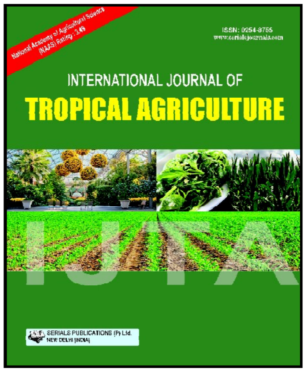

INTERNATIONAL JOURNAL OF TROPICAL AGRICULTURE

ISSN : 0254-8755

available at http: www.serialsjournals.com

Volume 36 • Number 4 • 2018

Furrow Irrigated Raised Bed Method a Viable Option to Enhance Productivity for Sustainable Cultivation of Rose-scented geranium (*Pelargonium graveolens* L. Herit.)

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Abstract: Rose-scented geranium (*Pelargonium graveolens* L. Herit.), an industrially important aromatic crop, produces an essential oil, which has high economic value and demand in national and international market due to its profound rose-like odour. A field experiment was conducted to develop a new agro-technology for quality cultivation of rose-scented geranium without increasing substantial inputs at CSIR-Central Institute of Medicinal and Aromatic Plants, Research Centre, Pantnagar. The productivity and essential oil quality of rose-scented geranium (*Pelargonium graveolens*) varieties, Bourbon, CIM-Pawan, CIMAP-Bio-G-171 were assessed and compared under different planting methods. The results of the experiment revealed that transplanting of rose-scented geranium on furrow irrigated raised bed (FIRB) 0.70 m wide provided significantly higher essential oil yield and yield attributes, and quality as compared to other methods of transplanting. Rose-scented geranium variety CIMAP-Bio-G-171 provided significantly higher plant height (75.0–77.3 cm), number of branches plant^{-1} (11–12), fresh herb yield (49.05–50.90 Mg ha^{-1}), oil content (0.20%), oil yield (99.0–100.9 L ha^{-1}), and quality oil under FIRB (1.2 m wide) as compared to other treatments. Major constituents of the oils were geraniol (24.0–31.4%), citronellol (22.3–28.0%), 10-*epi*-*ã*-eudesmol (8.0–9.2%), citronellyl formate (6.2–8.3%), isomenthone (6.3–7.5%), linalool (2.3–6.2%) and geranyl formate (2.8–5.3%). In conclusion, the transplanting of rose-scented geranium on FIRB (0.70 m) have potential to enhance the essential oil yield up to 58.26–59.14%, 28.56–30.29%, and 9.77–17.10% in cv. Bourbon, CIM-Pawan, CIMAP-Bio-G-171, respectively as compared to conventional transplanting method.

Keywords: Rose-scented geranium, transplanting method, variety, essential oil yield, productivity improvement

1. INTRODUCTION

Rose-scented geranium (*Pelargonium graveolens* L. Herit.) belongs to the family Geraniaceae, is an industrially important aromatic plant, producing essential oil with high economic value and demand in national and international market because of its profound rose-like odour. It is a high value, perennial aromatic shrub, originated from South Africa, Reunion Madagascar, Egypt and Morocco, and commercially cultivated in China, Egypt, Reunion, Morocco, and India for the production of quality geranium oil. The major producers and exporters of geranium oil are China and Egypt (Rajeshwara Rao, 2013). The geranium oil is most widely used in fragrance materials, rose-scented perfumes, and soaps. It possess rose-like fragrance, hence geranium oil is used as a substitute in many places for the too costly rose (*Rosa damascena*) oil, hence geranium oil also known as 'the poor man's rose oil' (Wells and Lis-Balchin, 2002). It has various types of industrially important medicinal and aromatic values (Matthews, 1995). Geranium oils are traditionally used to heal wounds, ulcers staunch bleeding, skin disorders, and to treat dysentery, diarrhoea, and colic (Matthews, 1995). Geranium is indispensable aromatherapy oil as well as considered as balancing oil for body and mind (Dorman and Deans, 2000). *P. graveolens* oils possess potent antifungal, antiplasmodial, antibacterial, antioxidant, immuno-modulating activities, and insecticidal, anticancer properties (Boukhris *et al*., 2015; Saraswathi *et al*., 2011).

The yield and essential oil composition of rose-scented geranium is influenced by various factors, namely varieties, climate, fertilizers management, time of the harvest, age of plant, storage of oil, growing in open and shade, date of transplanting, plant part used in distillation, season and weather, post-harvest storage, spacing, plant growth regulators, diseases, weeds, and height of harvest (Lis-Balchin, 2002; Rajeshwara Rao, 2013).

The demand of rose-scented geranium oil is on rise in national and international market, but the cultivable land is limited and non-expandable. So, the increasing demand of rose-scented geranium oil can be met by two options; first by developing new high yielding varieties, and secondly by development and application of new agro-technology that have potential to enhance the essential oil yield up to a significant level. Earlier, most of the research and development studies on rose-scented geranium were focused on variety development, nutrient management, post harvest storage effect, growing condition, quality planting material production, date of transplanting. However, the detailed scrutiny of the previous works on geranium makes clear that studies on transplanting method are scanty and untouched and mostly none of the researcher worked on the effect of transplanting methods on yield and quality production of geranium. Hence, the transplanting method can have potential to increase rose-scented geranium oil yield and ultimately total production up to significant level without increasing the additional input and land. Keeping the above view in mind, a field experiment was conducted to develop a new agro-technology for the quality cultivation of rose-scented geranium that can be affordable, economical, and sustainable in nature with wider societal impact.

2. MATERIALS AND METHODS

2.1. Experimental site

The field experiment was conducted to evaluate the transplanting method against the existing prevalent varieties of rose scented geranium, namely Bourbon, CIM-Pawan, CIMAP-Bio-G-171 at experimental farm, CSIR-Central Institute of Medicinal and Aromatic Plants, Research Centre, Pantnagar, Uttarakhand, India during 2015 and 2016. The experimental site is located between latitude 29° N and longitude 79.38° E, and at an altitude of 243 m above mean sea level. The experimental soil at

Pantnagar was sandy-loam in texture, neutral in reaction (7.4 pH), medium in organic carbon (0.58%), low in available nitrogen (145 kg ha^{-1}), and medium in available phosphorus (15 kg ha^{-1}) as well as in potassium (152 kg ha^{-1}).

2.2. Field preparation and transplanting methods

The well pulverized and leveled field was used for transplanting of rose-scented geranium. Quality farm yard manures at 10 ton ha^{-1} was applied in the field 30 days before transplanting during both the year. Soil was fertilized with nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O) at 100:60:40 kg ha^{-1}, respectively. The fertilizers were applied in geranium field as 1/3rd N and full dose of P_2O_5 and K_2O as basal, and 1/3rd N each at 25-30 DAT and 40-45 DAT, T_3- 100:60:40 kg NPK ha^{-1}. Existing prevalent varieties, namely Bourbon (V_1), CIM-Pawan (V_2), CIMAP-Bio-G-171 (V_3), of rose scented geranium were transplanted in two methods, conventional method or flat bed method (P_{-1}), furrow-irrigated raised bed method with 0.7 m and 0.3 m width of bed and channel (P_2), respectively. The transplanting of one month old rose-scented geranium rooted cutting was done at 50 × 50 cm inter-row and intra-row spacing.

2.3. Experimental design and details of treatments

The field experiment was laid out in a Factorial Randomized Block Design with three replications keeping two factors, two type of transplanting methods and three varieties of rose-scented geranium. The details of total treatment (Table 1) and total experimental units were 6 and 18, respectively. The numerical data obtained of all the components were subjected to statistical analysis of variance (ANOVA) using factorial randomized block design. The statistical analysis of data was done by following the standard procedures (Snedecor and Cochran, 1967).

Table 1
Treatment details of the experiment

Variety	*Transplanting methods*	
	P_1 (Conventional method or flat bed method)	*P_2 (Furrow-irrigated raised bed method with 0.7 m and 0.3 m width of bed and channel, respectively)*
V_1 (Bourbon)	P_1V_1	P_2V_1
V_{-2} (CIM-Pawan)	P_1V_2	P_2V_2
V_{-3} (CIMAP Bio-G-171)	P_1V_3	P_2V_3

2.4. Transplanting of the crop

The good and healthy 30 days old rooted cutting of rose-scented geranium (variety Bourbon, CIM-Pawan, and CIMAP Bio-G-171) were transplanted in the experimental field in the first fortnight of February, during 2015 and 2016. Total two weeding were done on 25th and 45th days after transplanting. The transplanted rose-scented geranium field was irrigated as per the need of crop during both the year of experiment.

2.5. Growth and yield characters

The rose-scented geranium crop was harvested at 120 days after transplanting (DAT) in the first fortnight of June during both the years. The observations pertaining to plant height (cm), no. of primary branches per plant, fresh herb yield (q ha^{-1}), essential oil (%), and essential oil yield (L ha^{-1}), were recorded at the time of harvest. Essential oil yield (L ha^{-1}) was calculated by multiplying fresh herb yield (q ha^{-1}) and oil content (%).

2.6. Isolation of the essential oil

Freshly harvested rose-scented geranium varieties transplanted in different method of transplanting were subjected to hydrodistillation process in a Clevenger apparatus for 3 h for the essential oil isolation (Clevenger, 1928). The essential oil was measured directly in the extraction burette and content (%) was calculated as volume (mL) of essential oil per 100 g of fresh biomass. The essential oil samples were dehydrated over Na_2SO_4 (anhydrous) and kept in a cool and dark place until their analyses.

2.7. GC and GC-MS analysis

GC analysis of essential oils was carried out on a Nucon gas chromatograph (5765) equipped with DB-5 (30 m ´ 0.32 mm; 0.25 µm film thickness) fused silica capillary column and flame ionization detector (FID). Hydrogen was used as carrier gas at 1.0 ml min^{-1}. Temperature programming was done from 60 - 230 °C at 3 °C min^{-1}. The injector and detector temperatures were 220 °C and 230 °C, respectively. The injection volume was 0.03 µL neat with a split ratio of 1:40. GC-MS analysis of the essential oil was carried out on a Clarus 680 GC interfaced with a Clarus SQ 8C mass spectrometer of PerkinElmer fitted with Elite-5 MS fused-silica capillary column (5% phenyl polysiloxane, 30 m × 0.25 mm internal diameter, film thickness 0.25 µm). The column temperature was programmed from 60 °C to 240 °C, at 3 °C min^{-1}, and programmed to 270 °C at 5 °C min^{-1}, using helium as a carrier gas at a flow rate of 1.0 mL min^{-1}. The injector temperature was 250 °C and MS conditions were: EI mode operating at 70 eV, transfer line and source temperatures 250 °C, injection size 0.03 µL neat, split ratio 1:50, mass scan range 40–500 amu. Identification of the essential oil constituents was performed on the basis of retention index, MS Library search (NIST and WILEY), and by comparing the MS and retention index data with literature (Adams, 2007). The relative amounts of individual components were calculated based on the relative peak areas (FID response), without using correction factor.

3. RESULTS AND DISCUSSION

3.1. Plant height

The plant height of rose-scented geranium (Table 2) clearly showed significant differences due to transplanting method and varieties. The mean plant height of rose-scented geranium was found to be significantly higher (75.4 cm and 78.1 cm) under

Table 2
Effect of varieties and transplanting methods on growth attributes of rose-scented geranium (*Pelargonium graveolens* L. Herit.)

Parameters	*Plant height (cm)*						*Branches plant^{-1}*					
	2015			*2016*			*2015*			*2016*		
Treatments	P_1	P_2	*Mean*	P_1	P_2	*Mean*	P_1	P_2	*Mean*	P_1	P_2	*Mean*
V_1	58.3	72.3	65.3	61.7	75.0	68.3	13.0	13.0	13.0	14.0	14.0	14.0
V_2	70.0	76.0	73.0	72.3	78.7	75.5	12.0	11.0	11.0	13.0	11.0	12.0
V_3	72.0	78.0	75.0	74.0	80.7	77.3	12.0	10.0	11.0	13.0	11.0	12.0
Mean	66.8	75.4		69.3	78.1		12.0	11.0		13.0	12.0	12.0
Analysis	P	V	P×V	P	V	P×V	P	V	P×V	P	V	P×V
$SEm_{\pm}$	0.26	0.39	0.79	0.26	0.39	0.77	0.07	0.11	0.22	0.12	0.18	0.36
$LSD_{(0.05)}$	0.83	1.24	2.48	0.81	1.22	2.44	0.23	0.35	NS	0.38	0.56	NS

P_{-1}- Conventional method or flat bed method; P_2- Furrow-irrigated raised bed method with 0.7 m and 0.3 m width of bed and channel, respectively; V_1- Bourbon; V_2- CIM-Pawan; V_3- CIMAP Bio-G-171.

furrow-irrigated raise bed (FIRB) with 0.7 m bed width (P_2) as compared to conventional method of transplanting (flat bet method) during 2015 and 2016, respectively. Among the varieties, CIMAP-Bio-G-171 (V_3) recorded significantly highest plant height (75.0–77.3 cm) compared to 73.0–75.5 cm and 65.3-–68.3 cm in CIM-Pawan (V_2) and Bourbon (V_1), respectively. The interaction effect between transplanting method and varieties also showed significant differences. The significantly highest plant height (78.0–80.7 cm) was recorded in CIMAP Bio-G-171 under transplanting of geranium on furrow-irrigated raise bed (FIRB) with 0.7 m width as compared to other treatments.

3.2. Branches per plant

Methods of transplanting employed in rose-scented geranium showed significant differences in number of branches plant^{-1} (Table 2). Significantly higher number of branches (12–13 plant^{-1}) was observed in rose-scented geranium transplanted on FIRB (P_2) as compared to conventional method with 11–12 branches plant^{-1}. Scrutiny of data depicted that significantly higher number of branches 13 and 14 plant^{-1} was recorded in Bourbon (V_1), followed by 11 and 12 plant^{-1} during 2015 and 2016, respectively with similar number in V_2 and V_3. The non-significant differences were observed between transplanting method and varieties.

3.3. Fresh herb yield

The fresh herb yield of rose-scented geranium was significantly influenced by different transplanting methods and varieties (Table 3). Transplanting of rose-scented geranium on FIRB (P_2) recorded significantly highest fresh herb yield 51.72 Mg ha^{-1} and 53.13 Mg ha^{-1} i.e. 33.43% and 31.54% higher during 2015 and 2016; respectively, as compared to conventional method of transplanting. Among the varieties, CIMAP Bio-G-171 (V_3) recorded significantly highest fresh herb yield 49.05 Mg ha^{-1} and 50.90 Mg ha^{-1} followed by CIM-Pawan (45.33–46.75 Mg ha^{-1}), and lowest was recorded in Bourbon (41.33–42.63 Mg ha^{-1}), during both the years. All of three varieties viz., Bourbon (V_1), CIM-Pawan (V_2), and CIMAP Bio-G-171 (V_3) recorded statistically similar fresh herb yield 51.00–52.50 Mg ha^{-1} and 52.73–53.70 Mg ha^{-1} during 2015 and 2016 respectively, under FIRB method of transplanting.

Table 3
Effect of varieties and transplanting methods on yield attributes of rose-scented geranium (*Pelargonium graveolens* L. Herit.).

Parameters	*Fresh herb yield (Mg ha^{-1})*						*Oil content (%)*						*Oil yield (L ha^{-1})*					
	2015			*2016*			*2015*			*2016*			*2015*			*2016*		
Treatments	P_1	P_2	*Mean*	P_1	P_2	*Mean*	P_1	P_2	*Mean*	P_1	P_2	*Mean*	P_1	P_2	*Mean*	P_1	P_2	*Mean*
V_1	31.67	51.00	41.33	32.53	52.73	42.63	0.20	0.19	0.20	0.19	0.19	0.19	62.3	98.6	80.4	62.9	100.1	81.5
V_2	39.00	51.67	45.33	40.53	52.97	46.75	0.20	0.20	0.20	0.20	0.20	0.20	77.9	101.5	89.7	80.9	104.0	92.5
V_3	45.60	52.50	49.05	48.10	53.70	50.90	0.20	0.20	0.20	0.20	0.20	0.20	91.2	106.8	99.0	96.2	105.6	100.9
Mean	38.76	51.72		40.39	53.13		0.20	0.20		0.20	0.20		77.1	102.3		80.0	103.2	
Analysis	P	V	P×V	P	V	P×V	P	V	P×V	P	V	P×V	P	V	P×V	P	V	P×V
SEm$_{\pm}$	0.25	0.38	0.76	0.29	0.44	0.88	0.001	0.001	0.002	0.001	0.001	0.002	0.51	0.76	1.52	0.50	0.75	1.50
LSD$_{(0.05)}$	0.80	1.20	2.39	0.93	1.39	2.78	NS	NS	NS	NS	NS	NS	1.59	2.39	4.78	1.58	2.37	4.74

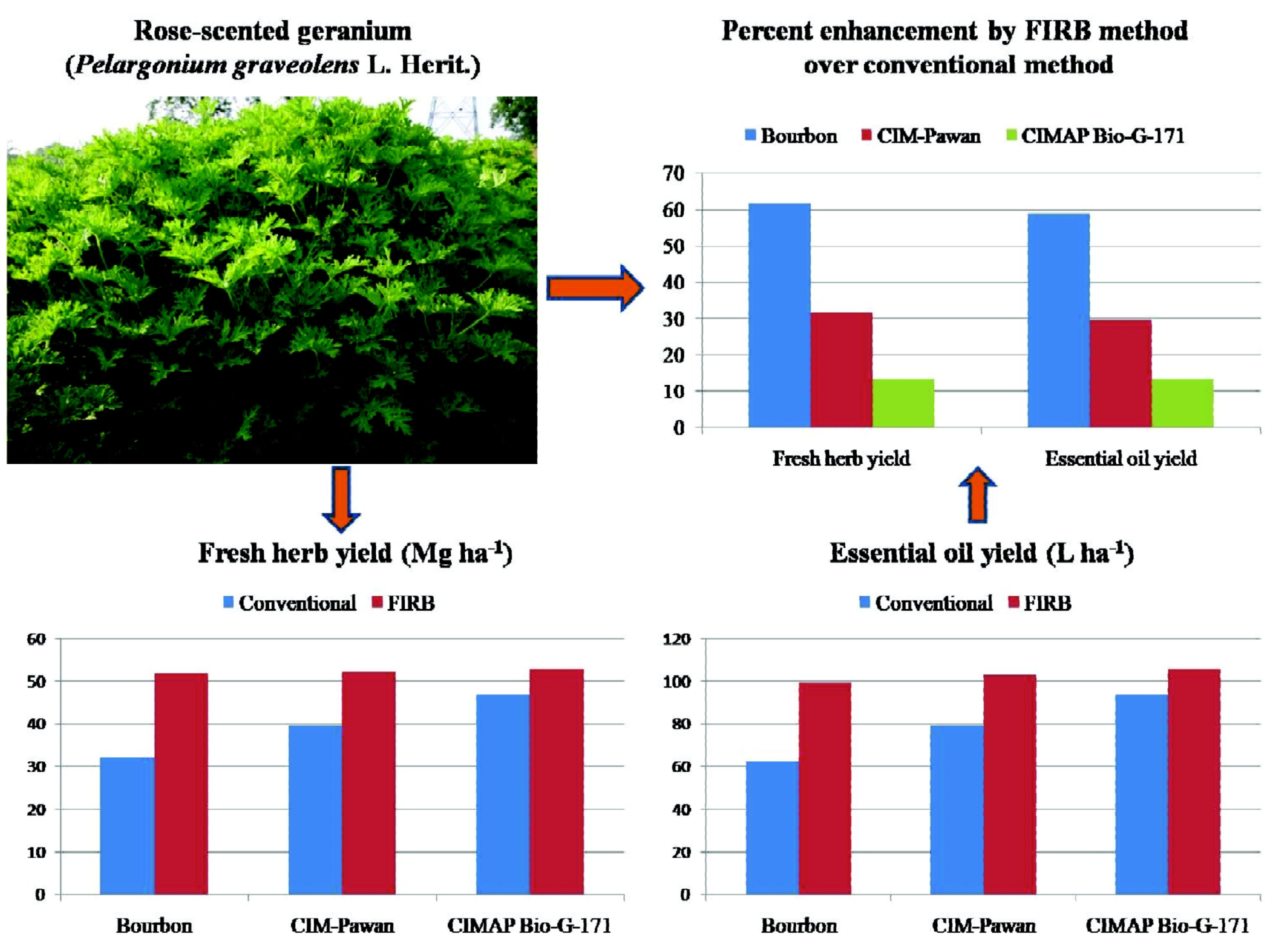
P_{-1}- Conventional method or flat bed method; P_2- Furrow-irrigated raised bed method with 0.7 m and 0.3 m width of bed and channel, respectively; V_1- Bourbon; V_2- CIM-Pawan; V_3- CIMAP Bio-G-171.

3.4. Essential oil content

In general, all varieties recorded non-significant variation with respect of the oil content under different method of transplanting (Table 3). The essential oil content in all the treatment varies from 0.19–0.20% during both the years

3.5. Essential oil yield

The data summarized in Table 3 makes it clear that the transplanting methods and varieties as well as their interaction showed significant differences with each other. Transplanting of rose-scented geranium at furrow irrigated raised bed method with 0.7 m and 0.3 m width of bed and channel, respectively (P_2) recoded significantly highest oil yield 102.3–103.2 L ha^{-1} as compared to conventional method of transplanting, recoded 77.1–80.0 L ha^{-1}, during both the years. Rose-scented geranium variety CIMAP Bio-G-171 recorded significantly highest essential oil yield 105.6–106.8 L ha^{-1} under FIRB transplanting method (P_2- Furrow-irrigated raised bed method with 0.7 m and 0.3 m width of bed and channel, respectively) during 2015 and 2016, respectively. In overall, the transplanting of rose-scented geranium on FIRB (0.7 m) have potential to enhance essential oil yield up to 58.26–59.14%, 28.56–30.29%, and 9.77–17.10% in Bourbon, CIM-Pawan, CIMAP Bio-G-171, respectively as compared to conventional method.



Graphical Abstract

3.6. Essential oil composition

The essential oils obtained from three rose-scented geranium varieties grown under different planting methods were analyzed using GC-FID and GC-MS. All together, 41 constituents, representing 92.1–94.4% of the total oil compositions were identified (Table 4). Major constituents of the oils were geraniol (24.0–31.4%), citronellol (22.3–28.0%), 10-*epi*-*γ*-eudesmol (8.0–9.2%), citronellyl formate (6.2–8.3%), isomenthone (6.3–7.5%), linalool (2.3–6.2%), geranyl formate (2.8–5.3%), germacrene D (1.5–2.5%), geranyl tiglate (1.7–2.2%) and 2-phenyethyl tiglate (0.1–1.0%). Although the oils of different varieties were comparable in qualitative composition; however they differ somewhat in their quantitative compositions due to transplanting methods. In variety Bourbon (V_1), the contents of linalool, citronellol and citronellyl formate were slightly higher in flat bed method (P_1) as compared to furrow-irrigated raised bed (P_2). In variety CIM-Pawan, the amount of citronellol, geraniol and citronellyl formate were recorded relatively higher in P_1 as compared to P_2; however its reverse was true for linalool, isomenthone, geranyl formate, and 10-*epi*-*γ*-eudesmol. Further, in variety CIMAP-Bio-G-171, the amount of isomenthone, geraniol, geranyl formate, germacrene D and 10-epi-γ-eudesmol were recorded relatively higher in P_1 as compared to P_2, while its reverse trend was noticed for linalool, citronellol, and citronellyl formate. Moreover, free rhodinol (linalool + geraniol + citronellol) content was relatively higher in P_2 as compared to P_1 in variety V_1 and V_3. However, in variety V_2, free rhodinol was higher in P_1 as compared to P_2.

Table 4
Essential oil composition of rose-scented geranium (*Pelargonium graveolens* L. Herit.) varieties grown under different planting methods

S. no.	*Compound*	*Content (%)*					
		P_1			P_2		
		V_1	V_2	V_3	V_1	V_2	V_3
1.	(3*Z*)-Hexenol	0.2	t	0.4	0.2	-	0.2
2.	α-Pinene	0.3	0.3	0.2	0.2	0.4	0.3
3.	Sabinene	t	0.1	-	-	-	t
4.	Myrcene	0.1	0.1	0.1	0.1	0.6	t
5.	α-Phellandrene	0.1	0.1	0.1	0.1	-	0.1
6.	p-Cymene	t	t	-	-	-	-
7.	Limonene	0.2	0.2	0.2	0.1	0.2	0.3
8.	(*Z*)-β-Ocimene	0.1	t	0.1	t	-	0.1
9.	(*E*)-β-Ocimene	t	t	0.1	t	-	0.1
10.	*cis*-Linalool oxide†	0.1	0.1	0.1	t	t	0.1
11.	*trans*-Linalool oxide†	t	0.1	-	-	-	0.1
12.	Linalool	3.8	2.8	4.3	2.3	4.8	6.2
13.	*cis*-Rose oxide	0.2	0.3	0.1	0.2	0.9	0.2
14.	*trans*-Rose oxide	0.1	0.1	0.1	0.1	t	0.1
15.	Menthone	0.2	0.3	0.3	0.1	0.2	0.2
16.	Isomenthone	6.4	6.5	7.2	6.3	7.5	6.7

contd. table 4

S. no.	Compound	Content (%)					
		P_1			P_2		
		V_1	V_2	V_3	V_1	V_2	V_3
17.	Menthol	0.1	0.1	0.2	0.2	-	0.2
18.	α-Terpineol	0.2	0.1	0.3	0.1	0.2	0.3
19.	Citronellol	25.0	28.0	22.9	23.1	22.3	26.7
20.	Neral	0.4	0.3	0.4	0.5	0.5	t
21.	Geraniol	25.0	25.3	27.5	31.4	24.0	25.7
22.	Citronellyl formate	8.6	8.3	6.2	6.6	7.0	7.1
23.	Geranyl formate	3.4	3.5	3.3	3.5	5.3	2.8
24.	Citronellyl acetate	0.1	0.1	0.2	0.1	t	0.1
25.	α-Copaene	0.3	0.3	0.2	0.3	0.4	0.1
26.	Geranyl acetate	0.8	0.9	0.7	0.8	0.9	0.8
27.	β-Bourbonene	t	0.1	-	0.1	-	t
28.	(*E*)-Caryophyllene	0.8	0.9	1.0	1.0	1.3	0.8
29.	Citronellyl propionate	0.4	0.4	0.4	0.3	0.7	0.4
30.	α-Humulene	0.3	0.4	0.3	0.2	0.4	0.3
31.	*allo*-Aromadendrene	0.3	0.2	0.2	0.2	0.7	0.2
32.	Geranyl propionate	1.0	0.2	0.3	0.6	t	0.6
33.	Germacrene D	2.1	2.5	2.2	2.3	2.4	1.5
34.	Citronellyl butyrate	0.2	0.1	-	0.1	-	0.1
35.	Geranyl butyrate	0.6	0.1	t	0.2	0.3	0.3
36.	Caryophyllene oxide	t	-	-	0.1	-	-
37.	2-Phenylethyl tiglate	0.7	0.7	0.9	0.7	0.1	1.0
38.	10-epi-*ã*-Eudesmol	8.2	8.1	9.2	8.4	9.1	8.0
39.	Geranyl valerate	0.5	0.5	0.6	0.3	0.5	0.5
40.	Citronellyl tiglate	0.4	0.4	0.1	0.3	0.3	0.3
41.	Geranyl tiglate	2.1	1.9	1.7	2.2	1.7	1.8
	Total identified (%)	93.3	94.4	92.1	93.3	92.7	94.3

P_{-1}- Conventional method or flat bed method; P_2- Furrow-irrigated raised bed method with 0.7 m and 0.3 m width of bed and channel, respectively; V_1: Bourbon; V_2: CIM-Pawan; V_3: CIMAP Bio-G-171; †Furanoid; t: trace (component <0.05%).

3.7. Discussions

Rose-scented geranium transplanted on FIRB (P_2) produced significantly higher fresh herb yield (51.72–53.13 Mgha^{-1}) and essential oil yield (102.3–103.2 L ha^{-1}) as compared to conventional method of transplanting. The transplanting method P_2 showed 31.54–33.43% and 19.42–29.00% mean improvement in fresh herb yield and essential oil yield, respectively, over conventional method. It is also clear from the data essential oil content have not influenced by transplanting method, hence the improvement in oil yield was due to enhancement in fresh herb yield production. These enhancements in fresh herb yield and essential oil yield might be due to transplanting of rose-scented geranium on FIRB (0.7 m) which provided better utilization of water, nutrient, and accumulation of furrow slice on FIRB than conventional method. These results are supported by the earlier finding of the various researchers on other crops (Majeed *et al.*, 2015; Singh *et al.*, 2012; Upadhyay *et al.*, 2014).

4. CONCLUSIONS

The transplanting of rose-scented geranium variety CIMAP Bio-G-171 on furrow irrigated raised bet (0.7 m) was recorded highest plant height (78.0–80.7 cm) fresh herb yield (52.5–53.7 Mg ha $^{-1}$), essential oil content (0.20%), essential oil yield (105.6–106.8 L ha $^{-1}$) as compared to others treatments. The transplanting of rose-scented geranium on FIRB (0.7 m) was able to enhance the essential oil yield up to 58.26–59.14%, 28.56–30.29%, and 9.77–17.10% in Bourbon, CIM-Pawan, CIMAP Bio-G-171; respectively as compared to conventional method. Finally, it was concluded that farmers should adopt FIRB method for quality cultivation of rose-scented geranium, which emerged as an affordable, sustainable and profitable practice.

ACKNOWLEDGEMENTS

Authors are thankful to the Council of Scientific and Industrial Research, New Delhi, for financial support (Project: BSC 0110). We also thank the Director, CSIR-CIMAP Lucknow for contentious support and encouragement.

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