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Biomass yield, essential oil yield and essential oil composition of rose-scented geranium (*Pelargonium* species) as influenced by row spacings and intercropping with cornmint (*Mentha arvensis* L.f. *piperascens* Malinv. ex Holmes)

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Abstract

Rose-scented geranium (*Pelargonium* species, family, Geraniaceae) is a vegetatively propagated (through rooted stem cuttings), initially slow growing, high value aromatic crop. Cornmint (*Mentha arvensis* L. f. *piperascens* Malinvaud ex Holmes, family, Lamiaceae) is also a vegetatively propagated (through rhizomes, runners or stolons and terminal stem cuttings), high demand aromatic–cum–medicinal crop. Essential oils isolated through steam distillation of shoot biomass of these two crops are extensively used in fragrance, flavor, and pharmaceutical industries and in aromatherapy. A field experiment was carried out during the vegetation periods of 1996–1998 in semi-arid tropical climate to investigate the influence of different row spacings (60 × 30, 75 × 30, 90 × 30 and 120 × 30 cm) and intercropping cornmint cv. Shivalik on the biomass yield, essential oil yield and essential oil composition of rose-scented geranium cv. Bourbon. The row spacing of 60 × 30 cm (60 cm between rows and 30 cm between plants within the rows) was superior to other row spacings and produced 57.4 t/ha total (total of four harvests) biomass yield (132.4% higher than 120 × 30 cm spacing) and 52.7 kg/ha total essential oil yield (98.9% greater than 120 × 30 cm spacing). Intercropping of cornmint did not affect biomass yield and essential oil yield of rose-scented geranium and yielded 5.6 t/ha of biomass and 21.3 kg/ha of essential oil of cornmint as bonus yields over and above that of rose-scented geranium. However, biomass yield and essential oil yield of intercropped cornmint suffered reductions of 53.4 and 59.1%, respectively, compared with monocropped cornmint. Intercropping controlled weed growth and decreased total (total of three harvests) biomass yield of weeds by 40.0% in rose-scented geranium intercropped with cornmint. The chemical composition of essential oils of both the crops was not influenced either by row spacings or by intercropping. The quality of essential oils of both the crops was good and was readily accepted in the market.

Keywords: *Pelargonium* species; *Mentha arvensis*; Row spacings; Intercropping; Biomass yield; Essential oil yield; Essential oil composition; Citronellol; Geraniol; Menthol

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1. Introduction

The essential oil of rose-scented geranium (*Pelargonium* species, family, Geraniaceae) extracted by steam distilling the above ground freshly harvested shoot biomass and aroma chemical rhodinol separated through fractional distillation of the volatile oil, are widely used in the fragrance industry, aromatherapy and sparingly used in the flavor industry. Rose-scented geranium oil has a strong, rose-like odor with minty top note accompanied by a slight grassy background. The aromatic oil is extensively used in various types of rose fragrances where petal and foliage effects are desired; in scenting of soaps due to its stability in slightly alkaline medium and in cosmetic products. In aromatherapy the volatile oil is used for menopausal problems, skin disorders, nervous tension and anxiety.

The essential oil of menthol mint or cornmint (*Mentha arvensis* L.f. *piperascens* Malinvaud ex Holmes, family, Lamiaceae) isolated by steam distilling the above ground freshly harvested or partially dried flowering or vegetative shoot phytomass and menthol crystals isolated through chilling and centrifuging the fragrant oil are extensively used in flavor, fragrance and pharmaceutical industries. Cornmint oil has a characteristic strong minty odor. It is used in prescriptions for cold remedies, cough drops, dentifrices, mouth washes; in scenting cigarettes; flavoring tobacco, chewing pan (rolled betel leaf containing menthol, lime paste, betel nut and other products), bakery products and in cosmetic products. In aromatherapy, the essential oil is prized for its cooling effect on the skin; for pain relieving properties; for treating digestive problems, migraine, heartburn, aching feet, travel sickness, sinus and catarrh problems.

India is a net importer of rose-scented geranium oil as demand far exceeds its production, therefore, excellent potential exists for extending its cultivation. Rose-scented geranium is propagated vegetatively through rooted terminal stem cuttings. The transplanted cuttings have a characteristic initial slow growth and are susceptible to weed competition during this lag phase leading to yield losses (Rajeswara Rao and Bhattacharya, 1997). To utilize the uncovered inter row space, applied inputs such as irrigation water and fertilizers, to check weed growth and to enhance crop productivity, attempts were made to grow short duration legumes like cowpea (*Vigna unguiculata* (L.) Walp.), blackgram (*Vigna mungo* (L.) Hepper) (Prakasa Rao et al., 1984, 1986) or greengram (*Vigna radiata* (L.) Wilez.), clusterbean (*Cyamopsis tetragonoloba* (L.) Taub.) (Rajeswara Rao et al., 2000) or butterbeans (*Phaseolus luteus* L.) (Narayana et al., 1986) and spices like garlic (*Allium sativum* L.) (Muni Ram and Kumar, 1998) as intercrops in rose-scented geranium. Similarly, for controlling soil erosion and for reaping higher returns, rose-scented geranium was intercropped in trees such as lemon-scented gum (*Eucalyptus citriodora* Hook.) (Singh et al., 1998b), bluegum (*Eucalyptus globulus* Labill.) (Dhyani et al., 1995) or wattle (*Acacia mearnsii* L.) (Agarwal et al., 1995).

India and China are the important producers and exporters of cornmint oil, menthol crystals, dementholised oil and mint terpenes (Rajeswara Rao, 1999). Cornmint is also propagated vegetatively through rhizomes, runners or stolons and terminal stem cuttings. Intercropping cornmint with tomato (*Lycopersicon esculentum* Mill.) (Rajeswara Rao, 1999), or greengram (Muni Ram et al., 1998) or radish (*Raphanus sativus* L.), okra (*Abelmoschus esculentus* Moench.), and cowpea (Singh et al., 1998a) improved land use efficiency and economic returns. Growing menthol mint as an intercrop in sugarcane (*Saccharum officinarum* L.) (Kothari et al., 1987; Randhawa et al., 1989) or citronella (*Cymbopogon winterianus* Jowitt.) (Singh and Ram, 1991) or poplar (*Populus deltoides* Bartram ex Marshall) (Singh et al., 1990) was also recommended for higher productivity and returns.

Rose-scented geranium and cornmint can be planted during the winter season in the semi-arid tropical climate of India and they need frequent, light irrigations for their optimum growth. The former is a deep rooted crop and the latter is a shallow rooted crop. Cornmint takes 4 months and rose-scented geranium 5 months to come to maturity for their first harvest. The compatibility of these two crops as companion crops in an intercropping system was not explored earlier.

Though, different spacings ranging from 30 × 30 to 120 × 30 cm were recommended for rose-scented geranium in various agro–climatic locations, these recommendations were based on general cultivation practices, rather than experimental evidences (Rajeswara Rao, 2000a). However, Prakasa Rao et al. (1988) found 60 × 45 cm spacing to be optimum for obtaining high yields of rose-scented geranium in Bangalore plains, India.

This field experiment was, therefore, conducted to investigate the influence of row spacings and intercropping cornmint on biomass yield, essential oil yield and essential oil composition of rose-scented geranium in semi-arid tropical climate.

2. Material and methods

The field study was carried out during the vegetation periods of 1996–1998 at the Central Institute of Medicinal and Aromatic Plants, Field Station, Hyderabad, India. The experimental location experiences semi-arid tropical climate. The soil of the experimental field was a red sandy loam (alfic ustochrept) with pH 7.4 (1:2.5 soil to solution ratio), EC 0.42 dS/m, organic C 0.3%, total N 0.03%, available P 10 μg/g soil and exchangeable K 128 μg/g soil. The experiment was laid out in randomized block design with four replications. There were nine treatments namely, four row spacings of rose-scented geranium without intercrop, four row spacings of rose-scented geranium with cornmint as intercrop and sole crop of cornmint planted with 60 cm row spacing. Terminal stem cuttings of uniform size (9–10 cm in length having seven to eight nodes and three to four terminal leaves) of rose-scented geranium cv. Bourbon were grown in polythene bags (10 cm in diameter and 16 cm in length, filled with native red soil, kept under partial shade and regularly watered. One cutting was planted in each bag) for rooting in the first week of October 1996. Healthy, profusely rooted, 60 days old cuttings were transplanted in the field on 7 December 1996 in defined row spacings (60, 75, 90 and 120 cm) maintaining 30 cm uniform spacing between the plants within the rows. After the establishment of rose-scented geranium cuttings, rhizomes of cornmint cv. Shivalik were planted end to end in furrows 3–5 cm deep in between two rows of rose-scented geranium in intercropping treatments on 11 December 1996. A sole crop of cornmint was planted similarly in rows spaced 60 cm apart. Rose-scented geranium plots were fertilized with 10 t farm yard manure (FYM), 150 kg N, 60 kg P_2O_5, 60 kg K_2O and 25 kg $ZnSO_4$ per hectare. FYM, zinc sulphate, phosphorus as single superphosphate and potassium as muriate of potash were applied prior to transplanting and thoroughly mixed with the soil. Nitrogen as urea was applied in four equal splits at one split per harvest. Urea was applied in 5–7 cm deep furrows, which were closed manually. Sole crop of cornmint was supplied with 5 t FYM, 60 kg N, 30 kg P_2O_5, 30 kg K_2O and 5 kg $ZnSO_4$ per hectare. FYM, zinc sulphate, phosphorus and potassium were applied as in rose-scented geranium. Nitrogen as urea was applied in three equal splits at planting, 60 and 90 days after planting. Cornmint plants intercropped in rose-scented geranium were not given extra fertilizers over and above that given to rose-scented geranium. All the experimental plots were flood irrigated at weekly intervals and maintained weed free through manual weedings. At each weeding, the green matter of the weeds was weighed and recorded as biomass yield of weeds. Weed growth was minimal after the third harvest of rose-scented geranium.

Cornmint shoot biomass was manually harvested on 17 April 1997 (127 days after planting) when the plants were in flower. Only one harvest of cornmint could be performed as rose-scented geranium plants smothered and inhibited growth of intercropped cornmint plants after the first harvest, particularly in 60 and 75 cm row spacings. Though, the sole crop of cornmint grew after the first harvest and afforded subsequent harvests, the data of these harvests were not considered for this study. Four harvests of rose-scented geranium were performed manually on 7 May 1997, 4 September 1997, 28 November 1997 and 25 March 1998. After recording biomass yields of rose-scented geranium and cornmint at every harvest, the biomass of each crop was distilled separately in an experimental field distillation unit operating on water-cum-steam distillation principle. The distilled oils of both the crops were filtered, treated with anhydrous sodium sulfate to remove moisture, refiltered, weighed and recorded as respective essential oil (economic) yields.

To test the advantage of intercropping to that of sole cropping, land equivalent ratio (LER) and area time equivalent ratio (ATER) were computed following the methods of Mead and Willey (1980), Hiebsch and McCollum (1987):

$$\mathrm{LER} = \frac{\mathrm{Yab}}{\mathrm{Yaa}} = \frac{\mathrm{Yba}}{\mathrm{Ybb}}$$

where Yab is the total biomass yield (t/ha) of rose-scented geranium in intercropping; Yaa the total biomass yield (t/ha) of rose-scented geranium in sole cropping; Yba the biomass yield (t/ha) of cornmint in intercropping and Ybb is the biomass yield (t/ha) of cornmint in monocropping.

$$\mathrm{ATER} = \frac{\mathrm{Yab/Ybb} \times t_{\mathrm{a}} + \mathrm{Yba/Yaa} \times t_{\mathrm{b}}}{t}$$

where t_{a} is the duration of rose-scented geranium in days; t_{b} the duration of cornmint in days and t is the total duration of intercropping system in days.

By using LER and ATER values, the land utilization efficiency (LUE) was calculated:

$$\mathrm{LUE\%} = \frac{\mathrm{LER} + \mathrm{ATER}}{2} \times 100$$

The data were subjected to statistical analysis following analysis of variance (ANOVA) technique as applicable to randomized block design (Cochran and Cox, 1959). The significance of treatment variance was tested with variance (F) ratio at 5% probability level. The significance of differences between any two treatment means was determined by comparing with least significant difference (LSD) values at 5% level of probability ($P = 0.05$). LSD values were computed from error variance and table 't' values at 5% probability level.

The chemical profiles of essential oil samples were analyzed using a Perkin–Elmer gas chromatograph (model 8500) equipped with GP-100 printer-plotter, flame ionization detector (FID) and a bonded phase fused silica capillary column BP-1 (25 m × 0.5 mm i.d. × 0.25 μm film thickness) coated with polydimethylsiloxane. Nitrogen was the carrier gas at 40 ml/min. (linear velocity 34 cm/s) flow rate and 10 psi inlet pressure. Temperature was programmed from 60 to 220 °C at 5 °C/min ramp rate with a final hold times of 10 min. Injector and detector were maintained at 250 and 300 °C, respectively. The samples (0.1–0.2 μl) were injected neat with 1:80 split ratio.

GC–MS of the oil samples were carried out on a Hewlett–Packard 5890 GC coupled to HP 5970 MSD system, using HP-1 (25 m × 0.2 mm i.d. × 0.25 μm film thickness) column coated with methyl silicone. Helium was employed as carrier gas with a flow rate of 1 ml/min. Temperature programming was from 100 to 220 °C at 4 °C/min rising rate. Mass spectra were recorded over 40–400 amu range at one scan per second with ionization energy 70 ev and ion source temperature 250 °C.

Identification of the essential oil constituents was accomplished by comparing retention times of the peaks with those of reference compounds run under identical conditions, Kovat's retention indices of the peaks with literature data (Davies, 1990; Ramaswamy et al., 1988), mass spectra of the compounds with those published in the literature (Adams, 1980; Masada, 1976; Ramaswamy et al., 1988) and by peak enrichment on co-injection of standard samples, wherever possible. Peak areas and retention times were measured by the electronic integrator. Kovat's retention indices were calculated from the gas chromatograms by logarithmic interpolation between bracketing n-alkanes. The homologous series of n-alkanes (C-8–C-22; Poly Science Inc., Niles, USA) were used as standards. The relative amounts (peak area percent) of individual components were computed from peak areas without FID response factor correction.

3. Results and discussion

3.1. Rose-scented geranium

3.1.1. Plant height

In 60 and 75 cm row spacings, lack of sufficient

Table 1
Effect of different row spacings and cropping systems on plant height and plant spread of rose-scented geranium

Treatments	Plant height (cm)	Plant spread (cm)	
		East–West	North–South
Spacings (cm)			
60 × 30	52.5	69.8	73.5
75 × 30	49.2	70.8	73.3
90 × 30	48.1	76.2	79.6
120 × 30	44.6	78.4	78.4
LSD[a] ($P = 0.05$)[b]	3.8	2.9	3.4
Cropping systems			
Monocropping	49.1	73.0	77.4
Intercropping	48.6	73.8	76.2
LSD ($P = 0.05$)	NS[c]	NS	NS

[a] LSD, least significant difference.
[b] $P = 0.05$, probability level at 5%.
[c] NS, not significant.

inter and intra-row space and possible competition for sunlight resulted in significantly taller plants compared with 90 and 120 cm row spacings (Table 1). The plants were 17.7% lengthier in 60 than 120 cm row spacing.

Intercropping had no effect on plant height of rose-scented geranium. The plant height of citronella another aromatic crop was also not affected when intercropped with cornmint (Singh and Ram, 1991). A similar observation was made in sugarcane intercropped with various mint species (Kothari et al., 1987; Singh, 1998).

3.1.2. Plant spread

Availability of abundant space between the rows encouraged horizontal growth of rose-scented geranium plants in wider row spacings of 90 and 120 cm leading to plants with significantly larger spread in these spacings (Table 1). The 120 cm row spacing registered increases of 12.3 and 6.7% over 60 cm in East–West and North–South directions, respectively. A greater plant spread in wider rows was earlier reported in rose-scented geranium (Prakasa Rao et al., 1988).

Like plant height, plant spread of rose-scented geranium was not influenced by intercropping indicating cornmint to be a non-competitive intercrop.

Table 2
Biomass yield (t/ha) of different harvests and total biomass yield (t/ha) of rose-scented geranium as influenced by row spacings and cropping systems

Treatments	First harvest	Second harvest	Third harvest	Fourth harvest	Total biomass yield
Spacings (cm)					
60 × 30	24.7	17.7	7.5	7.6	57.4
75 × 30	22.1	11.3	7.6	7.5	48.6
90 × 30	7.3	8.6	5.5	5.4	26.8
120 × 30	7.9	5.2	7.2	4.5	24.7
LSD[a] ($P = 0.05$)[b]	6.1	3.5	NS	1.8	7.3
Cropping systems					
Monocropping	15.6	11.0	7.1	6.5	40.2
Intercropping	15.5	10.7	7.0	6.3	39.5
LSD ($P = 0.05$)	NS[c]	NS	NS	NS	NS

[a] LSD, least significant difference.
[b] $P = 0.05$, probability level at 5%.
[c] NS, not significant.

Table 3
Essential oil yield (kg/ha) of different harvests and total essential oil yield (kg/ha) of rose-scented geranium as influenced by row spacings and cropping systems

Treatments	First harvest	Second harvest	Third harvest	Fourth harvest	Total essential oil yield
Spacings (*cm*)					
60 × 30	17.3	10.6	20.1	4.6	52.7
75 × 30	15.8	7.2	20.4	3.9	47.4
90 × 30	9.4	5.2	11.9	3.7	30.2
120 × 30	7.9	3.3	12.0	3.2	26.5
LSD[a] ($P = 0.05$)[b]	1.2	1.9	3.4	NS	4.4
Cropping systems					
Monocropping	12.7	6.8	16.2	4.0	39.7
Intercropping	12.6	6.6	16.0	3.9	39.1
LSD ($P = 0.05$)	NS[c]	NS	NS	NS	NS

[a] LSD, least significant difference.
[b] $P = 0.05$, probability level at 5%.
[c] NS, not significant.

3.1.3. Biomass yield

Biomass yields of first, second, fourth harvests and total biomass yield were significantly higher in 60 cm followed by 75 cm row spacings than in wider row spacings (Table 2), due to more number of taller plants per unit area, lower yield of weeds in these row spacings (Table 7), better interception of solar radiation (the inter and intra-row spaces were more completely covered by crop canopy (evident from plant spread data) in 60 and 75 cm row spacings) by the crop canopy and more efficient utilization of applied inputs such as irrigation water, fertilizers (in the absence of weeds) by the crop plants. The yield enhancements in 60 over 120 cm row spacing were: 212.7% (first harvest), 240.4% (second harvest), 68.9% (fourth harvest) and 132.4% (total yield).

Mono- and intercropping systems produced identical biomass yields revealing cornmint to be a compatible intercrop in rose-scented geranium. The total biomass yield of rose-scented geranium was similarly not affected by intercropping legumes (Narayana et al., 1986; Prakasa Rao et al., 1984, 1986; Rajeswara Rao et al., 2000). The yields of sugarcane and citronella remained unchanged by intercropping cornmint (Kothari et al., 1987; Singh and Ram, 1991).

3.1.4. Essential oil yield

Essential oil yields of individual harvests and total essential oil yield (Table 3) followed biomass yield trends, except in the fourth harvest where all the row spacings were equally productive. Essential oil yield is a product of biomass yield and essential oil concentration in the plants. The essential oil concentration was not influenced by row spacings in any of the harvests, hence the data were not presented. In this investigation, essential oil yield of various row spacings was mainly influenced by biomass yield, therefore, the trends were identical for both biomass and essential oil yields.

The essential oil yield increases in 60 over 120 cm row spacing were: 119.0% (first harvest), 221.2% (second harvest), 67.5% (third harvest) and 98.9% (total oil yield).

The differences in essential oil yields of individual harvests and total essential oil yield were not significant in sole and intercropping systems because of non-significant variations in biomass yields in these cropping systems. Legumes as intercrops in rose-scented geranium (Narayana et al., 1986; Prakasa Rao et al., 1984, 1986; Rajeswara Rao et al., 2000) and cornmint as intercrop in citronella (Singh and Ram, 1991) produced similar results.

3.1.5. Essential oil composition

Twenty-five components out of 91 peaks in the chromatogram (Fig. 1) constituting 95.2–96.5% of the aromatic oil were identified and tabulated. The chemical composition of the fragrant oil of rose-scented geranium was affected neither by row spacings (data not given) nor by cropping systems (Table 4). The geraniol percentage in palmarosa oil was similarly not influenced by intercropping the crop with legumes (Rajeswara Rao et al., 1993b). The quality of essential oil of rose-scented geranium produced in all the row spacings and both the cropping systems was evaluated as good and was readily accepted in the market.

3.2. Cornmint

3.2.1. Plant height

Significantly taller plants were observed in 60 and 75 cm row spacings possibly due to competition for light between rose-scented geranium and cornmint plants in these spacings (Table 5). Rose-scented geranium plants in these spacings effectively covered the inter-row spaces through their branches (Table 1, plant spread) potentially cutting off light to intercropped cornmint plants. Under this highly competitive environment, cornmint plants grew taller in these spacings. Intercropped cornmint plants in wider rows did not

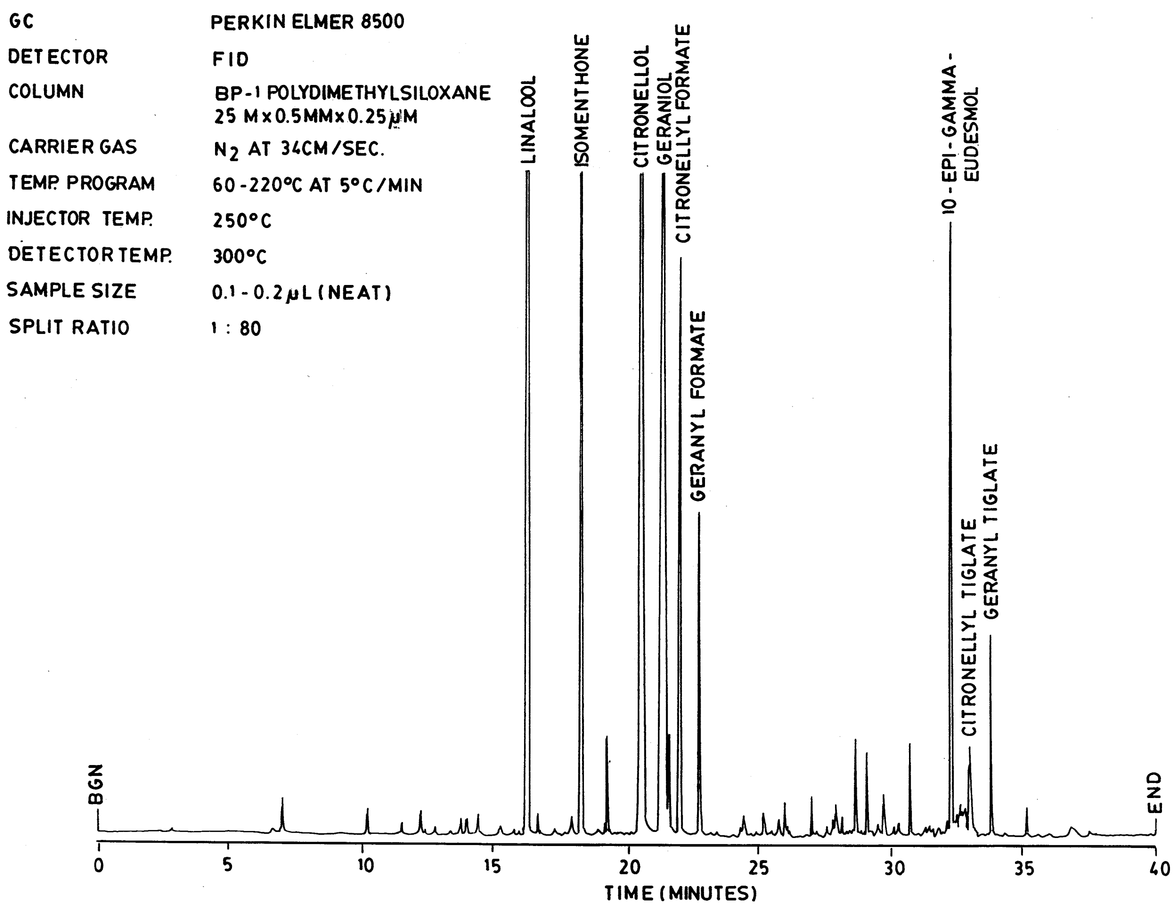

Fig. 1. Gas chromatogram of the essential oil of rose-scented greanium produced in semi-arid tropical climate.

Table 4
Chemical composition (% of essential oil) of the essential oil of rose-scented geranium in sole and intercropping systems

Compound	Retention index	Sole crop	Intercrop	Method of identification[a]
α-Pinene	935	0.2	0.2	a, b, c, d
β-Pinene	976	0.1	0.2	a, b, c, d
Limonene	1024	0.3	0.2	a, b, d
(*Z*)-β-Ocimene	1028	0.1	0.1	a, b, c, d
(*E*)-β-Ocimene	1042	0.2	0.2	a, b, d
cis-Linalool oxide (furanoid)	1063	0.2	0.1	a, b, d
trans-Linalool oxide (furanoid)	1076	0.1	0.2	a, b, d
Linalool	1088	13.3	13.0	a, b, c, d
cis-Rose oxide	1097	0.6	0.5	a, b, d
trans-Rose oxide	1107	0.4	0.4	a, b, d
Menthone	1139	0.6	0.4	a, b, d
Isomenthone	1149	7.2	7.4	a, b, d
Citronellol	1215	24.4	25.6	a, b, c, d
Geraniol	1242	28.0	27.3	a, b, c, d
Citronellyl formate	1261	4.8	4.0	a, b, c, d
Geranyl formate	1284	3.1	3.5	a, b, d
Geranyl acetate	1362	0.6	0.3	a, b, c, d
β-Caryophyllene	1422	0.5	0.4	a, b, c, d
6,9-Guaiadiene	1444	0.1	0.1	a, b, c, d
Citronellyl butyrate	1503	0.4	0.3	a, b, d
Geranyl butyrate	1534	0.4	0.6	a, b, c, d
2-Phenylethyl tiglate	1555	1.0	0.9	a, b, d
10-epi-γ-Eudesmol	1617	5.9	5.6	a, b, d
Citronellyl tiglate	1645	1.9	2.0	a, b, d
Geranyl tiglate	1675	2.1	1.7	a, b, d

[a] a, Retention time; b, Kovat's retention index; c, peak enrichment; d, mass spectra.

Table 5
Effect of row spacings and cropping systems on plant height, biomass yield and essential oil yield of cornmint

Treatments	Plant height (cm)	Biomass yield (t/ha)	Essential oil yield (kg/ha)
Spacings (*cm*)			
60 × 30	46.8	5.6	21.3
75 × 30	47.7	3.7	14.1
90 × 30	44.9	3.7	15.0
120 × 30	42.9	3.0	12.1
LSD[a] ($P = 0.05$)[b]	1.7	1.1	1.7
Cropping systems			
Monocropping	51.3	8.8	38.1
Intercropping	45.6	4.1	15.6
LSD ($P = 0.05$)	2.9	2.0	3.1

[a] LSD, least significant difference.
[b] $P = 0.05$, probability level at 5%.

experience such environment. The plants were taller by 9.1% in 60 over 120 cm row spacing.

Sole crop cornmint plants were taller by 12.5% to intercropped cornmint plants owing to absence of competition from rose-scented geranium and possibly also due to better availability of water and nutrients. Intercropped cornmint had to compete with companion crop for its water and nutrients needs inspite of their differences in root characteristics. In the present study, rose-scented geranium with its bush type of growth spreading laterally with numerous branches having big leaves (the leaf size is several times larger than cornmint leaves) was the dominant species and suppressed the growth of cornmint plants in intercropping system. Other mint species also suffered similar fate in association with more dominant sugarcane (Singh, 1998).

3.2.2. Biomass yield

The 60 cm row spacing produced 51.4% higher biomass yield than 75 and 90 cm row spacings and 86.6% more biomass than 120 cm row spacing (Table 5). These increases were attributed to greater plant density per unit area and lengthier plants in this treatment. Peppermint (*Mentha piperita* L.), bergamot mint (*Mentha citrata* Ehrh.), spearmint (*Mentha spicata* L.) and scotch spearmint (*Mentha gracilis* Sole) gave higher biomass yields when grown at higher density (two rows) than at lower density (one row) as intercrops in sugarcane (Singh, 1998).

The intercropped cornmint suffered 53.4% loss in biomass yield when compared with monocrop owing to lesser plant density (the sole crop had more number of rows per unit area than intercropped cornmint which occupied only 50% of the land area, the other 50% was occupied by rose-scented geranium), shorter plants and competition for resources with more dominant rose-scented geranium. Decreases in intercrop yields were earlier reported when the companion crop was rose-scented geranium (Muni Ram and Kumar, 1998; Rajeswara Rao et al., 2000). Biomass yield reductions in cornmint (Kothari et al., 1987; Randhawa et al., 1989) and other mint species (Kothari et al., 1987; Singh, 1998) were observed in intercropping system. Yield variations in cornmint intercropped with legumes or vegetables were also demonstrated (Singh et al., 1998a; Muni Ram et al., 1998).

3.2.3. Essential oil yield

The maximum essential oil yield was in 60 cm row spacing (76.0% more) and the minimum in 120 cm row spacing following differences in biomass yield in these treatments (Table 5). The other two row spacings were statistically on par.

The intercropped cornmint suffered 59.1% decrease in essential oil yield due to reduction in biomass yield in comparison with monoculture of cornmint. Essential oil yield reductions in intercropped mint species were recorded previously (Kothari et al., 1987; Randhawa et al., 1989; Singh, 1998; Singh and Ram, 1991).

3.2.4. Essential oil profile

Twenty-one compounds constituting 99.0% of the volatile oil were identified and tabulated. Though, cornmint suffered yield losses in intercropping system, the chemical profile of the aromatic oil was not influenced either by row spacings (data not presented) or by cropping systems (Table 6). Similar were the findings of Kothari et al. (1987), Muni Ram et al. (1998), Singh (1998). The quality of the essential oil of cornmint produced in different row spacings and cropping systems was considered as good and was readily accepted in the market.

3.3. Biomass yield of weeds

Increasing the row spacing significantly increased the biomass yield of weeds due to availability of uncovered interrow space for germination and growth of large number of weeds and probable less efficient utilization of applied inputs irrigation water and fertilizers by widely spaced crop plants (Table 7). However, reductions of 71.4, 80.0, 47.6, and 68.7% in the biomass yields of weeds in the first, second, third harvests and total yield of weeds, respectively, can be seen in 60 versus 120 cm row spacings. This was expected as tallest plants, which effectively covered the interrow space, thereby reducing weed growth were noted in 60 cm row spacing.

Intercropping successfully controlled weed growth leading to significant weed biomass yield decreases (42.1, 45.8, 30.4 and 40.0% in the first, second, third harvests and total yield of weeds, respectively) compared with monocropping. This was because of the ability of cornmint plants to develop overground runners and underground rhizomes, which occupied the interrow space in the intercropped treatments and restricted weed seeds germination and growth. The utility of intercrops to suppress growth and yield of weeds was demonstrated in other crops as well (Singh et al., 1986; Kothari, 1992; Rajeswara Rao et al., 1993a).

3.4. LER, ATER and LUE

The LER, ATER and LUE values were 1.45, 1.11 and 128.0%, respectively, clearly signifying the superiority of intercropping over monocropping of either of the two crops i.e. rose-scented geranium or cornmint. This advantage was mainly attributable to rose-scented geranium, which pro-

Table 6
Chemical composition (% of essential oil) of the essential oil of cornmint in sole and intercropping systems

Compound	Retention index	Sole crop	Intercrop	Method of identification[a]
α-Pinene	935	0.7	0.6	a, b, c, d
β-Pinene	976	0.6	0.3	a, b, c, d
Myrcene + 3-octanol	985	1.6	1.4	a, b, c, d
Limonene + 1,8-cineole	1024	1.5	1.2	a, b, d
(*Z*)-β-Ocimene	1028	0.1	0.1	a, b, c, d
(*E*)-β-Ocimene	1042	0.1	0.1	a, b, d
trans-Sabinene hydrate	1060	0.1	0.1	a, b, d
Linalool	1088	0.2	0.3	a, b, c, d
Menthone	1139	9.0	9.5	a, b, d
Isomenthone	1149	2.1	2.8	a, b, d
Neomenthol	1157	1.7	1.2	a, b, d
Menthol	1169	75.2	74.5	a, b, c, d
Isomenthol	1174	0.1	0.2	a, b, d
Pulegone	1219	1.3	1.9	a, b, c, d
Piperitone	1233	0.5	0.8	a, b, d
Methyl acetate	1280	3.8	3.0	a, b, c, d
β-Caryophyllene	1422	0.3	0.4	a, b, c, d
Germacrene D	1480	0.1	0.2	a, b, d
(*E*)-Nerolidol	1548	0.1	0.1	a, b, d

[a] a, Retention time; b, Kovat's retention index; c, peak enrichment; d, mass spectra.

Table 7
Yield of weeds (t/ha) in individual harvests and total yield of weeds (t/ha) as influenced by row spacings and cropping systems

Treatments	First harvest	Second harvest	Third harvest	Total yield of weeds
Spacings (cm)				
60 × 30	1.2	0.4	1.1	2.6
75 × 30	1.3	1.6	1.3	4.2
90 × 30	2.2	1.1	1.7	5.0
120 × 30	4.2	2.0	2.1	8.3
LSD[a] ($P = 0.05$)[b]	0.6	0.5	0.3	1.0
Cropping systems				
Monocropping	3.8	2.4	2.3	8.5
Intercropping	2.2	1.3	1.6	5.1
LSD ($P = 0.05$)	0.9	0.7	0.6	1.7

[a] LSD, least significant difference.
[b] $P = 0.05$, probability level at 5%.

duced identical yields in mono-and intercropping systems, whereby the yields of cornmint were obtained as bonus yields over and above that of rose-scented geranium in intercropping. Identical findings were reported by other investigators in rose-scented geranium (Prakasa Rao et al., 1986), mints (Kothari et al., 1987; Singh, 1998) and other crops (Rajeswara Rao and Singh, 1983).

3.5. Utilization of bio-wastes

The phytomass of cornmint after distillation (spent biomass) was dried in the Sun. A part of this dried spent biomass was used as fuel for running the distillation equipment and the ash obtained was added to the fields. The rest of the spent biomass was added to the fields and plowed in to serve as manure. The biomass of rose-scented geranium formed lumpy masses due to agglutination during distillation, therefore, could not be used as fuel for distillation unit. It was dried along with biomass of weeds, applied to the fields and plowed in to serve as manure. Thus, the spent biomass of cornmint and rose-scented geranium and weed biomass were beneficially recycled. The distillation water was let into the fields for irrigating the crops.

4. Conclusions

This field investigation demonstrated that:

(a) 60 × 30 cm (60 cm between the rows and 30 cm between the plants within the rows) spacing is optimum for rose-scented geranium for harvesting high biomass and essential oil yields and good quality essential oil;

(b) cornmint is a compatible intercrop in rose-scented geranium as it did not influence the growth, biomass and essential oil yields, quality of rose-scented geranium oil and produced additional yield of good quality cornmint oil in intercropping system and;

(c) intercropping rose-scented geranium with cornmint controlled weed growth and reduced total biomass yield of weeds by 40.0%.

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