 1967)
EC (dS m^{-1})	0.16	1:2 soil water suspension with solubridge (Jackson 1967)
Organic carbon (per cent)	0.35	Walkley and Black's rapid titration method (Jackson 1967)
Available N (kg ha^{-1})	116.5	Modified alkaline potassium permanganate method (Subbiah and Asija 1956)
Available P (kg ha^{-1})	20.2	0.5 N sodium bicarbonate extractable P by Olsen's method (Olsen *et al* 1954)
Available K (kg ha^{-1})	253.6	Ammonium acetate extractable K (Jackson 1967)

EXPERIMENTAL DETAILS AND LAYOUT

Experiment: Effect of crop geometry and nitrogen levels on different varieties of spearmint.

Treatments: The experiment comprised the following treatments

Treatments:

Main plots:

A.		**Varieties (2)**
	◦ MSS-5	◦ V1
	◦ Local	◦ V2
B.		**Row spacing (2)**
	◦ 45 cm	◦ S1
	◦ 60 cm	◦ S2

Sub plots:

	Nitrogen application levels (kg ha^{-1})
◦ 0	◦ N1
◦ 50	◦ N2
◦ 75	◦ N3
◦ 100	◦ N4

Total No. of treatments **:** 16

The experiment was laid out in split plot design, an experimental design that is used when a factorial treatment structure has two levels of experimental units. Two combinations of varieties and two row spacing in main plots and four nitrogen levels in sub plots were kept (Fig. 3.3). The treatments were replicated three times.

Number of treatments:	16
Number of replications:	3
Number of plots:	48
Gross plot size:	4.0 m x 3.0 m = 12.0 m^2
Net plot size:	4.0 m x 2.7 m = 10.8 m^2

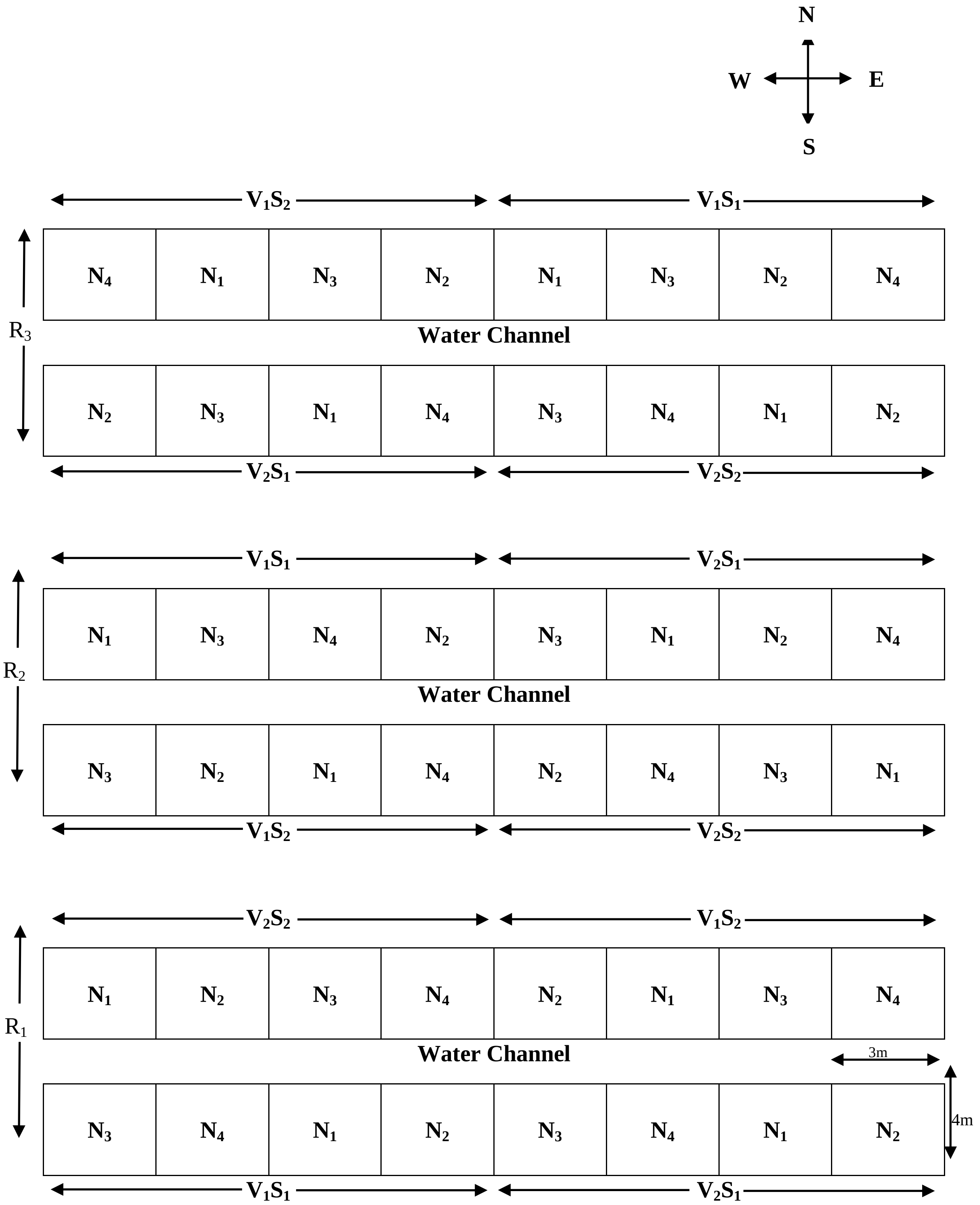

Fig. 3.3 Layout of experimental design

CULTURAL OPERATIONS

The details of cultural operations performed during crop seasons are as under:

Field preparation

In order to bring the site of experimentation in proper condition before planting, the field was cultivated twice with disc harrow and a fine seedbed was obtained by giving two ploughings with a tractor drawn cultivator and each followed by planking.

Planting

The planting of spearmint runners in experiment was done on January 30 as per technical programme of work with 5q ha^{-1} suckers used at two different row to row spacings at 45 and 60 cm during both the years. Five to eight cm long runners were dipped in 0.1 per cent bavistin (Carbendazim 50 WP) for 5-10 minutes were laid end to end at depth of 4-5 cm in an open furrow made with the help of a single tinned drill and covered with soil.

Manures and fertilizer application

Well rotten farm yard manure @ 25 t ha^{-1} was thoroughly mixed into the soil 15 days before planting. Crop was raised with the application of nitrogen as per technical program of work in two splits i.e. half before planting and other half at 40 days after planting (DAP).

Irrigation

The first irrigation was applied immediately after planting to ensure the proper soil moisture condition for sprouting of the runners. After that the subsequent irrigations were assured according to the need of the crop during whole crop season for both the years of investigation.

Weed control

The pre-emergence application of pendimethalin 30 EC@ 2.5 l ha^{-1} was carried out after planting. Manual weeding was also done regularly to keep the proper check on weeds during both the years.

Plant protection measures

To check the attack of termite, chloropyriphos 20 EC @ 5.0 l ha^{-1} was applied twice with irrigation water in both the experiments during both the years.

Harvesting

The crop was harvested manually with sickle about 5 cm above the ground level on 7 June during 2019 and on 11 June during 2020.

OBSERVATIONS RECORDING

Emergence count

Two spots of one meter row length were selected randomly in each plot and marked for recording emergence count. The number of emerged sprouts were counted at five days interval starting from 10 DAP to full emergence in both the experiments. The average data of both selected spots were expressed as plants per meter row length.

Number of stools

Two spots of one meter row length in each plot were selected at random for recording the number of stools. The reading was taken at 30 days interval starting from 60 DAP till harvesting and average number of stools per meter row length were worked out.

Plant height

Five plants were selected at random from each experimental plot to record the height. Height was measured from ground level to the tip of the uppermost leaf on the main shoot at 30 days interval starting from 60 DAP till harvesting.

Dry matter accumulation

Plants from half meter row length in each plot were harvested and sundried and then dried in oven at 60 °C temperature till a constant weight, at 30 days interval starting from 60 DAP till harvesting. Dry matter accumulation was then expressed as g m^{-2}.

Leaf Area Index (LAI)

Leaf area index (LAI) was recorded periodically at 30 days interval starting from 60 DAP till harvesting with the help of calibrated Sun Scan Canopy Analyzer system type SS1 (LICOR-make). The LAI was measured by placing the sensor once above the canopy followed by placing it at three different points below the crop canopy diagonally across the rows.

Leaf to stem ratio

Leaves and stems were separated manually from 100 g herbage taken from each plot at 30 days interval starting from 60 DAP till harvesting in both the experiments. The weight of leaves and stems were taken after drying first under sun and then in oven at 60 °C temperature till a constant weight. The leaf to stem ratio was calculated on dry weight basis as given below:

$$\text{Leaf to stem ratio} = \frac{\text{Leaf weight}}{\text{Stem weight}}$$

Fresh herb yield

Crop was harvested manually with sickle 5 cm above the ground level from each plot. The weight of fresh herbage was recorded immediately after harvesting from net plot area and expressed as q ha^{-1}.

Dry herb yield

Moisture content in fresh herb yield was determined by taking a sample of 500 g fresh herbage from each plot and dry herb yield was calculated accordingly.

Plant Nutrient content studies

N, P and K content studies

Samples taken for dry matter studies at harvest were used for chemical analysis. Oven dried samples were ground to 32 mesh size and analyzed for nitrogen, phosphorus and potassium contents.

Nitrogen content

Content of nitrogen element in herbage at harvest was determined by drying the samples in hot air oven at 60 °C temperature till a constant weight. For determining nitrogen content, herbage samples (0.5 g each) were digested using 10 ml of analytical grade concentrated H_2SO_4 along with a pinch of digestion mixture of K_2SO_4, $CuSO_4$, selenium powder and mercuric oxide (430:20:1:3). The digested material was made to 50 ml volume using distilled water and nitrogen content was estimated by Kjeldahl's apparatus (Piper 1966).

Phosphorus content

The estimation of phosphorus content in dry herbage at harvest was made using Vanado-Molybdo-Phosphoric yellow colour method in nitric acid system (Jackson 1967). Plant sample of 0.5 g was digested in triple acid mixture of HNO_3, $HClO_4$ and H_2SO_4 in ratio of 10:3:1, respectively. The intensity of colour was determined by spectronic-20 colorimeter at a wavelength of 470 μm using blue filter.

Potassium content

Potassium content in dry herbage at harvest was estimated with the help of Lange's Flame photometer (Jackson 1967) from the extract prepared for phosphorus estimation.

Oil quality studies

Oil content

The essential oil in 500 g of fresh herb from each plot was extracted in Clevenger's apparatus taken at harvesting of the crop. Oil percentage was calculated on v/w basis on fresh herb weight. The oil samples were dried using anhydrous sodium sulfate and stored at 5 ^{0}C in sealed glass vials prior to the analysis of essential oil profile.

Oil yield

Oil yield was computed by multiplying the fresh herb yield at harvest with respective essential oil content (on fresh weight basis) and expressed in l ha^{-1}.

Physic-chemical properties of oil

Physical properties *viz.* specific gravity, optical rotation and refractive index and chemical properties viz. acid, ester and saponification value of *M. spicata* oil were determined according to the specification of Indian Standard Institution (IS: 326-1968).

Specific gravity

The specific gravity of the oil was determined with the help of specific gravity bottle at room temperature and was corrected to 30 °C using the correction factor of $\pm$ 0.00076 for each degree centigrade change in temperature. The correction factor was added for temperature higher than 30 °C and vice-versa.

Refractive index

The refractive index of oil was determined by using Abbe-refractometer at room temperature and was corrected to 30 °C using the correction factor of +0.00040 for each degree centigrade change in temperature. The correction factor was added for temperature higher than 30° C and vice-versa.

Optical rotation

The optical rotation of essential oil was determined by using the polarimeter having D line of sodium (double at 5890°A) using the polarimeter tube of 50 mm length.

Acid value

Acid value of oil samples was determined by potassium hydroxide titration method as prescribed by ISI (IS: 326-1968) and was calculated by using formula as given below:

$$\text{Acid value} = \frac{56.1 \times V \times N}{W}$$

Where

V= volume (ml) of potassium hydroxide solution

N= Normality of potassium hydroxide solution

W= Weight (g) of material/oil taken for test

Ester value

Ester value of oil samples was also determined by method prescribed by Indian Standard institute (IS: 326-1968) and value was calculated by using the given formula:

$$\text{Acid value} = \frac{56.1 \times N \times (V1-V2)}{W}$$

Where,

V1= Volume (ml) of hydrochloric acid used for blank

V2= Volume (ml) of hydrochloric acid used for neutralizing the excess of alkali used for hydrolysis

N= Normality of hydrochloride acid

W= Weight (g) of material/oil taken for test

Saponification value

Saponification value of oil samples was worked out by adding the respective acid values and ester values.

Saponification value = Acid value + Ester value

Carvone content

The oil samples from each plot were chemically analyzed on gas chromatography using capillary column (30 m x 0.25 mm, 0.25 µm). The temperature of oven was kept at 250 °C and those of detector and injector at 270 °C. The temperature was programmed as: injector temperature 250 °C; column temperature was raised from 60 to 270 °C at 4 °C/min and then held at 270 °C for 5 min; carrier gas N_2; ignition gas H_2; injection volume 2 µl. Standard compounds of carvone (S & G lab supplier) were used to identify retention times for peaks of both constitutes in the oil while using acetone as solvent for preparation of the standard curve to check the reproducibility of the results. Compound identification was calculated based on retention time of standard compounds (carvone). Relative amounts (peak area per cent basis) of carvone were computed from peak area without FID response factor corrections.

CHAPTER IV

RESULTS AND DISCUSSION

The experimental results during the course of investigation entitled 'Effect of crop geometry and nitrogen levels on herb and oil yield and quality of spearmint (*Mentha Spicata* L.)' have been presented and discussed in this chapter. The trial was conducted during 2019 and 2020 on Research Area, School of Organic Farming, Punjab Agricultural University, Ludhiana. The experiment was laid out in split plot design, keeping combinations of two varieties of spearmint and two row spacings in main plots and four nitrogen levels in sub plots. The treatments were replicated three times. The data recorded on various aspects and results thereof have been presented and discussed under the following heads:

4.1 Biometric studies

4.1.1 Emergence count

Higher emergence count is considered an important adaptive trait marking a quick transition to the growth phase in the life-cycle of a plant. It determines the final plant population per unit area, total biomass production and yield of a crop. Data on emergence count was recorded at five days periodical interval starting from 10 days after planting (DAP) up to 20 DAP. The data pertaining to emergence count (plants per meter row length) is presented in Table 4.1. The emergence count recorded at 10, 15 and 20 DAP for both the varieties 'MSS-5' and 'Local' were statistically at par during both the years 2019 and 2020.

In case of different row spacing of 45 and 60 cm, the emergence count was statistically at par, however, numerically higher in 60 cm row spacing than 45 cm spacing. The values at 10 DAP were observed to be 2.5 m^{-1} and 2.8 m^{-1} for row spacing of 45 cm and 60 cm, respectively during 2019 and the values were accounted to be 2.0 m^{-1} and 2.1 m^{-1} during 2020 (Table 4.1). A similar trend was observed at 15 DAP and 20 DAP.

The effect of nitrogen levels on emergence count was also studied during both the years 2019 and 2020 and it was inferred that the increase in nitrogen application had significant effect on the emergence count particularly at 15 DAP and afterwards (Table 4.1). The response of nitrogen on emergence count during initial stage i.e. 10 DAP was not observed during both the year. However, at 15 DAP a significant increase in the emergence count was observed at 50 kg ha^{-1}, 75 kg ha^{-1} and 100 kg ha^{-1} input of nitrogen fertilizer as compared to control (zero nitrogen application). Further the increase in emergence count beyond 75 kg N ha^{-1} was non-significant during both the years. Application of 75 kg N ha^{-1} increased the emergence count significantly by 37.5 per cent as compared to control (zero nitrogen). During both the years the emergence count at 75 kg N ha^{-1} was statistically at par with that of 100 kg N ha^{-1} but significantly better than control and 50 kg N ha^{-1}. Interaction effects were found non-significant. This could be attributed to nitrogen providing better sprouting and emergence thereof as spearmint propagated vegetatively.

TABLE 4.1: Effect of varieties, row spacing and nitrogen application on emergence count of spearmint

Treatment	EMERGENCE COUNT (plant per meter row length)					
	10 DAP		15 DAP		20 DAP	
	2019	2020	2019	2020	2019	2020
VARIETIES						
MSS – 5	2.7	2.0	5.4	5.1	8.8	11.0
Local	2.6	2.1	5.2	4.8	8.1	10.4
CD (p=0.05)	NS	NS	NS	NS	NS	NS
ROW SPACING						
45 cm	2.5	2.0	4.9	4.8	7.9	10.5
60 cm	2.8	2.1	5.7	5.1	9.0	10.5
CD (p=0.05)	NS	NS	NS	NS	NS	NS
NITROGEN LEVELS						
0 kg ha^{-1}	2.2	2.0	5.0	4.5	7.2	8.8
50 kg ha^{-1}	2.3	1.9	5.2	4.7	7.7	10.2
75 kg ha^{-1}	3.1	2.3	5.4	5.3	8.9	11.0
100 kg ha^{-1}	3.1	2.0	5.6	5.4	9.9	12.1
CD (p=0.05)	NS	NS	NS	0.7	1.2	1.6

4.1.2 Stool population

Mentha is propagated through runners which ultimately emerge into new plants. With the growth of these plants, the size and number of suckers are also increased thereby higher numbers of stools per plant of per unit area. The stool population data was recorded periodically at 60, 90,120 DAP and at harvest stage which is presented in Table 4.2. The variety, ‘MSS-5’ performed significantly better having 8–12 per cent more stool population at all crop growth stages when compared to ‘Local’ variety during both the years. In 2019, ‘MSS-5’ variety had significantly better stool count over ‘Local’ variety with 41.1, 51.8, 68.9 and 71.3 per meter row length at 60, 90, 120 DAP and at harvest, respectively. Similar trend was followed in year 2020, stool count values were observed to be 56.2 m^{-1}at 60 DAP, 60.5 m^{-1} at 90 DAP, 68.3 m^{-1} at 120 DAP and 76.1 m^{-1} at harvest for ‘MSS-5’(Table 4.2).

The effect of row spacing on stool count was also estimated which comparatively decreased with increase in row spacing however the differences were remained non-significant except at 90 DAP during 2020 where stool count with 45 cm row spacing was significantly higher (10 per cent) *i.e.* 60.2 m^{-1} when compared at 60 cm row spacing *i.e.* 54.7 m^{-1}.

TABLE 4.2: Effect of varieties, row spacing and nitrogen application on stool population of spearmint

Treatment	**STOOL POPULATION (per meter row length)**							
	60 DAP		**90 DAP**		**120 DAP**		**At harvest**	
	2019	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**
VARIETIES								
MSS – 5	41.1	56.2	51.8	60.5	68.9	68.3	71.3	76.1
Local	38.8	51.6	49.8	54.4	62.6	63.2	66.8	71.4
CD (p=0.05)	1.2	3.5	1.6	2.7	5.6	3.0	2.3	2.5
ROW SPACING								
45 cm	39.7	54.8	51.0	60.2	66.3	65.6	69.2	73.8
60 cm	40.3	53.0	50.6	54.7	65.3	65.8	68.9	73.7
CD (p=0.05)	NS	NS	NS	2.7	NS	NS	NS	NS
NITROGEN LEVELS								
0 kg ha^{-1}	35.3	44.7	45.3	48.8	59.3	58.8	62.3	65.3
50 kg ha^{-1}	38.3	52.2	49.3	55.8	63.6	64.0	68.8	73.8
75 kg ha^{-1}	43.1	58.7	53.7	61.8	67.5	69.7	71.6	77.2
100 kg ha^{-1}	43.3	60.1	54.9	63.3	69.6	70.3	73.1	78.8
CD (p=0.05)	2.1	4.3	2.1	2.6	5.2	2.8	2.1	2.9

A positive effect on the stool population was observed with an increase in nitrogen application during both the years. As observed for emergence count and stool population also, significant increase was observed at 75 kg ha^{-1} and 100 kg ha^{-1} application of nitrogen fertilizer as compared to zero and 50 kg ha^{-1} nitrogen input. However, the results were statistically at par for 75 kg ha^{-1} and 100 kg ha^{-1} inputs. During 2019, stool population increased significantly by 23 per cent up to 75 kg N ha^{-1} when compared to control (zero nitrogen) at 60 DAP whereas in 2020, the increase was by 31.3 per cent. At 90 DAP the stool population improved significantly by 18 per cent up to 75 kg N ha^{-1} in 2019 and 26.6 per cent in 2020 when compared to control. At 120 DAP the stool population improved significantly by 13.8 per cent up to 75 kg N ha^{-1} in 2019 and 18.5 per cent in 2020 when compared to control. At harvest, the stool population improved significantly by 14.9 per cent up to 75 kg N ha^{-1} in 2019 and 18.2 per cent in 2020 when compared to control. The stool population at 100 kg N ha^{-1} was recorded to be statistically at par with that of 75 kg N ha^{-1} during both the years at all the crop growth stages (Table 4.2).

The higher plant density at narrow spacing results in proper distribution of suckers per unit area which led to better sprouting thereby higher stool population. On the other hand in wider row spacing (60 cm) there was competition among the plants within rows because of denser intra row planting and higher inter row spacing. Interaction effects were found non-significant. Kaur *et al* (2013) also observed higher stools count per square meter in narrow spacing (45 cm) over wider (60 and 75 cm) spaced crop at PAU, Ludhiana. Similar trend was also reported by Brar *et al* (2014) which stated that increased N level resulted in better number of suckers per square meter of area with maximum number at 100 kg ha^{-1} which was statistically at par with 75 kg ha^{-1}.

4.1.3 Plant height

Plant height is one of the most important plant growth characteristics representing vegetative growth which affects the herb and oil yield of spearmint. The data on plant height was recorded at 60, 90, 120 DAP and at harvest stages. During both the years, a progressive increase was observed in plant height with the advancement of crop age, with the increase in the days to planting as the plant grows and develops with time (Table 4.3). The data revealed that the 'MSS-5' variety was significantly taller as compared to the 'Local' variety during both the years (except initial stage of 60 DAP) with maximum height of 95.1 and 97.3 cm at harvest during 2019 and 2020, respectively. Later at 90 DAP; the plants of 'MSS-5' were 13.1 and 13.7 per cent taller than 'Local" variety during 2019 and 2020, respectively. Further, the plant height of the variety 'MSS-5' was 10.1, 8.2 per cent higher at 120 DAP and 10.6, 11.2 per cent higher at harvest than 'Local' variety during 2019 and 2020, respectively.

The effect of row spacing on plant height was also measured and it was observed to be non-significant except in 2019, where row spacing of 45 cm showed significant increase in plant height (97.2 cm) than that of 60 cm row spacing (84.3 cm) (Table 4.3). This could be attributed to the fact that due to lesser horizontal spread and higher intra row plant density, plants compete for nutrients and light thus, grow vertically higher.

An increasing trend of plant height with increase in nitrogen dose was observed during both the years (Table 4.3). At initial growth stage i.e. 60 DAP, plant height increased significantly with the application of 50 kg N ha^{-1} over control whereas the response beyond 50 kg N ha^{-1} was non-significant. However, at later stages (90 DAP to harvesting), plant height increased significantly with increased nitrogen (75 kg ha^{-1}) application. The plant height at harvest increased by 9.3 per cent and 10.6 per cent with the application of 50 kg N ha^{-1} over control during 2019 and 2020, respectively, whereas it was further increased by 9.7 and 10.6 per cent, respectively, with the application of 75 kg N ha^{-1} over 50 kg N ha^{-1}. Interaction effects were found non-significant.

Kothari and Singh (1995) observed taller plants in closer (45 cm) spaced crop as compared to wider (60 and 75 cm) in *M. arvensis*. Similarly, Sharma and Kanjilal (1999) also reported that there was a significant increase in the plant height at 45 cm row spacing as compared to the 30 cm spacing. Kattimani *et al* (2001) also recorded significantly taller plants with increasing level of nitrogen application from 0 up to 200 kg N ha^{-1}.

TABLE 4.3: Effect of varieties, row spacing and nitrogen application on plant height of spearmint

Treatment	PLANT HEIGHT (cm)							
	60 DAP		90 DAP		120 DAP		At harvest	
	2019	2020	2019	2020	2019	2020	2019	2020
VARIETIES								
MSS – 5	20.1	23.6	69.0	67.1	89.9	96.8	95.1	97.3
Local	20.1	23.6	61.0	59.0	81.7	89.4	86.4	87.7
CD (p=0.05)	NS	NS	3.9	3.1	3.8	7.0	7.7	7.7
ROW SPACING								
45 cm	20.7	24.2	64.7	64.8	84.7	96.2	97.2	95.4
60 cm	19.5	23.0	65.2	61.3	86.8	90.0	84.3	89.6
CD (p=0.05)	NS	NS	NS	NS	NS	NS	7.7	NS
NITROGEN LEVELS								
0 kg ha^{-1}	15.5	20.5	52.3	50.6	76.3	80.4	80.1	81.9
50 kg ha^{-1}	19.5	23.4	63.4	60.4	84.7	88.3	87.6	89.6
75 kg ha^{-1}	21.4	25.4	70.7	67.3	88.1	97.7	96.1	99.1
100 kg ha^{-1}	22.1	25.1	73.1	70.8	92.1	100.9	98.3	103.3
CD (p=0.05)	2.7	2.8	3.5	4.8	3.6	7.7	7.1	6.9

4.1.4 Dry matter accumulations (DMA)

The accumulation of dry matter is an important index which expresses the efficiency of photosynthesis of plants that ultimately determines the crop yield. The periodic accumulation of dry matter indicates the progressive growth and development of the crop. The dry matter accumulation increased substantially with the advancement in age of crop. Dry matter accumulation was estimated per square meter to infer the response of various factors on plant growth at the different periodic intervals of 60, 90 and 120 DAP and at harvest. The observations revealed that DMA was significantly higher in case of ‘MSS-5’ variety than the ‘Local’ variety during both the years 2019 and 2020. However, in 2019 DMA was statistically at par for ‘Local’ and ‘MSS-5’ varieties initially at 60 DAP but with increasing days to planting, ‘MSS-5' variety surpassed the ‘Local’ variety with significantly higher DMA recorded till the harvesting stage. At 90 DAP; recorded values for ‘MSS-5’ were 6.1 and 6.9 per cent higher than that of ‘Local’ variety during 2019 and 2020, respectively. Similarly, at 120 DAP, the maximum DMA of ‘MSS-5’was 2.5 and 3.1 per cent higher than that of ‘Local’ during 2019 and 2020, respectively. The maximum values for DMA were being recorded at the time of harvesting. During 2019, DMA for ‘MSS-5’ was 499.8 g m^{-2} and during 2020 it was 505.3 g m^{-2}, whereas in case of the ‘Local’ variety, DMA at harvesting was significantly lower with values being 475.1 g m^{-2} and 480.5 g m^{-2}, respectively. ‘MSS-5’ showed 5.3 and 5.2 per cent increase in DMA over ‘Local’ during 2019 and 2020, respectively (Table 4.4). Ram *et al* (2010) reported that dry matter accumulation was slow up to 60 DAP then gradually increased up to 120 DAP.

Different row spacing also had a significant effect on the DMA. Initially at 60 DAP, there was no significant difference seen between row spacing but as plant grows towards maturity, DMA was significantly higher at 45 cm as compared to 60 cm. In general, the DMA at 45 cm row spacing was (3-7 per cent) significantly higher than that of 60 cm row spacing at 90 DAP onwards till the harvesting stage during both the years (Table 4.4).

The higher DMA under narrower row spacing was due to higher stool count and the plant height as compared to wider spacing. The increase in DMA in closer row spacing was attributed due to taller plants and dense population per unit area. Kaur *et al* (2013) also reported significantly higher dry matter of *M. arvensis* in crop planted at 45 cm than 60 and 75 cm at PAU, Ludhiana. Kassahun *et al* (2011) has reported that row spacing had a significant influence on the dry matter accumulation in peppermint during the harvesting. Randhawa and Kaur (1996) have also reported the higher DMA at 45 cm row spacing in *M. spicata*.

The nitrogen application significantly improved the DMA from 0 kg N $ha^{-1}$to 75 kg N ha^{-1} during both the years, while the response of application of 75 kg N ha^{-1} and 100 kg N ha^{-1} was statistically non-significant. The DMA at 60 DAP increased significantly up to 75 kg N ha^{-1} which was 20.9 per cent and 18.4 per cent higher when compared over control (zero nitrogen) during 2019 and 2020, respectively; whereas it was statistically at par with that of 100 kg N ha^{-1}. The DMA at 120 DAP increased significantly (13.7 per cent and 11.3 per cent) with the application of 75 kg N ha^{-1} over control during 2019 and 2020 respectively; whereas it was statistically at par with that of 100 kg N ha^{-1}. The DMA at harvest increased significantly up to 75 kg N ha^{-1} by 14.4 per cent and 13.1 per cent when compared over control during 2019 and 2020 respectively; whereas it was statistically at par with that of 100 kg N ha^{-1}. Interaction effects were found non-significant.

Asundi (2001) has observed significant increase in DMA with an increase in nitrogen level form 0 to 200 kg ha^{-1} at all stages of crop growth and reported that the interaction between row spacing and increasing nitrogen levels was also significant in Japanese mint. Similarly, Bhardwaj and Kaushal (1989) also reported higher dry matter accumulation with higher dose of N because of beneficial effect of N in maintaining the taller plant and higher growth rate. Munsi (1992) reported that dry matter increased significantly with increasing levels of NPK.

TABLE 4.4: Effect of varieties, row spacing and nitrogen application on dry matter accumulation of spearmint

Treatment	DRY MATTER ACCUMULATION (g m^{-2})							
	60 DAP		90 DAP		120 DAP		At harvest	
	2019	2020	2019	2020	2019	2020	2019	2020
VARIETIES								
MSS – 5	95.2	102.5	269.2	262.6	439.1	436.8	499.8	505.3
Local	92.8	96.1	253.3	247.1	428.2	424.0	475.1	480.5
CD (p=0.05)	NS	3.3	4.6	4.4	9.6	8.9	6.9	6.4
ROW SPACING								
45 cm	93.5	100.0	266.4	258.1	440.2	436	491.7	496.5
60 cm	94.5	98.5	256.1	251.5	427.1	424.8	483.1	489.3
CD (p=0.05)	NS	NS	4.6	4.4	9.6	8.9	6.9	6.4
NITROGEN LEVELS								
0 kg ha^{-1}	83.2	89.6	239.9	237.1	399.2	394.2	446.9	458.0
50 kg ha^{-1}	88.1	94.6	254.0	250.9	425.2	418.2	474.5	474.3
75 kg ha^{-1}	100.6	106.1	272.8	263.8	453.2	456.2	510.1	518.6
100 kg ha^{-1}	104.2	108.7	276.4	267.5	456.9	461.0	515.1	520.6
CD (p=0.05)	4.7	4.6	6.1	7.6	11.6	11.1	7.2	7.0

4.1.5 Leaf area index

Leaf area index (LAI) is a measure of leafiness per unit ground area and indicates the extent of photosynthetic activities of the plant. It is the most important indicator of size of the assimilatory system to maximize harvest of the incident solar radiation. Leaf area affects the interception and utilization of solar radiation by crop canopies, consequently affecting dry matter accumulation and ultimately the herb yield. It was estimated at the periodic intervals of 60 DAP, 90 DAP, 120 DAP and at harvest. There was a continuous increase in the Leaf area index with the progressive age of plant till harvesting. 'MSS-5' performed significantly better than 'Local' variety except in 2019 at 60 DAP (Table 4.5). During 2020, at 60 DAP; 'MSS-5' variety recorded significantly higher (5.4 per cent) leaf area than 'Local'. At 90 DAP; the LAI for 'MSS-5' was significantly higher than 'Local' and recorded 48.2 and 34.1 per cent increased LAI during 2019 and 2020, respectively. At 120 DAP, the LAI for 'MSS-5' was 36.1 and 31.1 per cent significantly higher than 'Local' during 2019 and 2020, respectively. At harvesting stage, LAI for 'MSS-5' was significantly higher (33.6 and 26.4 per cent) than the 'Local' during 2019 and 2020 respectively. Therefore it can be inferred that 'MSS-5' performed significantly better in terms of LAI than the 'Local' variety and clearly illustrates that 'MSS-5' variety possessed higher leaf area than the 'Local'.

During both the years, a general trend of decrease in LAI was observed with an increase in the row spacing from 45 cm to 60 cm. At 90 DAP, narrow row spacing of 45 cm registered significantly higher (10.9 and 12.63 per cent) leaf area than wider 60 cm spacing during 2019 and 2020, respectively. At 120 DAP, 45 cm row spacing recorded 14.6 and 11.7 per cent higher LAI than that of 60 cm spacing. At the harvesting stage, similar trend was followed where narrow spacing of 45 cm registered significantly more leaf area (12.4 and 12.6 per cent) as compared to wider spacing of 60 cm during both the years. On contrary, Mahantesh *et al* (2017) reported maximum LAI at 60 cm row spacing.

Nitrogen application showed a significant effect on the LAI which increased with an increase in the rate of nitrogen fertilizer application during both the years. During 2019, LAI at 100 kg N ha^{-1} (0.75) was significantly higher (87.5 per cent) as compared to control i.e. zero N (0.40). However as plant grew towards maturity, it was observed that the LAI values were statistically at par with the nitrogen application rate of 75 kg ha^{-1} and 100 kg ha^{-1} and showed a significant increase over the lower nitrogen levels (0 and 50 kg N ha^{-1}). At 90 DAP, 84 per cent increase in leaf area was witnessed up to 75 kg N ha^{-1} during 2019; whereas 36.1 per cent increase was recorded in 2020 which were statistically at par with 100 kg N ha^{-1}. At 120 DAP; the significant increase in LAI was 41.9 and 53.6 per cent up to 75 kg N ha^{-1} when compared to control *i.e.* zero kg N ha^{-1} during 2019 and 2020, respectively (Table 4.5). At harvesting stage during 2019, LAI increased significantly up to 50 kg N ha^{-1} which was then at par with 75 and 100 kg N ha^{-1}. However during 2020, the significant increase in LAI was observed up to 75 kg N ha^{-1}.

It may be due to production of more number of leaves and branches with enhanced levels of nitrogen which probably has increased the LAI. Thus it could be inferred that row spacing of 45 cm with the nitrogen application at the rate of 50-75 kg ha^{-1} improves the LAI in spearmint. Interaction effects were found non-significant.

Singh *et al* (1986) has stated that increased nitrogen application influences the LAI significantly and the same was also signified by results of Kothari and Singh (1995). A linear increase in leaf area index with increase in nitrogen level was reported by Mahantesh *et al* (2017). Alsafar and Al-Hassan (2009) have also reported the significant influence of nitrogen fertilizer input on the LAI in *M. longifolia*.

TABLE 4.5: Effect of varieties, row spacing and nitrogen application on leaf area index (LAI) of spearmint

Treatment	LEAF AREA INDEX							
	60 DAP		90 DAP		120 DAP		At harvest	
	2019	2020	2019	2020	2019	2020	2019	2020
VARIETIES								
MSS – 5	0.61	0.76	2.43	2.32	3.47	4.11	3.90	4.21
Local	0.53	0.68	1.64	1.73	2.55	3.13	2.92	3.33
CD (p=0.05)	NS	0.16	0.20	0.17	0.09	0.34	0.29	0.31
ROW SPACING								
45 cm	0.55	0.68	2.13	2.14	3.21	3.82	3.61	3.43
60 cm	0.59	0.77	1.92	1.90	2.81	3.42	3.21	3.05
CD (p=0.05)	NS	NS	0.20	0.17	0.09	0.34	0.29	0.31
NITROGEN LEVELS								
0 kg ha^{-1}	0.40	0.68	1.16	1.55	2.53	2.61	2.79	2.62
50 kg ha^{-1}	0.48	0.63	1.81	1.87	2.80	3.55	3.30	3.59
75 kg ha^{-1}	0.64	0.74	2.14	2.11	3.59	4.01	3.61	4.11
100 kg ha^{-1}	0.75	0.85	2.38	2.27	3.72	4.31	3.74	4.40
CD (p=0.05)	0.08	NS	0.36	0.28	0.29	0.52	0.48	0.44

4.1.6 Leaf to stem ratio

Leaf is the main site for the oil synthesis by the *Mentha* species hence the proportion of higher weight of leaves than stem is mainly considered as an indicator for greater oil concentration thereby higher oil yield. It was observed that ‘MSS-5’ performed better in terms of leaf stem ratio when compared to the ‘Local’ variety during both the years. Leaf to stem ratio were significantly higher in case of ‘MSS-5’ (1.34 and 1.03) when compared to ‘Local’ (1.31 and 1.00) for the years 2019 and 2020, respectively. However, the effect of variable row spacing on leaf stem ratio was observed non-significant thereby showing comparative increase in both leaf and stem weight (Table 4.6). Kassahun *et al* (2011) also reported minimal effect of row spacing on the leaf to stem ratio in peppermint. The effect of varied level of nitrogen input was also observed where leaf-stem ratio tends to decline significantly with increase in nitrogen application from 0 to 100 kg ha^{-1}. With application rate of N from 0 to 100 kg ha^{-1}, leaf to stem ratio decreased significantly with each increase in level of nitrogen application. The leaf to stem ratio of 1.26 and 1.14 at 0 kg N ha^{-1} (control) was significantly higher than that observed at 50 kg N ha^{-1} (1.17 and 0.97), 75 kg N ha^{-1} (1.12 and 0.97) and 100 kg N ha^{-1} (1.08 and 0.96) during both the years 2019 and 2020, respectively.

Thus, it could be inferred that with increase in nitrogen application both stem and leaves were benefitted however stem growth was more favored than leaf growth. Interaction effects were found non-significant. Kothari and Singh (1995) have reported that increased nitrogen application decreases the leaf-stem ratio. Ram *et al* (2006) also observed significantly higher leaf to stem ratio in control (0 kg N ha^{-1}) as compared to 100 and 200 kg N ha^{-1}.

TABLE 4.6: Effect of varieties, row spacing and nitrogen application on leaf-stem ratio of spearmint

Treatment	**LEAF-STEM RATIO (at harvest)**	
	2019	**2020**
VARIETIES		
MSS – 5	1.34	1.03
Local	1.31	1.00
CD (p=0.05)	0.02	0.02
ROW SPACING		
45 cm	1.33	1.02
60 cm	1.32	1.01
CD (p=0.05)	NS	NS
NITROGEN LEVELS		
0 kg ha^{-1}	1.26	1.14
50 kg ha^{-1}	1.17	0.97
75 kg ha^{-1}	1.12	0.97
100 kg ha^{-1}	1.08	0.96
CD (p=0.05)	0.03	0.02

4.1.7 Fresh herb yield

Fresh herb yield is generally taken as an index for measurement of total assimilates accumulated during whole crop growing period. It's the most important factor other than the oil contents and active compound which directly affects the economy of cultivation of spearmint. It is the outcome of total solar light utilized and sinks of net resources like nutrient in plant after respiration losses. The varietal variation showed significant effect on fresh herb yield of spearmint. The better performing variety 'MSS-5' gave significantly higher fresh herb yield during 2019 and 2020 when compared to that of 'Local' (Table 4.7). The magnitude of the increase in fresh herb yield produced by 'MSS-5' over 'Local' variety was 9.5 and 14.8 per cent during 2019 and 2020, respectively. The significantly higher fresh herb yield of the variety 'MSS-5' could be attributed to significantly higher plant height, stool count, leaf area, and dry matter accumulation.

The variation in crop geometry showed significant effect on fresh herbage production during both the years. The fresh herb yield under narrower row spacing of 45 cm was significantly higher than 60 cm row spacing during both the years. Spearmint planted at 45 cm row spacing produced 166.9 and 163.0 q ha^{-1} fresh herb yield during 2019 and 2020, respectively, which was 5.1 and 10.6 per cent higher than that of the crop planted at 60 cm row spacing (Table 4.7). The higher fresh herb yield in closer spacing might have resulted from significantly higher plant height, stool count per square and dry matter accumulation than wider spacing. Brar *et al* (2014) recorded the maximum herb yield at 45 cm row spacing in Japanese mint.

TABLE 4.7: Effect of varieties, row spacing and nitrogen application on leaf fresh herb of spearmint

Treatment	**FRESH HERB YIELD (q ha^{-1})**	
	2019	**2020**
VARIETIES		
MSS – 5	170.1	165.4
Local	155.3	145.0
CD (p=0.05)	7.7	6.3
ROW SPACING		
45 cm	166.9	163.0
60 cm	158.8	147.4
CD (p=0.05)	7.7	6.3
NITROGEN LEVELS		

0 kg ha^{-1}	99.6	98.5
50 kg ha^{-1}	156.5	150.4
75 kg ha^{-1}	195.4	182.3
100 kg ha^{-1}	200.4	188.4
CD (p=0.05)	11.9	8.7

During 2019, with supplementation of 75 kg N ha^{-1}, the fresh herb yield increased significantly by 96.2 per cent as compared to control (zero nitrogen). The corresponding magnitude of increase in 2020 was 85.1 per cent (Table 4.7). Fresh herbage increased significantly with increase in nitrogen level up to 75 kg ha^{-1}. Further increase in dose of nitrogen i.e. 100 kg ha^{-1} did not show any significant effect on fresh herb yield than that of lower dose (75 kg ha^{-1}) for both the years. The higher biomass accumulation i.e. plant height, stool count and dry matter accumulation in crop raised with higher dose of nitrogen could be attributed to the fact that nitrogen being the major component of chlorophyll, helped in better harvesting of the solar energy in the form of photosynthesis thus increasing the herb yield as a result. Interaction effects were found non-significant. Khera *et al* (1986) reported significant increase in yield with increase in N level from 50 to 75 kg ha^{-1} to single cutting at Ludhiana and further increase in N level to 100 kg ha^{-1} resulted in non-significant increase herbage yield of *M. arvensis*. Kewalanand *et al* (1998) and Verma (2017) have also reported a maximum herb yield at higher levels of nitrogen inputs compared to zero nitrogen level in *M. arvensis*. Anwar *et al* (2010) also found higher fresh herbage yield with increasing fertilizer dose over control treatment.

4.1.8 Dry herb yield

Dry herb yield is the dry herbage output of mint obtained from fresh herbage yield. The varietal differences for dry herb yield of spearmint were significant during both the years, 'MSS-5' being capable of producing significantly higher dry herb yield when compared to the 'Local' variety showing an increase of 10 and 15 per cent during 2019 and 2020, respectively. Dry herb yield at 45 cm row spacing was significantly higher (10.2 per cent) in comparison to 60 cm row spacing during 2020. However, the yield under different spacing was statistically at par with each other in 2019 (Table 4.8). Higher dry herb yield under 45 cm may be due to significantly higher plant height, number of stools and dry matter accumulation. Samra (1973), Yadav *et al* (1983) and Kaur *et al* (2013) also reported significantly higher dry herb yield of *M. arvensis* in crop planted at 45 cm than 60 and 75 cm row spacing.

Dry herb yield of spearmint was influenced significantly with different nitrogen levels and the increase in nitrogen application rate gave significantly higher dry herb yield during both the years. During 2019, the magnitude of increase in dry herb yield was such that crop fertilized with 75 kg N ha^{-1} gave 103.2 per cent higher dry herb yield than control and 27.6 per cent higher than 50 kg N ha^{-1} while being statistically at par with that of 100 kg N ha^{-1}. During 2020, similar trend was followed in which 75 kg N ha^{-1} being statistically at par with 100 kg N ha^{-1} produced 86.5 per cent higher than control and 23.4 per cent higher dry herb yield than 50 kg N ha^{-1} (Table 4.8). Higher dry herb yield at 100 kg N ha^{-1} application might be due to luxuriant growth and development of crop due to extra nitrogen input. Interaction effects were found non-significant. Khera *et al* (1986) also revealed a significant increase in mint yield with increase in N level from 50 to 75 kg N ha^{-1} at Ludhiana and further increase in N level to 100 kg N ha^{-1} resulted in non-significant increase herbage yield of *M. arvensis*.

TABLE 4.8: Effect of varieties, row spacing and nitrogen application on dry herb of spearmint

Treatment	**DRY HERB YIELD (q ha^{-1})**	
	2019	**2020**
VARIETIES		
MSS – 5	119.1	114.8
Local	108.2	99.8
CD (p=0.05)	10.4	6.1
ROW SPACING		
45 cm	116.1	112.6
60 cm	111.1	102.1
CD (p=0.05)	NS	6.1
NITROGEN LEVELS		
0 kg ha^{-1}	68.3	68.4
50 kg ha^{-1}	108.7	103.4
75 kg ha^{-1}	138.8	127.6
100 kg ha^{-1}	139.2	129.8
CD (p=0.05)	9.8	9.8

4.1.9 Oil content

Oil content in both the varieties was observed to be at par with each other with values ranging from 0.48 per cent to 0.54 per cent for both the years. It was also observed that varying row spacing did not influence the oil content significantly during both the years. Similarly, the oil content did not vary significantly with increase in nitrogen level from 0 to

100 kg ha^{-1} during both the year (Table 4.9). Interaction effects were found non-significant.

Randhawa *et al* (1984) reported similar results in Japanese mint. Row spacing did not affect the oil content significantly however; maximum oil content (0.93 per cent) was recorded at 60 cm row spacing. Mahantesh *et al* (2017), Kassahun *et al* (2011) and Solomon and Beemnet (2011) reported that row spacing had a non-significant effect on the oil content of peppermint.

TABLE 4.9: Effect of varieties, row spacing and nitrogen application on oil content of spearmint

Treatment	**OIL CONTENT (per cent)**	
	2019	**2020**
VARIETIES		
MSS – 5	0.49	0.51
Local	0.51	0.54
CD (p=0.05)	NS	NS
ROW SPACING		
45 cm	0.50	0.57
60 cm	0.48	0.53
CD (p=0.05)	NS	NS
NITROGEN LEVELS		
0 kg ha^{-1}	0.51	0.52
50 kg ha^{-1}	0.48	0.51
75 kg ha^{-1}	0.52	0.54
100 kg ha^{-1}	0.49	0.53
CD (p=0.05)	NS	NS

4.1.10 Oil yield

Oil yield is taken as the criterion for assessing the ultimate effect of treatments on economic returns. The oil yield of the varieties 'MSS-5' and 'Local' was statistically at par during 2019. However, during 2020, 'MSS-5' variety indicated an increase of 11.2 per cent significantly higher oil yield than 'Local' variety. The oil yield was found to be significantly impacted with change in row spacing during 2020 and maximum oil yield was obtained in crop planted at 45 cm row spacing which was 13.2 per cent higher as compared to that of 60 cm row spacing. The results were non-significant during 2019 for both the varieties as well as row spacing. 45 cm rows allowed better penetration of light creating an optimal temperature favorable for accumulation of oils in the leaf, thus increasing the oil yield of the crop (Table 4.10). The higher oil yield in 45 cm spacing resulted from significantly higher plant height, stools per square and dry matter accumulation than wider spacing, which resulted in significantly higher fresh biomass and thus the oil yield.

Randhawa and Kaur (1996) reported increase in oil yield of spearmint with increase in row spacing from 30 to 45 cm, while further increase in row spacing to 60 cm led to decreasing trend at PAU, Ludhiana (Punjab). Sharma and Kanjilal (1999) also reported the maximum oil yield at 45 cm row spacing. Saini *et al* (2002) at Ludhiana also obtained maximum essential oil yield of *M. arvensis* planted at 45 cm row to row spacing which was at par with 60 cm but significantly superior than 75 cm row to row spacing.

TABLE 4.10: Effect of varieties, row spacing and nitrogen application on oil yield of spearmint

Treatment	**OIL YIELD (l ha^{-1})**	
	2019	**2020**
VARIETIES		
MSS – 5	86.1	83.7
Local	80.7	75.3
CD (p=0.05)	NS	4.8
ROW SPACING		
45 cm	84.9	86.0
60 cm	82.1	76.0
CD (p=0.05)	NS	4.8
NITROGEN LEVELS		
0 kg ha^{-1}	49.8	50.3
50 kg ha^{-1}	80.1	76.9
75 kg ha^{-1}	101.5	94.6
100 kg ha^{-1}	102.4	96.2
CD (p=0.05)	8.1	5.7

The increasing level of nitrogen rates had a significant effect on the oil yield of spearmint which increased with an increase in N level during both the years. The oil yield increased significantly (by 103.8 per cent) up to 75 kg N ha^{-1} when compared to control. The maximum oil yield was reported at 100 kg N ha^{-1} which was statistically at par with crop fertilized with 75 kg N ha^{-1} during both the years. The magnitude of increase in oil yields with addition of 75 kg N ha^{-1} was 88.1 per cent from that of control during 2020. Increased nitrogen promotes the luxuriant vegetative grow and therefore increases the oil yield of crop. Thus, it could be inferred that a row spacing of 45 cm with nitrogen input of 75 kg N ha^{-1} could be beneficial to improve the oil yield of spearmint crop. Interaction effects were found non-significant.

Asundi (2001) reported a significant effect of increased nitrogen supplementation on the oil yield of Japanese mint. Kothari and Singh (1995) also reported an increase in oil yield significantly up to the application 200 kg N ha^{-1} at 45 cm or 60 cm row spacing. Mahantesh *et al* (2017) recorded the highest oil yield at 45 cm row spacing at nitrogen input of 150 kg ha^{-1} as compared to control which again was in accordance with the results of Verma (2017) which states that oil yield increases with increase in fertilizer inputs.

4.2 Quality analysis of oil

4.2.1 Optical rotation

The purity of optically active samples can be checked by measurement of their optical rotation. The optical rotation of oil of spearmint herb varied significantly between the two varieties during both the year. Higher optical rotation means substance is more optically denser. The variety 'MSS-5' proved to have higher optical rotation when compared to the 'Local' variety which means oil from 'MSS-5' was more condensed than that of 'Local' variety. Optical rotation indicates purity and concentration of enantiomers present in oil substance. It did not vary significantly with change in row to row spacing. Optical rotation was not significantly influenced but increased numerically with increase in nitrogen level during both the years (Table 4.11). Interaction effects were found non-significant. The negative sign illustrates the levo rotatory or anti clockwise rotation of plane. Kaur *et al* (2013) reported a non-significant effect of row spacing and nitrogen application on the mint oil optical rotation.

4.2.2 Specific gravity

The specific gravity is an important parameter for ascertaining the purity of spearmint oil. During both the years, specific gravity of the oil of variety 'MSS-5' was significantly higher than that of Local variety. This indicated that oil from 'MSS-5' variety was comparatively condensed and lesser volatile than that of 'Local' variety. The values below one indicate that oil would be floating on surface of water because of its lower mass and weight than that of water. Row spacing did not significantly influence the specific gravity, however numerically specific gravity decreased with wider row spacing. Increase in nitrogen levels did not affect the specific gravity of the oil significantly during both the years (Table

4.11). Interaction effects were found non-significant. Kaur *et al* (2013) and Randhawa and Kaur (1996) also observed the non-significant effect of row spacing and nitrogen level on the physiochemical properties of Japanese mint and spearmint, respectively.

4.2.3 Refractive index

The refractive index is ratio of speed of light in vacuum to speed of light in a substance. 'MSS-5' variety recorded significantly higher values for refractive index than the 'Local' variety which indicated that oil from 'MSS-5' was more condensed than that of 'Local' as light was refracted more in case of 'MSS-5' than that of 'Local'. An increase in the row spacing or increased nitrogen application did not significantly influence the refractive index of the spearmint oil during both the years (Table 4.11). Interaction effects were found non-significant. Randhawa and Kaur (1996) and Kaur *et al* (2013) also reported that row spacing does not influence the refractive index in spearmint and Japanese mint, respectively. Similarly, Nitrogen application rate was also reported to be non-significant for this parameter (Brar *et al* 2012).

TABLE 4.11: Effect of varieties, row spacing and nitrogen application on optical rotation, specific gravity and refractive index of spearmint oil

Treatment	OPTICAL ROTATION		SPECIFIC GRAVITY		REFRACTIVE INDEX	
	2019	2020	2019	2020	2019	2020
VARIETIES						
MSS – 5	-49.7	-57.3	0.937	0.932	1.562	1.564
Local	-46.4	-48.5	0.924	0.920	1.391	1.393
CD (p=0.05)	0.02	0.16	0.005	0.003	0.024	0.026
ROW SPACING						
45 cm	-48.1	-52.8	0.932	0.929	1.476	1.478
60 cm	-48.0	-52.9	0.930	0.923	1.476	1.479
CD (p=0.05)	0.02	NS	NS	NS	NS	NS
NITROGEN LEVELS						
0 kg ha^{-1}	-48.0	-52.8	0.934	0.927	1.476	1.478
50 kg ha^{-1}	-48.0	-52.9	0.926	0.925	1.476	1.479
75 kg ha^{-1}	-48.1	-52.9	0.932	0.926	1.476	1.480
100 kg ha^{-1}	-48.1	-52.9	0.932	0.926	1.476	1.476
CD (p=0.05)	NS	NS	NS	NS	NS	NS

4.2.4 Acid value

Acid value is used to determine age, quality, solubility and edibility of oils. It is an indicator of freshness of the oil and checks the rancidity in oil. Acid value of oil of 'MSS-5' variety (1.403 and 0.852) was significantly higher than the 'Local' variety (1.122 and 0.787) during 2019 and 2020, respectively (Table 4.12). Acid value of spearmint oil showed non-significant results with change in row spacing from 45 to 60 cm during both the years. Similar was the case with nitrogen application that no significance in values was observed during both the years. However, a numerically decreasing trend was observed in acid value of spearmint oil with increase in nitrogen application rate from 0 to 100 kg N ha^{-1} during both the years. Interaction effects were found non-significant. Thus, it could be inferred that acid value decreases with increase in nitrogen level concentration as reported in Japanese mint oil by Brar *et al* (2014). However, Dan and Randhawa (2002) reported that acid value of Japanese oil was not affected due to varied nitrogen levels application. Brar *et al* (2014) also reported a significant increase in acid value with increase in spacing from 45 cm to 75 cm with the values being statistically at par between 45 cm and 60 cm row spacing.

4.2.5 Ester value

Esters enhance flavor and are responsible for fragrance of the oil. Ester value of Local variety was observed to be significantly higher than 'MSS-5' during both the years (Table 4.12). Maximum ester values of 'Local' variety (35.923 and 20.471) were observed which were significantly better than 'MSS-5' variety (28.333 and 19.682) during 2019 and 2020, respectively. It was observed that an increase in row spacing had a non-significant effect on the ester value of the oil during both the years. Nitrogen level supplementation increased the ester values of the oil significantly from 0 kg N ha^{-1} (31.684) to 50 kg N ha^{-1} (32.297) which was then at par with 75 kg N ha^{-1} (32.230) and 100 kg N ha^{-1} (32.302) during 2019. However, the observations during 2020 showed non-significant results with increase in N application. Interaction effects were found non-significant. Thus, it could be inferred that nitrogen supplementation could improve the ester value of spearmint oil. Brar *et al* (2014) also reported the similar results with non-significant effect of row spacing however a significant effect of increasing nitrogen level on ester value of Japanese mint oil.

4.2.6 Saponification value

Saponification value, sum of acid value and ester value helps to know the amount of free fatty acids present in a substance and determine the length of carbon chains. Saponification value for 'Local' variety (37.045 and 21.538) was significantly higher than the 'MSS-5' variety (29.736 and 20.814) during both 2019 and 2020, respectively (Table 4.12).

Lower saponification value means increase in weight of fats in oil. The effect of row spacing on the saponification value was observed to be non-significant during both the years. An increase in the saponification values was observed with an increase in nitrogen level supplementation during 2019 where values at 50 kg N ha^{-1} (33.554) were statistically at par with values of 75 kg N ha^{-1} (33.495) and 100 kg N ha^{-1} (33.565) but significantly higher than that of control treatment i.e. 0 kg N ha^{-1} (32.947). During 2020, maximum values were recorded at 75 kg N ha^{-1} (20.870) and 100 kg N ha^{-1} (21.938) being statistically at par with each other but comparatively better than that values at 50 kg N ha^{-1} (20.942) and at 0 kg N ha^{-1} (20.953).

TABLE 4.12: Effect of varieties, row spacing and nitrogen application on acid value, ester value and saponification value of spearmint oil

Treatment	ACID VALUE		ESTER VALUE		SAPONIFICATION VALUE	
	2019	2020	2019	2020	2019	2020
VARIETIES						
MSS – 5	1.403	0.852	28.333	19.682	29.736	20.814
Local	1.122	0.787	35.923	20.471	37.045	21.538
CD (p=0.05)	0.079	0.031	0.025	0.023	0.022	0.015
ROW SPACING						
45 cm	1.262	0.819	32.136	20.076	33.399	21.176
60 cm	1.262	0.818	32.120	20.075	33.382	21.175
CD (p=0.05)	NS	NS	NS	NS	NS	NS
NITROGEN LEVELS						
0 kg ha^{-1}	1.253	0.796	31.684	20.156	32.947	20.953
50 kg ha^{-1}	1.257	0.816	32.297	20.125	33.554	20.942
75 kg ha^{-1}	1.265	0.824	32.230	20.025	33.495	20.870
100 kg ha^{-1}	1.266	0.842	32.302	20.028	33.565	21.938
CD (p=0.05)	NS	NS	0.438	NS	0.436	0.076

4.3 N, P and K content

4.3.1 Nitrogen content

The nitrogen content in 'MSS-5' was estimated to be significantly higher (13.5 and 29.9 per cent) than 'Local' variety during 2019 and 2020, respectively (Table 4.13). Row to row spacing did not influence the N content in herb of spearmint during 2019 while during 2020, 60 cm spacing showed a significant increase (17.3 per cent) in N content as compared to the 45 cm row spacing. This might be due to the increased dry matter at 45 cm which resulted in dilution of nutrient contents in plant. Interaction effects were found non-significant.

Nitrogen content increased significantly with increase in nitrogen rate and maximum values recorded in crop planted with input of 100 kg N ha^{-1} were statistically at par with 75 kg N ha^{-1} during both the years. N content increased by 27.4 per cent with application of 75 kg N ha^{-1} over the control (zero nitrogen) treatment during 2019. The magnitude of increase during 2020 was 35.8 per cent up to 75 kg N ha^{-1}. Similar to these results, Brar *et al* (2014) reported a significant increase in nitrogen uptake with increasing nitrogen levels till 100 kg N ha^{-1} which was at par with 75 kg N ha^{-1} in the Japanese mint oil. Also, Dan and Randhawa (2002) signified increased N uptake with increasing N level up to 75 kg N ha^{-1}.

4.3.2 Phosphorus content

Phosphorus content was observed to be significantly higher in 'MSS-5' (0.40) than 'Local' (0.31) during 2019 but in 2020, both were statistically at par with each other (Table 4.13). It was also observed that the increasing row spacing and nitrogenous inputs had no significant effect on the phosphorus content of the spearmint. Interaction effects were found non-significant. The general phosphorus content ranged between 0.31-0.40 per cent. Similarly, Brar *et al* (2014) also depicted that increased row spacing and nitrogen levels do not influence the phosphorus uptake of the Japanese mint oil.

4.3.3 Potassium content

As observed for the nitrogen content, potassium content was also significantly higher in 'MSS-5' (2.16 and 2.33) when compared to that of 'Local' (1.92 and 1.73) during 2019 and 2020, respectively (Table 4.13). No significant effect was observed in the concentration of potassium with an increase in the row spacing. Interaction effects were found non-significant. During 2019, the potassium content in herb decreased numerically with increased nitrogen application.

TABLE 4.13: Effect of varieties, row spacing and nitrogen application on N, P and K content of spearmint

Treatment	N (per cent)		P (per cent)		K (per cent)	
	2019	**2020**	**2019**	**2020**	**2019**	**2020**
VARIETIES						
MSS – 5	2.09	2.17	0.40	0.38	2.16	2.33
Local	1.84	1.67	0.31	0.37	1.92	1.73
CD (p=0.05)	0.29	0.05	0.06	NS	0.02	0.02
ROW SPACING						
45 cm	2.07	1.90	0.35	0.38	2.06	2.03
60 cm	2.25	2.23	0.36	0.38	2.06	2.03
CD (p=0.05)	NS	0.05	NS	NS	NS	NS
NITROGEN LEVELS						
0 kg ha^{-1}	1.79	1.73	0.39	0.38	2.15	2.80
50 kg ha^{-1}	2.03	2.12	0.37	0.38	1.99	2.19
75 kg ha^{-1}	2.28	2.35	0.38	0.37	1.86	1.71
100 kg ha^{-1}	2.36	2.40	0.38	0.39	1.17	1.41
CD (p=0.05)	0.10	0.09	NS	NS	NS	0.06

However, during 2020, nitrogen supplementation resulted in highest K content at 0 kg N ha^{-1} (2.80) which significantly declined with each increase in N application up to 100 kg N ha^{-1} (1.41). The values for potassium ranged between 1.41-2.80 per cent.

4.4 Carvone content

Carvone is the most important active compound present in spearmint for which spearmint oil is traded. carvone content of variety 'MSS-5' was slightly on higher side as compared to 'Local' variety during both the years (Table 4.14).

Table 4.14: Effect of varieties, row spacing and nitrogen application on carvone content of spearmint

Treatment	CARVONE CONTENT (per cent)	
	2019	2020
VARIETIES		
MSS – 5	62.2	61.7
Local	61.9	61.5
CD (p=0.05)	0.08	0.08
ROW SPACING		
45 cm	61.9	61.4
60 cm	62.2	61.7
CD (p=0.05)	0.08	0.08
NITROGEN LEVELS		
0 kg ha^{-1}	61.3	60.8
50 kg ha^{-1}	61.4	60.9
75 kg ha^{-1}	63.1	62.6
100 kg ha^{-1}	62.5	62.0
CD (p=0.05)	0.04	0.02

During year 2019, the carvone content of 'MSS-5' was 62.2 per cent whereas variety 'Local' showed 61.9 per cent. Similar trend was observed next year; carvone content of 'MSS-5' was found slightly higher (61.7 per cent) as compared to variety 'Local' (61.5 per cent). Interaction effects were found non-significant.

Crop grown as per crop geometry of 60 cm (61.9 and 61.4 per cent) row spacing resulted in more carvone content as compared to 45 cm row spacing (62.2 and 61.7 per cent) during 2019 and 2020, respectively. Nitrogen dose of 75 kg ha^{-1} (63.1 during 2019 and 62.6 during 2020) resulted in highest carvone content among the nitrogen application treatments.

CHAPTER V

SUMMARY

The present investigation entitled, "Effect of crop geometry and nitrogen levels on herb and oil yield and quality of spearmint (*Mentha Spicata* L.)" was conducted at Research Area, School of Organic Farming, Punjab Agricultural University, Ludhiana, during year 2019 and 2020. The treatment consisted all possible combinations of two varieties (MSS-5 and Local), two row spacing (45 cm and 60 cm) and four levels of nitrogen (0, 50, 75 and 100 kg N/ha). The experiment was laid out in split plot design with three replications. The effect of different treatments on growth, herb yield, oil content and oil yield are summarized as under:

Emergence count

The emergence count recorded at 10, 15 and 20 DAP for both the varieties 'MSS-5' and 'Local' were statistically at par during 2019 and 2020. In case of row spacing, it was statistically at par, however numerically higher in 60 cm row spacing than 45 cm spacing. The increase in nitrogen application had significant effect on the emergence count particularly at 15 DAP and afterwards. The emergence count at 75 kg N ha^{-1} was statistically at par with that of 100 kg N ha^{-1} but significantly better than control and 50 kg N ha^{-1} during both the years.

Stool population

The variety, 'MSS-5' performed significantly better having 8 – 12 per cent more stool population at all crop growth stages when compared to 'Local' variety during both the years. Stool count comparatively decreased with increase in row spacing, however the differences remained non-significant except at 90 DAP during 2020 where stool count at 45 cm row spacing was significantly higher (10 per cent) i.e. 60.2 m^{-1} when compared at 60 cm row spacing i.e. 54.7 m^{-1}. In case of nitrogen application, the stool population improved significantly by 14.9 per cent up to 75 kg N ha^{-1} in 2019 and 18.2 per cent in 2020 when compared to control (zero nitrogen) at harvesting stage, however statistically at par with that of at 100 kg N ha^{-1} during both the years.

Plant height

'MSS-5' variety was significantly taller at the time of harvesting (10.6 and 11.2 per cent) as compared to the 'Local' variety during 2019 and 2020, respectively. Plant height was not much affected by row spacing, however the 45 cm row spaced crop was taller by 15 per cent when compared with 60 cm spaced crop (84.3 cm) during 2019 at the time of harvesting. An increasing trend of plant height with increase in nitrogen dose was observed during both the years. It increased by 9.7 and 10.6 per cent with the application of 75 kg N ha^{-1} over 50 kg N ha^{-1}during 2019 and 2020, respectively.

Dry matter accumulation

With increasing days to planting, 'MSS-5' variety surpassed the 'Local' variety with significantly higher DMA recorded. At the harvesting stage, 'MSS-5' showed 5.3 and 5.2 per cent increase over 'Local' (475.1 g m^{-2} and 480.5 g m^{-2}) during 2019 and 2020 respectively. In general, the DMA at 45 cm row spacing was significantly higher (3-7 per cent) than that of 60 cm row spacing at 90 DAP onwards till the harvesting stage during both the years. The nitrogen application significantly improved the DMA up to 75 kg N ha^{-1} during both the years, while the difference between 75 kg N ha^{-1} and 100 kg N ha^{-1} was statistically non-significant. Application of 75 kg N ha^{-1} registered 7.5 and 9.3 per cent higher DMA over plots applied with 50 kg N ha^{-1} during 2019 and 2020, respectively.

Leaf area index

'MSS-5' variety possessed higher leaf area than the 'Local' as LAI for 'MSS-5' was significantly higher (33.6 and 26.4 per cent) than the 'Local' at the time of harvesting during 2019 and 2020, respectively. A general trend of decrease in LAI was observed with an increase in the row spacing from 45 cm to 60 cm during both the years. At the harvesting stage, spacing of 45 cm registered significantly more leaf area (12.4 and 12.6 per cent) as compared to wider spacing of 60 cm during both the years. LAI increased with an increase in the rate of nitrogen fertilizer application and the values were statistically at par with the nitrogen application rate of 75 kg ha^{-1} and 100 kg ha^{-1} and showed a significant increase over the lower nitrogen levels (0 and 50 kg N ha^{-1}).

Leaf-stem ratio

Leaf to stem ratio was significantly higher in case of 'MSS-5' (1.34 and 1.03) when compared to 'Local' (1.31 and 1.00) for the years 2019 and 2020, respectively. However, the effect of variable row spacing on leaf-stem ratio was observed non-significant thereby showing comparative increase in both leaf and stem weight. With application rates of N ranging from 0 to 100 kg ha^{-1}, leaf to stem ratio decreased significantly with each increase in level of nitrogen application.

Fresh herb yield

The better performing variety 'MSS-5' gave significantly higher (9.5 and 14.8 per cent) fresh herb yield when compared to that of 'Local' (155 and 145 q ha^{-1}) during 2019 and 2020, respectively. Spearmint planted at 45 cm row spacing produced 8.1 and 15.6 quintals more fresh herb yield, which was 5.1 and 10.6 per cent higher than that of the crop planted at 60 cm row spacing (158.8 and 147.4 q ha^{-1}) during 2019 and 2020, respectively. Supplementation of 75 kg N ha^{-1} produced 19.8 and 17.5 per cent higher fresh herb yield over 50 kg N ha^{-1} (156.5 and 150.4 q ha^{-1}) during 2019 and 2020, although values were statistically at par with that of 100 kg N ha^{-1}.

Dry herb yield

'MSS-5' being capable of producing 10 and 15 per cent higher dry herb yield when compared to the 'Local' variety (108.2 and 99.8 q ha^{-1}) during 2019 and 2020, respectively. The yield under different spacing was statistically at par with each other in 2019. However, crop planted under 45 cm spacing produced 10.2 per cent higher dry herb yield when compared with 60 cm (102.1 q ha^{-1}) spaced crop during 2020. In case of nitrogen application, crop fertilized with 75 kg N ha^{-1} gave 27.6 and 23.4 per cent higher yield than 50 kg N ha^{-1} (108.7 and 103.4 q ha^{-1}) during 2019 and 2020, respectively, while being statistically at par with that of 100 kg N ha^{-1}.

Oil content

Oil content in both the varieties was observed to be at par with each other with values ranging from 0.48 per cent to 0.54 per cent for both the years. It was also observed that varying row spacing did not influence the oil content significantly during both the years. Similarly, the oil content did not vary significantly with increase in nitrogen level from 0 to 100 kg ha^{-1} during both the years.

Oil yield

The oil yield of the varieties 'MSS-5' and 'Local' was statistically at par during 2019 However, during 2020, 'MSS-5' variety indicated an increase of 11.2 per cent higher oil yield than 'Local' variety (75.3 kg ha^{-1}). The results were non-significant during 2019 for both the varieties as well as row spacing. Crop planted at 45 cm produced 13.2 per cent higher oil yield as compared to that of 60 cm spacing (76 kg ha^{-1}) during 2020. Addition of 75 kg N ha^{-1} produced 26.7 and 18.7 per cent higher oil yield over 50 kg N ha^{-1} (80.1 and 76.9 kg ha^{-1}) during 2019 and 2020, however that was at par with 100 kg N ha^{-1}.

NPK content

Nitrogen content in 'MSS-5' was estimated to be significantly higher (13.5 and 29.9 per cent) than 'Local' variety during 2019 and 2020, respectively. Phosphorus content was observed to be significantly higher in 'MSS-5' (0.40) than 'Local' (0.31) during 2019 but in 2020, both were statistically at par with each other. Potassium content was also significantly higher in 'MSS-5' (2.16 and 2.33) when compared to that of 'Local' (1.92 and 1.73) during 2019 and 2020, respectively. Nitrogen content increased significantly with increase in nitrogen rate and maximum values recorded in crop planted with input of 100 kg N ha^{-1} was statistically at par with 75 kg N ha^{-1} during both the years. Potassium content in herb decreased numerically with increased nitrogen application. NPK content in herb did not exhibit any significant variation with change in row spacing during both the years.

Optical rotation

The variety 'MSS-5' variety proved to have higher optical rotation when compared to the 'Local' variety which means oil from 'MSS-5' was more condensed than that of 'Local' variety. Optical rotation did not vary significantly with change in row to row spacing. It was also not significantly influenced by nitrogen levels but increased numerically with increase in nitrogen level during both the years.

Specific gravity

Specific gravity of the oil of variety 'MSS-5' was significantly higher than that of Local variety during both the years. This indicated that oil from 'MSS-5' variety was comparatively condensed and lesser volatile than that of 'Local' variety.

Refractive index

'MSS-5' variety recorded significantly higher values for refractive index than the 'Local' variety which indicated that oil from 'MSS-5' was more condensed than that of 'Local' as light was refracted more in case of 'MSS-5' than that of 'Local'. Row spacing and nitrogen application had not significant effect on this property of spearmint.

Acid value

Acid value of oil of 'MSS-5' variety (1.403 and 0.852) was significantly higher than the 'Local' variety (1.122 and 0.787) during 2019 and 2020, respectively. Acid value of spearmint oil showed non-significant results with change in row spacing from 45 to 60 cm during both the years. Similar was the case with nitrogen application that no significance in values was observed during both the years. Yearly values changed due to storage of oil for longer period due to corona pandemic and this lead to changes in properties of oil by phenomenon of rancidity and acidity.

Ester value

Ester value of Local variety was observed to be significantly higher during both the years than MSS-5. Row spacing had non-significant effect on the ester value of the oil during both the years. Nitrogen supplementation increased the ester values of the oil significantly from 0 kg N ha^{-1} (31.684) to 50 kg N ha^{-1} (32.297) which was then at par with 75 kg N ha^{-1} (32.230) and 100 kg N ha^{-1} (32.302) during 2019. However, the observations during 2020 showed non-significant results with increase in N application.

Saponification value

Saponification value for 'Local' variety (37.045 and 21.538) was significantly higher than the 'MSS-5' variety (29.736 and 20.814) during both 2019 and 2020 respectively. Lower saponification value means increase in weight of fats in oil. The effect of row spacing on the saponification value was observed to be non-significant during both the years. Values decreased numerically with increase in nitrogen application. Yearly values changed due to storage of oil for longer period due to corona pandemic and this lead to changes in properties of oil by phenomenon of rancidity and acidity.

Carvone content

Carvone content of variety 'MSS-5' was slightly on higher side as compared to

‘Local’ variety during both the years. Crop grown as per crop geometry of 60 cm (61.9 and 61.4 per cent) row spacing resulted in more carvone content as compared to 45 cm row spacing (62.2 and 61.7 per cent) during 2019 and 2020, respectively. Nitrogen dose of 75 kg ha^{-1} (63.1 during 2019 and 62.6 during 2020) resulted in highest carvone content among the nitrogen application treatments.

Conclusion:

Spearmint variety ‘MSS-5’ variety performed better than ‘Local’ variety and produced 9.53 - 14.06 per cent higher herb, along with higher oil yield. Planting of spearmint at 45 cm row spacing produced significantly higher herb yield (5.1 and 10.6 per cent) than 60 cm spacing. Application of 75 kg N ha^{-1} was found to be optimum dose of N for improving herb and oil yield than lower doses of 0 kg N ha^{-1} (85-96 per cent) and 50 kg N ha^{-1} (21-25 per cent) and the response beyond 75 kg N ha^{-1} was non-significant during both the years. N @ 75 kg ha^{-1} also resulted in higher oil yield than 0 kg N ha^{-1} (88-105 per cent) and 50 kg N ha^{-1} (23-27 per cent). It may be concluded that spearmint variety ‘MSS-5’ performed better in terms of herb and oil yield and oil quality at 45 cm row spacing along with addition of 75 kg N ha^{-1}.

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VITA

Name of the student	:	Anshmeet
Father's name	:	Sh. Gurmeet Singh
Mother's name	:	Mrs. Ravinder Lamba
Nationality	:	Indian
Date of birth	:	26th February, 1996
Permanent home address	:	Q. No. D-10, Govt. Polytechnic College, Dulchi Ke Road, Ferozepur City - 152002

EDUCATIONAL QUALIFICATIOINS

Bachelor degree	**:**	**B.Sc. (Agriculture)**
University	:	Punjab Agricultural University, Ludhiana.
Year of award	:	2018
OCPA	:	7.17/10.00
Master's degree	**:**	**M.Sc. (Agronomy)**
University and year of award	:	Punjab Agricultural University, Ludhiana.
Year of award	:	2022
OCPA	:	7.24/10.00
Title of Master thesis	:	Effect of crop geometry and nitrogen levels on herb and oil yield and quality of spearmint (*Mentha spicata* L.)
Award/ Scholarships	:	-