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ORIGINAL PAPER

Vermicompost Application in Different Intercropping Patterns Improves the Mineral Nutrient Uptake and Essential Oil Compositions of Sweet Basil (*Ocimum basilicum* L.)

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Abstract

Only a few studies have hitherto investigated the effects of the application of organic fertilizers in intercropping systems on the plant essential oil (EO) productivity. Hence, this work has aimed to study the effect of different intercropping patterns on EO quality and quantity of sweet basil (*Ocimum basilicum* L.) under vermicompost application. In the present study, the cropping patterns consisted of 1B:1CB, 2B:2CB, 3B:2CB, and 4B:2CB (basil: common bean) as well as the pure culture of both crops and fertilizer treatments including usage or non-usage of vermicompost. The maximum seed yield of common bean (2786 kg ha^{-1}) and dry matter yield of basil in the first (261.5 g m^{-2}) and second harvests (214.7 g m^{-2}) were recorded in the pure cultures fertilized with vermicompost. In addition, the nutrient uptake rate of macronutrients and micronutrients in both plants after application of vermicompost improved in intercropping patterns. In both harvests, the maximum EO content of basil (0.84% in the first harvest and 0.69% in the second harvest) was observed at the cropping ratio of 3B:2CB fertilized with vermicompost. Chemical analysis, achieved by GC–MS, evidenced 1,8-cineole, linalool, methyl chavicol, α-*trans*-bergamotene, methyl eugenol, and *epi*-α-cadinol as the main basil EO constituents in both harvests. The highest increment level for most ofEO constituents, nutrient uptake, and land equivalent ratio (1.52) were obtained in the intercropping pattern of 3B:2CB fertilized with vermicompost. In general, the intercropping pattern of 3B:2CB after use of vermicompost can improve the EO productivity and quality of basil. This intercropping pattern was accompanied by the increment of nutrient uptake. Therefore, this treatment can be introduced as a valid and sustainable strategy to replace chemical fertilizer and plant monoculture.

Keywords Basil · Cropping patterns · Essential oil · Linalool · Nutrient uptake · Vermicompost

1 Introduction

Application of organic fertilizer is a major approach to manage soil fertility and plant nutrition which can alleviate chemical contaminations and preserve biodiversity of the soil and the quali-quantitative yield of crops which in turn are expected to be increased in sustainable agricultural systems (Liu et al. 2011; Emami Bistgani et al. 2018). Nowadays,

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the application of organic fertilizers for improving the crops' productivities is increasing in developing countries (Parastesh et al. 2019). Vermicompost, as a biological organic fertilizer, promotes the growth of the plants by increasing the soil microbial activity, porosity, penetrability, nutrient uptake, and gradual release of nutrients (Coulibaly et al. 2018). An advantage of vermicompost is its higher nutrient contents, such as nitrogen, phosphorous, and potassium, as compared to other organic fertilizers (Parastesh et al. 2019). Vermicompost contains a great deal of humic matter that improves the moisture retention capacity of soils, thereby inhibiting the leaching of nutrients and soil erosion and providing a good growing medium for roots (Rakkini et al. 2018; Zaremanesh et al. 2017). Undoubtedly, it is imperative to employ ecological principles in a context of alternative, eco-friendly agriculture with the aim of replacing the use of chemical fertilizers for cleaner production of medicinal and crop plants (Rezaei-Chiyaneh et al. 2020).

Medicinal and aromatic plants (MAPs) are reservoirs of secondary metabolites such as EOs, alkaloids, terpenoids, glycosides, and phenolic compounds which are exploited in several fields including pharmaceuticals, aromatherapy, perfumery, cosmetics, and food industries (Morshedloo et al. 2018; Mumivand et al. 2019; Pavela et al. 2020). Increasing the yield of secondary metabolites is one of the major challenges in the production of MAPs. Organic fertilizers improve the secondary metabolism in EO-bearing plants by increasing the available nutrients (Emami Bistgani et al. 2018; Rostaei et al. 2018).

The genus *Ocimum* sp. belongs to the Lamiaceae family and consists of more than 150 species throughout the world (Akbari et al. 2018). Among different *Ocimum* species, sweet basil (*O. basilicum* L.) is definitely one of the most important herbs on a commercial scale (Zahran et al. 2020). Sweet basil can be easily grown in different climates and soil conditions and is generally preferred to other *Ocimum* species for its higher quality of EO (Damalas 2019). In addition, sweet basil EO is endowed with antibacterial (Akbari et al. 2018), antifungal (Lemos et al. 2005), antimalarial (Ezekwesili et al. 2004), and insecticidal (Rodríguez-González et al. 2019) properties. Basil EO composition consists of different classes of metabolites including monoterpenoids (e.g., limonene, linalool, camphor, 1,8-cineole, citral, and geraniol), phenylpropanoids (e.g., methyl chavicol, eugenol, and methyl eugenol), and sesquiterpenoids (e.g., α-bisabolene, α-*trans*-bergamotene, β-bisabolene, β–caryophyllene, and β-elemene) (Akbari et al. 2018; Burducea et al. 2018).

Intercropping patterns, in which priority is given to the use of ecological and environmentally friendly methods, are of crucial importance for the improvement of the production of MAPs (Vafadar-Yengeje et al. 2019; Rezaei Chiyaneh et al. 2020). In developing countries, intercropping is known as a sustainable agricultural strategy that provides more than 15% of the world's food and feed supply (Liu et al. 2017). Intercropping is the simultaneous planting of two or more plant species at a certain time and area (Ofori and Stern 1987). In comparison with monocropping, this intercropping pattern shows several advantages such as increasing ecological and economic diversity and stability of the ecosystems; enhancing yield per unit area; improving environmental factors such as land, light, water and nutrients; and mitigating the problem of pests and diseases (Duchene et al. 2017; Kassam and Brammer 2013; Latati et al. 2018).

Among various cropping patterns, intercropping legumes with other plants such MAPs has shown a significant potential for improving the EO quantity and quality, which is based on a more efficient exploitation of available resources and also N transfer from legumes to the companion plants (Génard et al. 2016; Rezaei-Chiyaneh et al. 2020).

Given the importance of MAPs such as sweet basil and the use of sustainable farming systems for improving the quality and quantity of EOs, we have conducted this research to elucidate and extend future sustainable practices for MAP production.

We hypothesized that (i) intercropping of sweet basil with common bean under application of vermicompost can increase the productivity and EO quality of basil, (ii) vermicompost and intercropping will improve the uptake of macro- and micronutrients, and (iii) application of vermicompost in the intercropping system will increase the land use efficiency (LER index).

2 Materials and Methods

2.1 Study Area

The experiment was conducted during the 2016 and 2017 growing seasons (May–August 2016 and May–August 2017) in the city of Naqadeh, Western Azerbaijan, Iran (longitude 45° 24′ E, latitude 38° 52′ N, altitude 1318 m). Based on the physical and chemical properties of experimental soil (depth of 0–30 cm), the texture soil was silty clay with a pH of 7.4. The EC content, organic matter, and total N, P, and K content were 0.74 dS m^{-1}, 0.92%, 0.08%, 13.4 mg kg^{-1}, and 262 mg kg^{-1}, respectively. The experimental area has arid and semi-arid climate conditions. The climatic data of experimental region was obtained from the Iran Meteorological Organization (IRIMO) and the chemical properties of vermicompost, which are shown in Tables 1 and 2, respectively.

2.2 Experimental Design

A factorial experiment was performed with three replications and 12 treatments, based on the Randomized Complete Block Design (RCBD). The planting patterns consisted of "1 row of

Table 1 Mean monthly temperature and precipitation in 2016 and 2017

Month	Averaged temperature (°C)		Averaged precipitation (mm)	
	2016	2017	2016	2017
January	2.3	− 3.1	69.3	10.2
February	6.5	− 1.8	11.4	26.4
March	9.3	8	26.4	38.1
April	14.7	14.6	73.1	38.6
May	19.5	20.8	35.3	12.8
June	23.7	25.6	18	2.0
July	27.1	28.8	0.4	2.2
August	27.9	28.6	0.0	0.6
September	22.6	24.6	0.0	0.0
October	15.5	16.2	7.0	0.0
November	7.4	9.3	8.0	33.2
December	−0.4	4.7	74.2	16

basil + 1 row of common bean (1B:1CB),” “2 rows of basil + 2 rows of common bean (2B:2CB),” “3 rows of basil + 2 rows of common bean (3B:2CB),” and “4 rows of basil + 2 rows of common bean (4B:2CB),” as well as pure culture of both crops as the first factor and the fertilizer treatments including usage or non-usage of vermicompost as the second factor. The number of rows for common bean pure culture, basil pure culture, and 1B:1CB, 2B:2CB, 3B:2CB, and 4B:2CB intercropping ratios were 6, 6, 6, 12, 15, and 18, respectively. The optimum plant density for common bean and sweet basil was adjusted to 25 and 16.7 plants m^{-2}, respectively. Both plants were sown in rows 4 m long and with a distance of 40 cm each row. The on-row spacing for common bean and sweet basil was 10 and 15 cm, respectively.

2.3 Agronomic Practices

The plant seeds were from Urmia local landraces with green leaves for basil and COS16 varieties for common bean. The seeds of common beans and sweet basil were simultaneously sown on the 5th of May 2016 and 2017. The seeds of common beans were first placed in a plastic bag and a sugar solution (20%), and inoculated (100 g inoculant per kg ha^{-1} seeds) with *Rhizobium phaseoli*; then, the seeds were shade-dried and sown. To facilitate the emergence of plants, seeds were irrigated immediately 1 day after sowing, and the next irrigations were conducted every 7 days by a furrow system as per local climate and agronomic practices. Weeds were controlled manually as required during the growing season. Vermicompost, at a rate of 10 t ha^{-1}, was uniformly dispersed over the treatments before sowing then incorporated into the soil. The experiment was carried out as a low-input system;

Table 2 Chemical properties of vermicompost

pH	EC (dS m^{-1})	Organic matter (%)	Total N (%)	Phosphorus (%)	Potassium (%)	Ca (%)	Na (%)	Mg (%)	Fe (%)	Cu (%)	Zn (%)	Mn (%)
7.1 ± 0.15	4.5 ± 0.09	7.6 ± 0.11	1.7 ± 0.02	1.1 ± 0.01	0.8 ± 0.021	2.5 ± 0.09	0.8 ± 0.012	0.5 ± 0.025	0.5 ± 0.018	0.3 ± 0.011	0.6 ± 0.029	0.7 ± 0.032

therefore, during the growing seasons, no chemical fertilizers, herbicides, or pesticides were applied.

2.4 Preparation of Vermicompost

An area of 5 m^2 was considered for the production of vermicompost; then, well-rotted cow manure was spread over an area of 50 m long, 1 m wide, and 40 cm thick. However, prior to production, well-rotted cow manure was washed away with water in order to decrease the salt. After 1 day when the bed moisture reached about 65–70%, 8 to 10 kg of adult earthworms (*Eisenia foetida*) with some previous substrate (to reduce losses and increase compatibility) were added per ton of cow manure. Daily watering was arranged to provide sufficient moisture (60 to 70%). Attempts were also made to keep the ambient temperature at 23 ± 3 °C. Vermicompost was stirred and aerated with a rake every 7 to 10 days to supply enough air and oxygen inside the vermicompost, which became ready after 3 months. Irrigation was stopped before harvesting. When the surface layer dried, the earthworms were transferred to the lower part due to the moisture in the lower layers. Vermicompost was harvested from the upper layers, accordingly.

2.5 Determination of Seed Yield of Common Bean and Dry Matter Yield of Basil

The seeds of common bean were harvested on the 29th of August 2016 (first year) and the 25th of August 2017 (second year) when the pods turned yellow. Basil biomass was harvested twice at a 50% flowering of each plot. Prior to harvesting, the external rows at each experimental plot were cut at the ground level, as they were not in the harvestable area. Harvesting was done by cutting the plants when 10 cm height from the soil. Finally, dry matter yield of basil and seeds of common bean were obtained by harvesting the four central rows in a 3.2-m^2 area.

The first harvest was performed on the 8th and 12th of July 2016 and the second harvest on the 14th and 17th of August 2017. Basil samples were dried at 25 °C in the dark for 12 days. In addition to determining the dry weight of the common beans, the seeds were separately weighed to find out seed yield. The final seed yield of common beans and dry matter yield of basil were measured as kg ha^1 and g m^2, respectively.

2.6 Plant Nutrient Analysis

For measuring macro- and micronutrient concentration of basil leaves and common bean seeds, samples were digested according to the Jones and Case (1990) methods. For this purpose, the ash weight of basil leaves and common bean seeds was calculated by grinding 10 g of sample to obtain a fine powder and heating the resulting powder at 500 °C for 5 h. The obtained ash was used to determine the absorption of nutrients. The Kjeldahl method was used to determine the N content. The concentration of K was also found by flame-photometry (Jones 1972). The concentration of P was determined by the yellow method, in which vanadate–molybdate (Tandon et al. 1968) was used as an indicator. The P content was measured at 470 nm using a spectrophotometer. Concentrations of Ca, Mg, Fe, Zn, Cu, and Mn in the digests were determined by an atomic absorption spectrophotometer (AA-6300 F; Shimadzu, Kyoto, Japan).

2.7 Essential Oil Isolation

Thirty grams of dried aerial parts (leaf + flower) from each treatment was roughly ground and placed in a 1-L flask including 300 mL of distilled water and subjected to hydrodistillation using a Clevenger device for 3 h. Once obtained, the EOs were dried adding anhydrous sodium sulfate and then cold-stored at 4 °C in dark vials capped with PTFE-silicon septa which were placed in a refrigerator until analysis.

The EO content and EO yield were calculated using the following equation (Rostaei et al. 2018):

$$\text{Essential oil content }(\%) = \frac{\text{Extracted essential oil (g)}}{30\text{ g of basil ground sample}} \times 100$$

EO yield of basil (g m^{-2}) = dry matter yield (g m^{-2}) × EO content (%)

2.8 Essential Oil Analysis

Gas chromatography–mass spectrometry (GC–MS) analysis was done using an Agilent 7890/5975A GC/MSD instrument. For separation of EO components, an HP-5MS capillary column (5% phenyl methyl polysiloxane, 30 m length, 0.25 mm id, 0.25 μm film thickness) was used. The following oven temperature was applied: 3 min at 80 °C, subsequently 8 °C min^{-1} to 180 °C, held for 10 min at 180 °C. Helium was used as the carrier gas at a flow rate of 1 mL min^{-1}. The sample was injected (1 μL) in split mode (ratio, 1:50). The electron impact (EI) mode was 70 eV. The mass range was set between 40 and 550 *m/z*. The components were identified by comparing the calculated Kovats retention indices (RIs), in respect to a mixture of *n*-alkane series (C8-C30, Supelco, Bellefonte, CA), and a mass spectra (Adams 2007). GC–FID analysis was done using an Agilent 7890 A instrument. Details regarding quantification methods used in this study were thoroughly defined and can be found in recent papers published by this lab (Rezaei-Chiyaneh et al. 2020; Amani Machiani et al. 2019).

2.9 Land Equivalent Ratio

To evaluate the performance of basil and common bean intercropping compared to pure culture, the land equivalent ratio (LER) was calculated as follows (Ofori and Stern 1987):

$$\mathrm{LER} = \frac{Y_1}{B_1} + \frac{Y_2}{CB_2}$$

where Y_1 and Y_2 are basil and common bean yield in the intercropping, and B_1 and CB_2 denote their yield in pure culture, respectively.

2.10 Statistical Analysis

The analysis of variance was performed using PROC Mixed procedures of SAS version 9.3 (SAS Institute Inc., Cary, NC, USA). The vermicompost application, cropping pattern, and year were considered fixed effects, whereas blocks were considered random. In addition, the comparison of the mean of each trait was done using Duncan's multiple range test at the $p < 0.05$ level.

3 Results

3.1 Sweet Basil

Based on results of the variance analysis, all the recorded traits of basil (dry matter yield in the first harvest, and in the second harvest total dry matter yield; EO content in the first harvest, and in the second harvest total EO content; EO yield in both harvests, and total EO yield) were influenced by the cropping pattern and vermicompost application. In addition, the interaction of the cropping pattern and vermicompost application was significant for all recorded traits. Basil dry matter yield, total dry matter yield, EO yield, and total EO yield were also affected by the end of the year (Table 3).

3.1.1 Dry Matter Yield of Basil

The dry matter yield in different intercropping patterns of basil was lower than that of the pure culture. With application of vermicompost, the dry matter yield of basil increased by 28% and 33% in the first and second harvest, respectively, when compared to the control. The means comparison indicated that the highest dry matter yields in the first harvest (261.5 g m^{-2}) and the second harvest (214.7 g m^{-2}) were obtained in the basil pure culture fertilized with vermicompost (Fig. 1 A and B). The average biomass productivity in the first harvest of 2017 was about 5.6% higher than that of 2016 (Table 3).

Furthermore, the maximum total dry matter yield of basil (476.2 g m^{-2}) was achieved in the basil pure culture with

Table 3 Means comparison: the effects of years on the studied traits

Treatments	Dry matter yield (first harvest) (g m^{-2})	Dry matter yield (second harvest) (g m^{-2})	Total dry matter yield (g m^{-2})	Essential oil content (first harvest) (%)	Essential oil content (second harvest) (%)	Total essential oil content (%)	Essential oil yield (first harvest) (g m^{-2})	Essential oil yield (second harvest) (g m^{-2})	Total essential oil yield (g m^{-2})
Year (Y)									
2016	159.2 ± 54.5 b	138.8 ± 45.6 a	297.93 ± 98.9 b	0.69 ± 0.10 a	0.54 ± 0.09 a	1.25 ± 0.18 a	1.12 ± 0.38 b	0.76 ± 0.27 a	1.88 ± 0.64 b
2017	169.6 ± 57.44 a	140.4 ± 47.71 a	309.7 ± 101.9 a	0.70 ± 0.08 a	0.55 ± 0.08 a	1.26 ± 0.16 a	1.18 ± 0.38 a	0.78 ± 0.29 a	1.99 ± 0.65 a
Year (Y)	**	NS	**	NS	NS	NS	**	NS	**
Vermicompost (V)	**	**	**	**	**	**	**	**	**
Intercropping (I)	**	**	**	**	**	**	**	**	**
V × I	*	**	**	**	**	**	**	**	**
Y × V	NS	NS	NS	NS	NS	NS	NS	NS	NS
Y × I	NS	NS	NS	NS	NS	NS	NS	NS	NS
Y × V × I	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS, *, and ** indicated nonsignificant, significant difference at 5%, and significant difference at 1% probability level, respectively

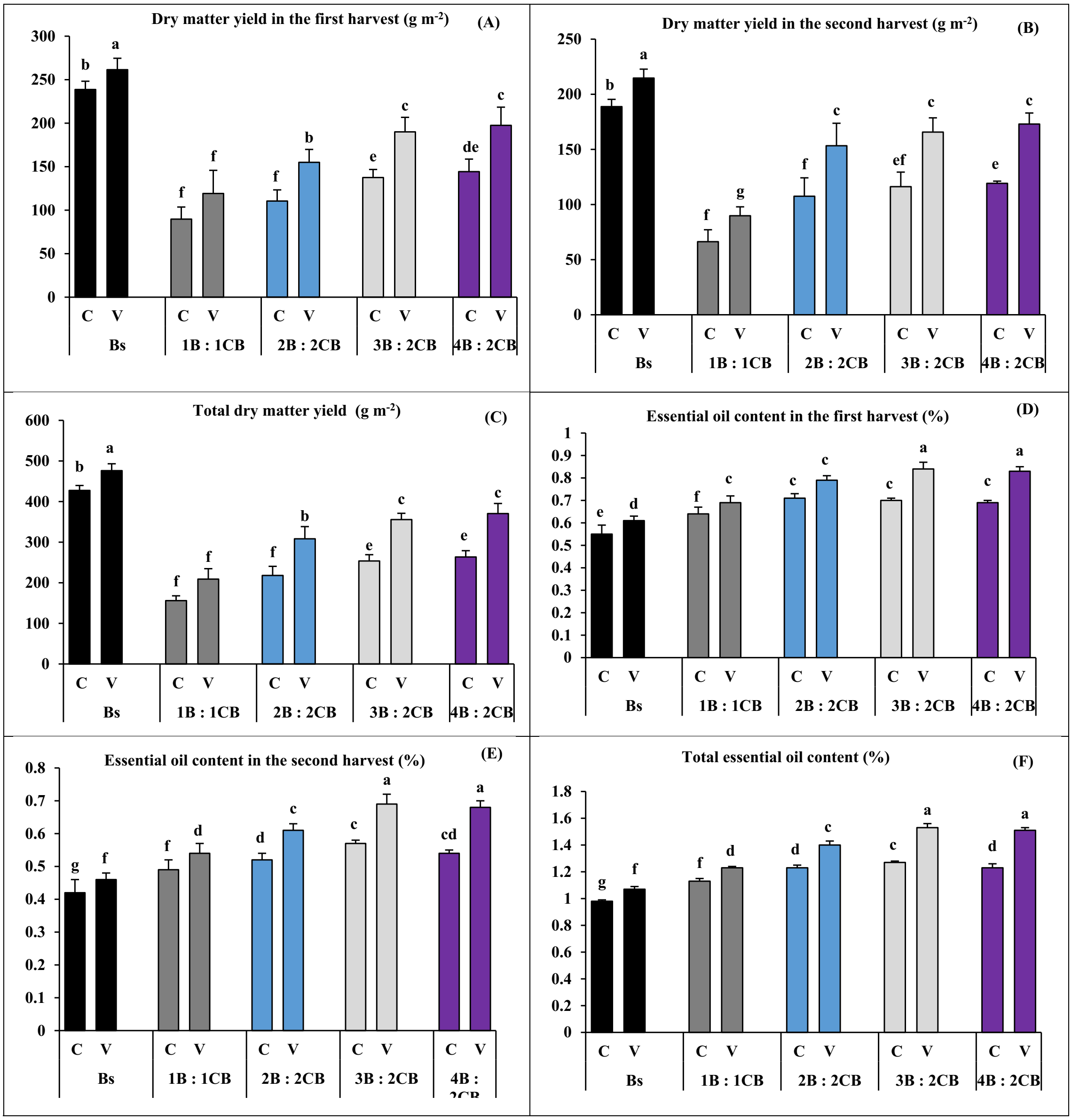

Fig. 1 Basil dry matter yield in the first harvest (A), dry matter yield in the second harvest (B), total dry matter yield (C), essential oil content in the first harvest (D), essential oil content in the second harvest (E), and total essential oil content (F), as affected by interaction of different cropping patterns Bs (basil sole cropping), 1B:1CB, 2B:2CB, 3B:2CB and 4B:2CB; where B and CB indicate the ratios basil and common bean in intercropping pattern) and vermicompost [C (control); V (vermicompost)]. Different lowercase letters above bars indicate significant difference at the $P < 0.05$ level

vermicompost treatment. However, the minimum total dry matter yield of basil (156 g m^{-2}) was achieved at the cropping ratio of 1B:1CB without fertilizer (Fig. 1C). Finally, the total dry matter yield in 2017 was 6.5% greater than that in 2016 (Table 3).

3.1.2 Essential Oil Content

Fertilized vermicompost treatments in both harvests in the intercropping pattern of 3B:2CB resulted in higher EO content of basil than in the other cropping pattern. In addition, the average EO content of the intercropping pattern in the first and second harvests was 27.1% and 31.8% higher than the pure culture, respectively. The maximum EO content of basil in the first harvest (0.84%) and in the second harvest (0.69%) was obtained in the cropping pattern of 3B:2CB, followed by 4B:2CB cropping pattern, with application of vermicompost (Fig. 1D). In contrast, the lowest EO content in the first (0.55%) and second harvests (0.42%) was obtained in the pure culture without vermicompost application (control) (Fig. 1E).

Furthermore, the EO content of basil in the first harvest was 21.7% greater than that of the second harvest. Moreover, the application of vermicompost increased the EO content in the first and second harvests by 14% and 18%, respectively, when compared with the control.

In addition, the total maximum (1.53%) EO content of basil was measured in the cropping pattern of 3B:2CB fertilized with vermicompost, while the minimum EO content (0.98%) was obtained in the pure culture without fertilizer (Fig. 1F).

3.1.3 Essential Oil Yield

The share of EO yield was higher in intercropping systems and application of vermicompost. In the first harvest, the higher EO yield (1.65 g m^{-2}) of basil was obtained in the cropping pattern of 4B:2CB followed by 3B:2CB with application of vermicompost. In contrast, the lowest EO yield (0.57 g m^{-2}) was produced in the cropping pattern of 1B:1B and 2B: 2CB (Fig. 2A).

In the second harvest, the highest EO yield (1.18 g m^{-2}) was recorded in the cropping pattern of 4B:2CB after application of vermicompost and the lowest EO yield (0.32 g m^{-2}) was achieved in the cropping pattern of 1B:1CB without vermicompost application (control) (Fig. 2B).

In the present study, the highest total EO yield of basil (2.82 g m^{-2}) was achieved in the cropping pattern of 4B:2CB + vermicompost followed by 3B:2CB + vermicompost. However, the minimum total EO yield of basil (1.31 g m^{-2}) was produced in the cropping pattern of 1B:1CB without vermicompost application (Fig. 2C). Interestingly, vermicompost application increased the total EO yield of basil by 53.3% in comparison with the control. The total EO in 2017 was 8.49% greater than that in 2016 (Table 3).

3.1.4 Chemical Composition of Basil Essential Oil

GC–FID and GC–MS analyses identified 21 components in the basil EOs (93.4–98.7% and 90.3–94.1% of the total

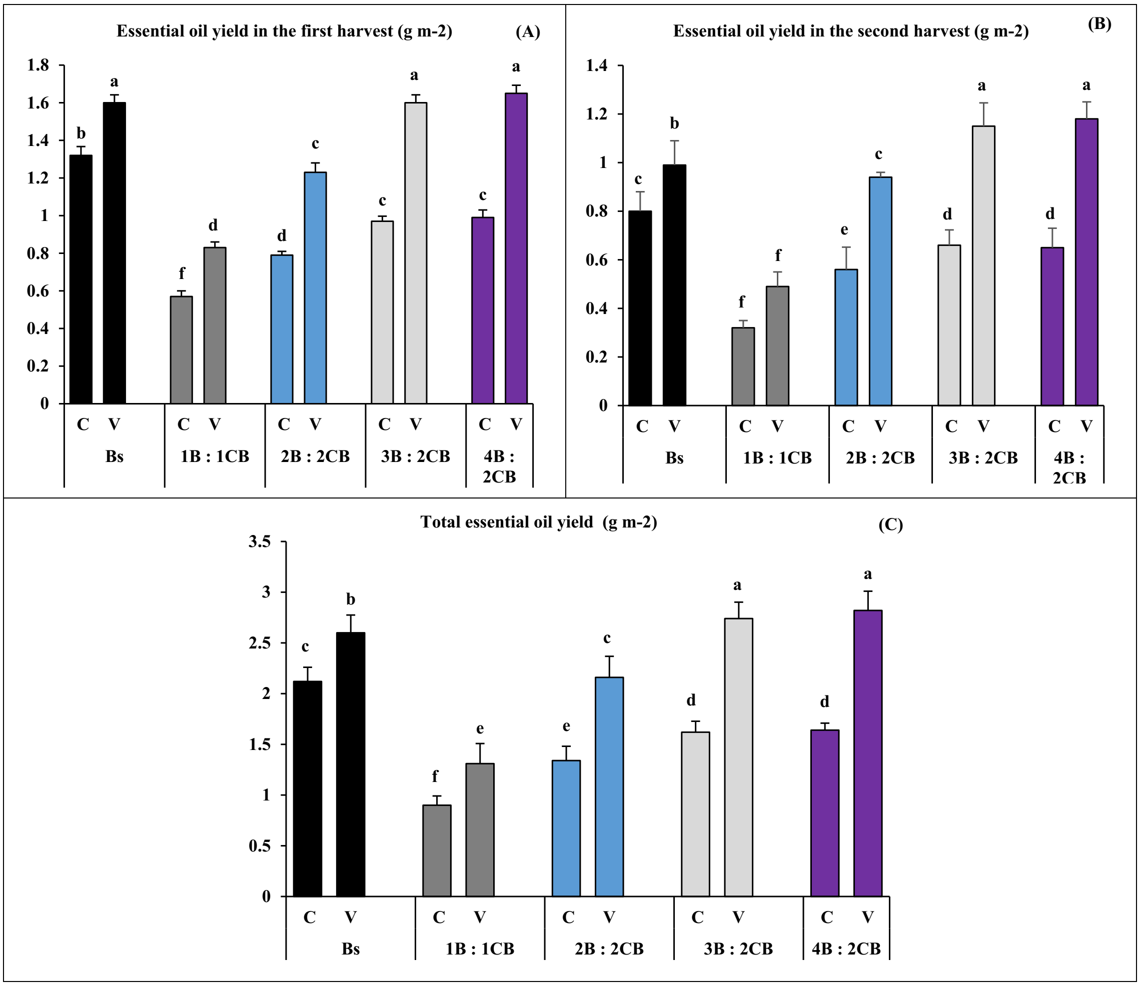

Fig. 2 Basil essential oil yield in the first harvest (A), essential oil yield in the second harvest (B), and total essential oil yield (C), as affected by interaction of different cropping patterns (Bs (basil sole cropping), 1B:1CB, 2B:2CB, 3B:2CB and 4B:2CB; where B and CB indicate the ratios basil and common bean in intercropping pattern) and vermicompost [C (control); V (vermicompost)]. Different lowercase letters above bars indicate significant difference at the $P < 0.05$ level

compositions, in the first and second harvests, respectively). In the first harvest, the main EO compounds were linalool (37.7–44%), methyl chavicol (13–20.1%), *epi*-α-cadinol (10.5–14.9%), 1,8-cineole (5.3–8.9%), α-*trans*-bergamotene (3.1–6.8%), and methyl eugenol (2.4–5.8%) depending on treatments. The contents of 1,8-cineole, linalool, *epi*-α-cadinol, α-*trans*-bergamotene, α-caryophyllene, and methyl eugenol in different intercropping patterns were greater than those in the basil pure culture. The average of the mentioned constituents in the intercropping pattern was 29.9%, 11.5%, 26.2%, 4.4%, 7.1%, and 22.2%, respectively, that was higher than that in the basil pure culture. In addition, the higher content of linalool, methyl eugenol, and *epi*-α-cadinol was recorded in the cropping pattern of 3B:2CB fertilized with vermicompost (Table 4).

In the second harvest, depending on the treatment, the major EO compounds were linalool (32–39.2%), methyl chavicol (18–24.9%), *epi*-α-cadinol (13.6–16.2%), 1,8-cineole (4.4–6.8%), α-*trans*-bergamotene (3.4–5.9%), and methyl eugenol (2–3.3%) (Table 5). Similarly, the contents of all mentioned components in all intercropping planting (except methyl chavicol) were greater than those in the basil pure culture. The average contents of 1,8-cineole, linalool, α-*trans*-bergamotene, methyl eugenol, and *epi*-α-cadinol in intercropping patterns were 20.4%, 13.9%, 9.3%, 10.6%, and 3.1%, respectively, when compared with the pure culture. Furthermore, the highest content of linalool, *epi*-α-cadinol, methyl eugenol, α-caryophyllene, and limonene was observed at the ratio of 3B:2CB using vermicompost. Additionally, in both harvests the content of most constituents changed after application of vermicompost (Table 5).

3.1.5 Nutrient Uptake

The uptake of all measured macro- and micro-nutrients (i.e., N, P, K, Ca, Mg, Fe, Zn, Cu, and Mn) in both harvests was influenced by the planting patterns and vermicompost application. In addition, the interaction of the two factors was significant for all macro- and micro-nutrients (Tables 6 and 7). Compared to other systems, the highest nutrient uptake in the leaves of basil was found in the cropping pattern of 3B:2CB. Within each cropping pattern, the vermicompost fertilizer always resulted in higher macro- and micro-nutrient uptake (Tables 6 and 7).

In the first harvest of basil, the highest nutrient uptake of N (7172.5 μg N m^{-2} DW), P (566.7 μg P m^{-2} DW), Cu (3.7 μg Cu m^{-2} DW), and Mn (26.99 μg Zn m^{-2} DW) was obtained in the cropping pattern of 3B:2CB with application of vermicompost. The maximum nutrient uptakes of K (3560.2 μg K m^{-2} DW), Ca (1995.3 μg Ca m^{-2} DW), Mg (1415.6 μg Mg m^{-2} DW), Fe (29.6 μg Fe m^{-2} DW), and Zn (13.7 μg Zn m^{-2} DW) were achieved in the basil pure culture with application of vermicompost (Table 6).

In the second harvest of basil, the highest nutrient uptake of all macro- (N, P, K, Ca, and Mg) and micro- (Fe, Cu, and Mn) nutrients was observed in the cropping pattern of 3B:2CB with application of vermicompost (Table 7). Moreover, in 2017 the P, K, Ca, Mg, Zn, and Mn nutrient uptake in the leaves of basil was 11.05%, 5.68%, 9.05%, 8.85%, 11.27%, and 6.62% higher than the ones obtained in 2016, respectively (Table 7).

3.2 Common Bean

The analysis of variance showed that the cropping pattern and vermicompost had a significant ($p \leq 0.01$) effect on common bean seed yield, protein content, and macro- and micronutrients (i.e., N, P, K, Ca, Mg, Fe, Zn, Cu, and Mn). However, a significant interaction between these two factors was observed for all recorded traits (Table 8).

3.2.1 Seed Yield

In general, the highest seed yields of common bean were recorded in the pure cultures, followed by the 2B:2CB + V and then in the other cropping patterns. Furthermore, the vermicompost application increased the seed yield by 26% when compared with the control (no fertilizer). Means comparison indicated that the highest seed yield (279.2 g m^{-2}) was achieved in the pure culture of common bean fertilized with vermicompost, while the lowest seed yield (100.8 g m^{-2}) was achieved at the cropping ratio of 4B:2CB without use of vermicompost (Table 8). In addition, among different intercropping patterns, the highest seed yield (2153 kg ha^{-1}) was obtained with the vermicompost treatment in the 3B:2CB intercropping pattern (Table 8).

3.2.2 Common Bean Protein Content

The maximum protein content (PC) was produced in the cropping pattern of 3B:2B (21.8%) after vermicompost application, followed by the other intercropping pattern. In contrast, the minimum PC (19.6%) was recorded in the common bean pure culture without fertilizer (Table 8). The results obtained show that the PC in the intercropping pattern of 1B:1CB, 2B:2CB, 3B:3CB, and 4B:2CB was 3.52%, 3.33%, 4.48%, and 1.6% greater than that in the common bean pure culture, respectively. Interestingly enough, the PC of common bean seeds increased by 7.2% after application of vermicompost in comparison with the control (Table 8).

Table 4 Proportion of basil essential oil constituents in the first harvest under different cropping pattern and application of vermicompost (mean of 2 years)

No.	Component	RI	Cropping patterns (%)										
			Bc	Bs + V	1B:1CB	1B:1CB+ V	2B:2CB	2B:2CB + V	3B:2CB	3B:2+ V	4B:2CB	4B:2CB + V	Average of intercropping
1	α-Pinene	931	–	–	–	–	–	–	–	–	–	–	–
2	Sabinene	973	tr.	–	–	–	–	–	–	–	–	–	tr.
3	β-Pinene	979	0.5 ± 0.02	1.1 ± 0.09	0.6 ± 0.05	0.6 ± 0.04	0.9 ± 0.08	1.7 ± 0.01	–	–	1.2 ± 0.02	–	0.6
4	Myrcene	989	–	–	–	0.1 ± 0.01	–	–	–	–	–	–	tr.
5	Limonene	1028	–	–	–	tr.	1.1 ± 0.004	1.3 ± 0.008	–	–	–	–	0.3
6	1,8-Cineole	1033	5.3 ± 0.04	5.7 ± 0.03	6.4 ± 0.05	7.4 ± 0.06	6.9 ± 05	7.6 ± 0.04	7.1 ± 0.08	5.8 ± 0.04	7.1 ± 0.03	8.9 ± 0.07	7.1
7	Linalool	1098	37.7 ± 1.05	38.2 ± 0.88	41.3 ± 0.92	41.4 ± 1.07	40.4 ± 0.29	43.1 ± 0.70	42 ± 0.99	44 ± 1.1	42.1 ± 0.23	43.7 ± 0.21	42.2
8	α-Terpineol	1189	1.5 ± 0.04	–	–	–	0.9 ± 0.01	0.9 ± 0.01	–	–	–	–	0.2
9	Methyl chavicol	1197	20.1 ± 0.21	16.6 ± 0.41	16.1 ± 0.17	15.7 ± 0.50	15.8 ± 0.35	14.2 ± 0.71	15.1 ± 0.82	13 ± 0.55	16 ± 0.19	14.5 ± 0.41	15.1
10	Pulegone	1243	–	–	–	–	–	–	–	–	–	–	–
11	Bornyl acetate	1283	1.80 ± 0.05	1.6 ± 0.01	1.3 ± .06	1.4 ± 0.04	1.14 ± 0 .05	2.3 ± 0 .09	1.1 ± 0.08	1.3 ± 0.06	1.2 ± 0.05	1.7 ± 0.04	1.4
12	Thymol	1286	–	–	1.6 ± .07	–	–	–	–	–	–	–	0.2
13	Carvacrol	1298	–	–	–	–	–	–	2 ± 0.9	–	–	–	0.2
14	α-*trans*-Bergamotene	1417	4.2 ± 0.02	4.9 ± 0.01	4.6 ± 0.01	4.9 ± 0.03	3.1 ± 0.02	3.7 ± 0.03	4.6 ± 0.02	5.8 ± 0.02	4.8 ± 0.01	6.8 ± 0.03	4.8
15	(*E*)-Caryophyllene	1417	–	–	–	–	0.9 ± 0.01	–	1.8 ± 0.08	–	–	–	0.3
16	α-Caryophyllene	1420	1.2 ± 0.01	1.5 ± 0.04	1.3 ± 0.05	1.3 ± 0.04	1.1 ± 0.01	1.7 ± 0.03	1.4 ± 0.01	1.6 ± 0.08	1.57 ± 0.07	1.7 ± 0.02	1.5
17	α-Humulene	1452	2 ± 0.08	1 ± 0.02	1.8 ± 0.04	1.1 ± 0.03	1.2 ± 0.04	1.3 ± 0.05	1.6 ± 0.07	1.7 ± 0.06	1.4 ± 0.04	1.4 ± 0.03	1.4
18	Germacrene D	1465	2.1 ± 0.09	1.3 ± 0.01	1.3 ± 0.05	1.6 ± 0.01	1.4 ± 0.07	1.5 ± 0.02	2.9 ± 0.08	1.4 ± 0.06	1.2 ± 0.05	1.11 ± 0.05	1.6
19	Methyl eugenol	1467	3.8 ± 0.01	3.3 ± 0.01	5.5 ± 0.02	5.1 ± 0.04	4.4 ± 0.03	4.8 ± 0.2	3.5 ± 0.01	5.8 ± 0.06	2.4 ± 0.01	3.6 ± 0.03	4.4
20	*cis*-α-Bisabolene	1540	2.9 ± 0.01	1.8 ± 0.08	1.2 ± 0.06	2.3 ± 0.14	2.6 ± 0.01	1.8 ± 0.07	2.1 ± 0.04	2.5 ± 0.08	2.6 ± 0.11	3.2 ± 0.02	2.3
21	*epi*-α-Cadinol	1628	10.5 ± 0.18	10.9 ± 0.11	13.4 ± 0.19	12.6 ± 0.07	11.8 ± 0.21	13.8 ± 0.22	12.7 ± 0.27	14.9 ± 0.11	14.5 ± 0.2	14.4 ± 0.44	13.5
	Total identified (%)		93.6	93.4	93.8	95.8	94.5	97.6	97.8	97.8	98.7	96.1	97.1

RI, linear retention index on DB-5 MS column, experimentally determined using homolog series of n-alkanes. Bs (basil sole cropping), 1B:1CB, 2B:2CB, 3B:2CB and 4B:2CB; where B and CB indicate the ratios basil and common bean in intercropping pattern and vermicompost [C (control); V (vermicompost)]; data are mean ± SE ($n = 3$)

Table 5 Proportion of basil essential oil constituents in the second harvest under different cropping pattern and application of vermicompost (mean of 2 years)

No.	Component	RI	Cropping patterns (%)										
			Bc	Bs + V	1B:1CB	1B:1CB+ V	2B:2CB	2B:2CB + V	3B:2CB	3B:2+ V	4B:2CB	4B:2CB + V	Average of intercropping
1	α-Pinene	931	–	–	–	–	tr.	tr.	–	–	–	–	tr.
2	Sabinene	973	–	–	–	–	tr.	tr.	–	–	–	–	tr.
3	β-Pinene	979	1.5 ± 0.01	1.7 ± 0.05	1.1 ± 0.01	1.7 ± 0.09	1.1 ± 0.03	1.3 ± 0.04	1 ± 0.005	1.2 ± 0.07	1 ± 0.02	1.3 ± 0.04	1.2
4	Myrcene	989	–	–	–	–	–	–	–	–	–	–	–
5	Limonene	1028	1 ± 0.07	0.9 ± 0.01	1 ± 0.03	1 ± 0.09	1.1 ± 0.05	1.3 ± 0.01	1.1 ± 0.04	1.4 ± 0.06	1 ± 0.06	1.1 ± 0.05	1.1
6	1,8-Cineole	1033	5.4 ± 0.01	4.4 ± 0.05	5.6 ± 0.04	5.4 ± 0.08	6.1 ± 0.14	6.8 ± 0.09	5.5 ± 0.11	6 ± 0.14	5.7 ± 0.04	6.1 ± 0.07	5.9
7	Linalool	1098	32.1 ± 0.98	32 ± 1.18	33.3 ± 1.44	34.9 ± 1.88	36.4 ± 0.78	37.9 ± 1.68	37.8 ± 1.88	39.2 ± 1.48	37.9 ± 1.08	39 ± 1.99	37
8	α-Terpineol	1189	–	–	–	–	–	tr.	–	tr.	–	–	tr.
9	Methyl chavicol	1197	24.9 ± 0.61	23.6 ± 0.81	22.1 ± 0.41	20.2 ± 0.97	19.8 ± 0.41	20.1 ± 0.66	21.2 ± 0.71	18 ± 0.22	19.7 ± 0.91	19.5 ± 1.01	20.1
10	Pulegone	1243	–	–	–	–	tr.	–	–	tr.	–	–	tr.
11	Bornyl acetate	1283	2.1 ± 0.01	1.40 ± 0.03	1.1 ± 0.09	1.4 ± 0.05	1.6 ± 0.005	1.7 ± 0.03	2.20 ± 0.07	2.6 ± 0.11	1.04 ± 0.08	1.6 ± 0.04	1.7
12	Thymol	1286	–	–	1.6 ± 0.14	–	–	–	–	–	–	–	0.2
13	Carvacrol	1298	–	–	–	–	–	–	2.00 ± 0.09	–	–	–	0.3
14	α-*trans*-Bergamotene	1417	4.1 ± 0.05	4.5 ± 0.08	4.9 ± 0.07	5.9 ± 0.03	4.2 ± 0.07	5.1 ± 0.05	4.1 ± 0.01	3.4 ± 0.08	5 ± 0.11	5.1 ± 0.09	4.7
15	(*E*)-Caryophyllene	1417	–	–	–	–	–	–	0.6 ± 0.004	–	–	–	0.08
16	α-Caryophyllene	1420	0.7 ± 0.08	0.6 ± 0.01	1 ± 0.01	1.1 ± 0.03	1.1 ± 0.06	1.2 ± 0.02	1.22 ± 0.01	1.4 ± 0.07	1.2 ± 0.09	1.3 ± 0.04	1.2
17	α-Humulene	1452	1.6 ± 0.04	1.1 ± 0.08	1.2 ± 0.05	1 ± 0.01	1.19 ± 0.09	1.2 ± 0.04	0.84 ± 0.07	1 ± 0.06	1.2 ± 0.03	1.2 ± 0.08	1.1
18	Germacrene D	1465	1.6 ± 0.01	1.2 ± 0.03	1.2 ± 0.04	1.4 ± 0.09	1.3 ± 0.01	1.4 ± 0.03	1 ± 0.04	1.1 ± 0.09	1.2 ± 0.02	2 ± 0.04	1.3
19	Methyl eugenol	1467	2 ± 0.03	2.7 ± 0.04	2.6 ± 0.06	2.2 ± 0.01	2.5 ± 0.07	2.7 ± 0.11	2.4 ± 0.008	3.3 ± 0.004	2.2 ± 0.10	2.9 ± 0.09	2.6
20	*cis*-α-Bisabolene	1540	2.7 ± 0.01	1.88 ± 0.07	2 ± 0.02	1.9 ± 0.14	2.1 ± 0.08	2.5 ± 0.01	1.9 ± 0.03	2.2 ± 0.04	1.7 ± 0.09	2.4 ± 0.11	2.1
21	*epi*-α-Cadinol	1628	13.9 ± 0.14	15.2 ± 0.19	15.2 ± 0.24	15 ± 0.10	14.3 ± 0.33	15.1 ± 0.16	15.8 ± 0.16	16.2 ± 0.444	15 ± 0.24	13.6 ± 0.27	15
	Total identified (%)		93.8	93.4	91.1	93.9	93.1	90.3	91.7	93.8	94.1	91.7	95.58

RI, linear retention index on DB-5 MS column, experimentally determined using homolog series of *n*-alkanes. Bs (basil sole cropping), 1B:1CB, 2B:2CB, 3B:2CB and 4B:2CB; where B and CB indicate the ratios basil and common bean in intercropping pattern and vermicompost [C (control); V (vermicompost)]; data are mean ± SE ($n = 3$)

Table 6 Means comparison: the interaction effects of vermicompost application and cropping patterns on macro- and micronutrient uptake of basil in the first harvest

Treatment	N (μg m^{-2} DW)	P (μg m^{-2} DW)	K (μg m^{-2} DW)	Ca (μg m^{-2} DW)	Mg (μg m^{-2} DW)	Fe (μg m^{-2} DW)	Zn (μg m^{-2} DW)	Cu (μg m^{-2} DW)	Mn (μg m^{-2} DW)
Bs	4908.3 ± 293.4 c	453.5 ± 46.1 b	2892.5 ± 266.7 c	1625.7 ± 133.4c	1147.3 ± 64.3 c	25.1 ± 2.5b	11.4 ± 0.80 b	2.2 ± 0.35 c	5.4 ± 0.58 ab
1B: 1CB+ C	2631.7 ± 316.3 e	272.2 ± 30.3 d	1330.0 ± 156.5 e	794.0 ± 95.9 f	565.9 ± 72.5 g	12.7 ± 1.5 e	4.4 ± 0.48 e	1.1 ± 0.21 e	2.8 ± 0.40 c
2B: 2CB+ C	3732.5 ± 284.7 d	318.6 ± 24.7 cd	2040.0 ± 162.2 d	1026.2 ± 66.4 e	747.5 ± 61.4ef	16.0 ± 1.6 d	4.9 ± 0.59 e	1.6 ± 0.35 d	3.9 ± 0.33 bc
3B: 2 CB+ C	4791.8 ± 565.8 c	351.17 ± 37.5 c	2207.7 ± 242.8 d	1096.8 ± 110.0de	801.8 ± 92.6 de	16.6 ± 2.2 cd	5.1 ± 0.56 e	1.8 ± 0.28 cd	4.5 ± 0.43 bc
4B: 2 CB+ C	2868.3 ± 441.4 e	207.5 ± 30.6 e	1334.2 ± 237.8 e	634.7 ± 106.6 g	468.4 ± 79.2 h	9.8 ± 1.8 f	3.02 ± 0.63f	1.0 ± 0.19 e	2.5 ± 0.45 c
Bs + V	5967.0 ± 425.8 b	546.8 ± 57.8 a	3560.2 ± 215.3 a	1995.3 ± 204.4a	1415.6 ± 94.6 a	29.6 ± 3.0 a	13.7 ± 0.88 a	3.3 ± 0.36 b	7.3 ± 0.79 a
1B:1CB + V	4108.8 ± 395.7 d	432.0 ± 49.5 b	2005.8 ± 197.5 d	1195.3 ± 138.3d	893.4 ± 85.0d	18.6 ± 1.9 c	7.1 ± 0.95 d	2.0 ± 0.24 c	4.6 ± 0.52 bc
2B:2CB + V	5910.3 ± 497.4 b	519.9 ± 56.9 a	3280.7 ± 399.9 b	1600.2 ± 129.4c	1178.6 ± 124.4 bc	26.9 ± 2.2 b	9.1 ± 0.73 c	3.6 ± 0.85 ab	6.9 ± 0.75 a
3B:2CB + V	7172.5 ± 782.8 a	566.7 ± 68.9 a	3554.2 ± 441.1 a	1782.4 ± 244.4 b	1274.8 ± 163.9 b	26.7 ± 3.8 b	9.3 ± 1.2 c	3.7 ± 0.44 a	7.5 ± 0.97 a
4B:2CB + V	4145.8 ± 999.6 d	325.3 ± 70.7 c	1971.8 ± 383.4 d	972.5 ± 200.7 e	692.9 ± 160.2 f	15.0 ± 3.9 d	5.0 ± 1.3 e	1.9 ± 0.41 cd	4.1 ± 1.02 bc
Year									
2016	4559.9 ± 1472.4 a	378.5 ± 116.7 b	2350.9 ± 858.9 b	1217.2 ± 435.9 b	879.7 ± 309.7 b	18.9 ± 6.7 a	6.9 ± 3.3 b	2.2 ± 1.01 a	4.8 ± 1.7 b
2017	4687.6 ± 1464.4 a	420.3 ± 133.5 a	2484.5 ± 857.7 a	1327.4 ± 473.3 a	957.6 ± 331.1 a	20.6 ± 7.2 a	7.7 ± 3.4 a	2.2 ± 1.01 a	5.1 ± 1.9 a
Year (Y)	NS	**	*	**	**	NS	**	NS	*
V	**	**	**	**	**	**	**	**	**
I	**	**	**	**	**	**	**	**	**
V × *I*	**	**	**	**	**	**	**	**	**
Y × *V*	NS	NS	NS	NS	NS	NS	NS	NS	NS
Y × *I*	NS	NS	NS	NS	NS	NS	NS	NS	NS
Y × *V* × *I*	NS	NS	NS	NS	NS	NS	NS	NS	NS

Bs (basil sole cropping), 1B:1CB, 2B:2CB, 3B:2CB and 4B:2CB; where B and CB indicate the ratios basil and common bean in intercropping pattern and vermicompost [C (control); V (vermicompost)]. NS, *, and ** indicated nonsignificant, significant difference at 5%, and significant difference at 1% probability level, respectively

Table 7 Means comparison: the interaction effects of vermicompost application and cropping patterns on macro- and micronutrient uptake of basil in the second harvest

Treatment	N (μg m^{-2} DW)	P (μg m^{-2} DW)	K (μg m^{-2} DW)	Ca (μg m^{-2} DW)	Mg (μg m^{-2} DW)	Fe (μg m^{-2} DW)	Zn (μg m^{-2} DW)	Cu (μg m^{-2} DW)	Mn (μg m^{-2} DW)
Bs	3168.2 ± 220.1 c	311.8 ± 49.0 c	193.9 ± 13.1 c	1183.7 ± 71.7b	828.4 ± 37.2 c	15.1 ± 0.82 c	8.2 ± 0.72 b	1.5 ± 0.021 cd	0.021 ± 0.0016 d
1B: 1CB+ C	1603.7 ± 209.7 e	152.9 ± 30.2 e	94.1 ± 11.7 f	548.0 ± 63.1 f	397.4 ± 38.1 g	8.2 ± 0.96 f	2.7 ± 0.39 f	0.8 ± 0.022 e	0.022 ± 0.0015 cd
2B: 2CB+ C	2387.8 ± 188.9 d	232.9 ± 46.8 d	153.8 ± 20.7 de	883.2 ± 118.6 cd	619.8 ± 66.3 e	12.5 ± 1.7 de	3.8 ± 0.60 e	1.3 ± 0.023 d	0.023 ± 0.0013 b-d
3B: 2 CB+ C	2752.0 ± 345.8 d	264.6 ± 31.1 d	172.6 ± 16.2 cd	942.9 ± 77.6 c	687.3 ± 46.7 d	14.1 ± 1.3 cd	4.1 ± 0.39 de	1.5 ± 0.02 cd	0.024 ± 0.0008 b-d
4B: 2 CB+ C	1462.5 ± 432.7 e	135.8 ± 42.0 e	94.0 ± 33.3 f	476.6 ± 137.4 f	352.8 ± 112.5 g	7.1 ± 2.1 f	2.1 ± 0.60 g	0.8 ± 0.023 e	0.023 ± 0.0011 b-d
Bs + V	3974.4 ± 310.5 b	388.8 ± 43.7 b	249.9 ± 18.4 b	1403.8 ± 73.5a	1004.1 ± 64.7 b	18.8 ± 0.84 b	10.4 ± 0.93 a	2.2 ± 0.024 b	0.024 ± 0.0015 bc
1B:1CB + V	2489.2 ± 499.7 d	235.4 ± 44.7 d	145.1 ± 30.5 e	783.5 ± 118.9 de	573.0 ± 78.2 ef	12.5 ± 2.3 de	4.4 ± 0.63 d	1.3 ± 0.026 d	0.026 ± 0.0027 ab
2B:2CB + V	4288.3 ± 371.8 b	397.4 ± 63.6 b	268.4 ± 37.3 b	1406.2 ± 193.8 a	994.1 ± 88.1 b	21.7 ± 3.1 a	7.3 ± 0.66 c	2.9 ± 0.028 a	0.028 ± 0.0017 a
3B:2CB + V	4925.5 ± 812.0 a	457.1 ± 65.9 a	312.6 ± 35.7 a	1474.1 ± 151.0 a	1077.4 ± 90.9 a	22.8 ± 2.5 a	7.9 ± 1.0 bc	3.0 ± 0.028 a	0.029 ± 0.0014 a
4B:2CB + V	2456.7 ± 508.1 d	244.6 ± 48.6 d	172.0 ± 34.3 cd	742.8 ± 147.6 e	528.1 ± 92.2 g	11.8 ± 2.5 e	3.8 ± 0.88 de	1.6 ± 0.028 c	0.028 ± 0.0012 a
Year									
2016	3017.8 ± 1184.4 a	263.9 ± 98.76 b	185.6 ± 69.50 a	987.1 ± 342.2 a	714.2 ± 244.5 a	14.3 ± 4.8 a	5.2 ± 2.6b	1.66 ± 0.76 a	0.02 ± 0.003 a
2017	2883.9 ± 1144.6 a	300.4 ± 119.65 a	185.7 ± 78.31 a	981.9 ± 394.1 a	698.2 ± 272.8 a	14.6 ± 5.8 a	5.6 ± 2.7 a	1.7 ± 0.77 a	0.02 ± 0.002 a
Year (Y)	NS	*	NS	NS	NS	NS	*	NS	NS
V	**	**	**	**	**	**	**	**	**
I	**	**	**	**	**	**	**	**	**
V × *I*	NS	**	**	**	**	**	**	**	**
Y × *V*	NS	NS	NS	NS	NS	NS	NS	NS	NS
Y × *I*	NS	NS	NS	NS	NS	NS	NS	NS	NS
Y × *V* × *I*	NS	NS	NS	NS	NS	NS	NS	NS	NS

Bs (basil sole cropping), 1B:1CB, 2B:2CB, 3B:2CB and 4B:2CB; where B and CB indicate the ratios basil and common bean in intercropping pattern and vermicompost [C (Control); V (vermicompost)]. NS, *, and ** indicated nonsignificant, significant difference at 5%, and significant difference at 1% probability level, respectively

Table 8 Means comparison: the interaction effects of vermicompost application and cropping patterns on seed yield, seed protein content, and macro- and micronutrient uptake of common bean

Treatment	Seed yield (kg ha^{-1})	Seed protein (%)	N (μg m^{-2} DW)	P (μg m^{-2} DW)	K (μg m^{-2} DW)	Ca (μg m^{-2} DW)	Mg (μg m^{-2} DW)	Fe (μg m^{-2} DW)	Zn (μg m^{-2} DW)	Cu (μg m^{-2} DW)	Mn (μg m^{-2} DW)
CBs	2351.7 ± 81.8 b	19.6 ± 0.54 c	21,132.0 ± 1608.1a	1457.8 ± 142.0 b	8741.8 ± 507.2 b	5439.5 ± 306.4 c	4140.8 ± 232.7 b	54.0 ± 4.4 c	27.9 ± 1.9 b	6.0 ± 1.0 c	19.1 ± 1.4bc
1B: 1CB + C	1207.5 ± 135.3 fg	20.4 ± 0.58bc	11,056.0 ± 1467.9e	796.9 ± 109.5f	4388.0 ± 569.0 f	2795.5 ± 358.3 g	2190.7 ± 276.9 f	31.0 ± 4.1 f	10.6 ± 1.5 f	3.4 ± 0.4 e	10.4 ± 1.3 de
2B: 2CB + C	1525.2 ± 143.0 de	19.9 ± 0.44 c	12,330.1 ± 1125.8d	908.2 ± 82.4 e	5221.3 ± 384.2 a	3258.9 ± 257.5 ef	2518.7 ± 206.0 de	38.2 ± 3.3 e	12.9 ± 1.1 e	4.8 ± 0.7 d	13.0 ± 1.5 ce
3B: 2 CB + C	1653.3 ± 102.9 d	19.8 ± 0.28 c	12,746.7 ± 551.1 d	970.3 ± 50.7 de	5644.2 ± 247.0 d	3439.8 ± 103.7 de	2590.2 ± 93.0 d	44.6 ± 2.3 d	13.8 ± 0.7 e	4.9 ± 0.9 cd	13.8 ± 0.8c-e
4B: 2 CB + C	1008.3 ± 137.0 g	19.8 ± 0.64 c	8362.7 ± 916.3 f	600.5 ± 60.7 g	3272.0 ± 296.1 g	2081.5 ± 214.4 h	1542.2 ± 171.6 g	23.0 ± 3.0 g	8.0 ± 1.0 g	2.6 ± 0.3 e	8.7 ± 6.8 e
CBs + V	2786.2 ± 132.4 a	20.6 ± 0.66 ac	24,470.9 ± 1930.2a	1756.30 ± 118.0 a	10,226.1 ± 641.5 a	6232.1 ± 333.4 a	4760.9 ± 271.8 a	64.4 ± 4.6 b	34.2 ± 2.7 a	7.9 ± 2.0 b	26.9 ± 1.5 a
1B:1CB + V	1494.8 ± 150.9d-f	21.7 ± 0.40ab	14,551.7 ± 1140.1c	1157.3 ± 136.1 c	5917.2 ± 562.6 d	3598.2 ± 319.9 d	3042.1 ± 277.5 c	47.5 ± 5.4 d	15.8 ± 1.6 d	5.7 ± 0.7 cd	15.9 ± 0.7 dc
2B:2CB + V	1984.2 ± 167.0 c	21.7 ± 0.40ab	24,327.1 ± 1457.1a	1661.0 ± 111.2 a	7725.7 ± 452.8 c	5750.0 ± 643.1 bc	3995.5 ± 291.0 b	67.9 ± 5.8 ab	24.3 ± 1.9 c	10.9 ± 1.6 a	24.1 ± 1.6 ab
3B:2CB + V	2153.2 ± 120.4 bc	21.8 ± 0.75 a	24,826.8 ± 1171.0a	1757.6 ± 113.5 a	8580.3 ± 499.5 b	5775.8 ± 499.8 b	4058.6 ± 168.3 b	71.0 ± 4.2 a	25.6 ± 1.4 c	10.9 ± 1.6 a	22.3 ± 1.3 ab
4B:2CB + V	1329.8 ± 164.9ef	21.0 ± 0.75a-c	12,527.9 ± 1272.7d	1031.1 ± 137.4 d	4975.9 ± 387.7 e	3081.4 ± 332.7 gf	2340.8 ± 223.5 ef	39.3 ± 4.3 e	13.4 ± 1.4 e	5.3 ± 1.2 cd	15.0 ± 2.3 cd
Year											
2016	1716.7 ± 555.2 a	20.5 ± 1.1 a	16,350.8 ± 6324.5b	1170.1 ± 421.3 b	6467.7 ± 2313.3 a	4005.2 ± 1430.5 b	3034.9 ± 1049.8 b	47.6 ± 16.8 b	18.1 ± 8.2 b	5.9 ± 2.91 b	16.5 ± 3.8 b
2017	1782.1 ± 548.1 a	20.7 ± 0.94 a	16,901.6 ± 6147.7a	1244.6 ± 413.3 a	6470.8 ± 2065.3 a	4289.41514.3 ± a	3201.2 ± 1020.4 a	48.6 ± 15.2 a	19.9 ± 8.7 a	6.5 ± 2.97 a	17.4 ± 5.6 a
Year (Y)	NS	NS	*	*	NS	**	**	*NS*	**	*NS*	*NS*
V	**	**	**	**	**	**	**	**	**	**	**
I	**	**	**	**	**	**	**	**	**	**	**
V × *I*	**	**	**	**	**	**	**	**	**	**	**
Y × *V*	NS	NS	NS	NS	NS	NS	NS	*NS*	*NS*	*NS*	*NS*
Y × *I*	NS	NS	NS	NS	NS	NS	NS	*NS*	*NS*	*NS*	*NS*
Y × *V* × *I*	NS	NS	NS	NS	NS	NS	NS	*NS*	*NS*	*NS*	*NS*

CBs (common bean sole cropping), 1B:1CB, 2B:2CB, 3B:2CB and 4B:2CB; where B and CB indicate the ratios basil and common bean in intercropping pattern and vermicompost [C (control); V (vermicompost)]. NS, *, and ** indicated nonsignificant, significant difference at 5%, and significant difference at 1% probability level, respectively

3.2.3 Nutrient Uptake

Most of the nutrient uptakes were higher in the intercropping systems compared to the common bean pure culture. It was found that in the seed of common bean the highest nutrient uptake of N (24,826.8 μg N m^{-2} DW), P (1757.7 μg P m^{-2} DW), Fe (71 μg Fe m^{-2} DW), and Cu (10.9 μg Zn m^{-2} DW) was achieved in the cropping ratio of 3B:2CB (basil:common bean) with application of vermicompost. In addition, the maximum nutrient uptakes of K (10,226.1 μg K m^{-2} DW), Ca (6232.1 μg Ca m^{-2} DW), Mg (4760.9 μg Mg m^{-2} DW), and Zn (34.2 μg Mg m^{-2} DW) were obtained in the pure culture with application of vermicompost (Table 8). Moreover, application of vermicompost increased the nutrient uptake of N, P, K, Ca, Mg, Fe, Zn, Cu, and Mn by 53.4%, 55.5%, 37.2%, 30.4%, 40.2%, 52.1%, 54.3%, 86.3%, and 60.3%, respectively, when compared with the control (no fertilizer). In addition, the N, P, Ca, Mg, and Zn nutrient uptake in 2017 was 8.8%, 6.3%, 7.1%, 5.5%, and 10% higher than the ones obtained in the 2016, respectively (Table 8).

3.3 Land Equivalent Ratio

The greatest partial land equivalent ratios (LER) for basil (0.77) and common bean (0.75) were recorded in the cropping pattern of 3B:2CB with the application of vermicompost. Nevertheless, the lowest partial LER for basil (0.51) and common bean (0.36) was obtained in the cropping pattern of 1B:1CB without vermicompost application. In addition, the greatest total LER (1.52) was achieved in the cropping pattern of 3B:2CB fertilized with vermicompost. However, the lowest total LER (0.87) was recorded in the cropping ratio of 1B:1CB with the use of vermicompost (Fig. 3). In all intercropping patterns (except 1B:1CB cropping pattern), the total LER was greater than 1.

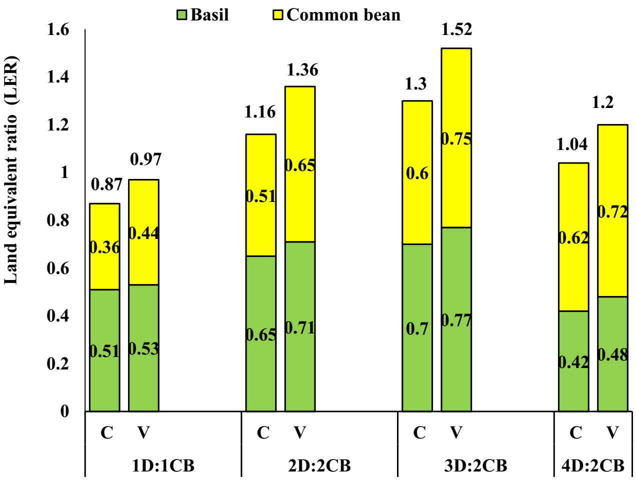

Fig. 3 Partial and total land equivalent ratio (LER) values in different cropping patterns and vermicompost application. C (control); V (vermicompost), 1B:1CB, 2B:2CB, 3B:2CB and 4B:2CB; where B and CB indicate the ratios basil and common bean in intercropping pattern

4 Discussion

In line with our second hypothesis, the nutrient uptake rate of common bean seeds and basil leaves in most of intercropping patterns was greater than that in the pure culture. The higher nutrient uptake rate in intercropping patterns may be due to the different root architecture, root exudation, and higher enzyme activity (e.g., carboxylates and phosphatases) (Latati et al. 2018).

As hypothesized in this study, the higher nutrient uptake with vermicompost application was attributed to the improvement of macro- and micronutrient availability as a result of realizing the importance of nutrients during the growth period of the plant leading to higher availability of nutrients (Singh et al. 2014). Thus, uptake of nutrients in common bean and basil increased due to the different root systems, root exudation, and availability of mineral nutrients to plants in the intercropping system. We, therefore, conclude that the nutrient uptake in basil and common bean increased due to the sufficient nutrients in vermicompost.

In agreement with our first hypothesis, the higher yields in pure culture could be explained by the higher inter-specific competition between the intercropping components (Esmaeili et al. 2011). As hypothesized, vermicompost consumption enhanced the yields of both crops compared with unfertilized treatments. This can be explained by the positive role of vermicompost in increasing the activity of beneficial microorganisms and improving the soil structure. On the other hand, vermicompost increased the water retention capacity leading to a higher nutrient availability and uptake (Coulibaly et al. 2018; Sarma et al. 2018). Therefore, the results confirm that crop productivity was affected by cropping patterns and nutrient uptake. In aprevious study where dragonhead (*Dracocephalum moldavica* L.)was intercropped with soybean (*Glycine max* (L.) Merr.), it was found that application of organic fertilizers increased the crop productivity due to a suitable supply of nutrients (Fallah et al. 2018).

Nitrogen is one of the main constituents of seed protein content (PC). In our experiment, the highest nitrogen uptake was recorded in the 3B:2CB + V cropping pattern. Therefore, the higher content of seed protein in this cropping pattern is due to the higher nutrient content of vermicompost and increase of the nitrogen absorption. Consistently with previous studies, the higher seed PC of common bean in intercropping was related to the optimal use of environmental resources such as nitrogen upon biological fixation (Belel et al. 2014). In the case of the intercropping pattern, previous studies indicated that when plants of the Fabaceae family are planted with MAPs, the complementary impact of the legume component stimulates more nitrogen fixation by legumes and consequently improves the number and rate of the formation of active rhizobium nodules, increases the nutrient uptake, particularly nitrogen, and led to an increased seed protein content (Banik et al. 2006; Belel et al. 2014; Amani Machiani et al. 2019; Rezaei-Chiyaneh et al. 2020). Therefore, the results also confirm that seed protein was affected by nitrogen uptake.

In line with our first hypothesis, the nutrient availability could enhance the EO synthesis in MAPs by increasing the plant growth characteristics and also the EO glands' cell size (Boveiri Dehsheikh et al. 2020). Therefore, the higher EO content after application of vermicompost was attributed to the gradual release of nutrients during crop growth and to the nutrient uptake, particularly N and P (Amooaghaie and Golmohammadi 2017). Moreover, the enhanced EO content in basil intercropping can be related to the availability of atmospheric N_2 by legumes and higher use of environmental resources such as nutrients, light and water due to superior chemical, special and temporal complementarity in basil/common bean intercropping pattern compared with the pure culture. It is important to note that when basil was used in the intercropping pattern, there was an increase in the EO content due to positive interactions with common bean. Previous studies (Esmaielpour et al. 2017) indicated that the basil EO content was significantly enhanced after application of vermicompost.

The EO yield of basil had a direct relation with the EO content and dry matter productivity. Thus, each agent that enhanced these indices could promote the EO yield. As hypothesized, the higher EO yield in intercropping patterns at a ratio of 3B:2CB and 4B:2CB with application of vermicompost may be attributed to the higher dry matter productivity and EO content in both treatments due to a higher availability of nutrients and environment use efficiency (Amani Machiani et al. 2019). Similarly, consistent with our hypothesis, the appropriate proportions of macro- and micronutrients play an important role in achieving higher biomass yield, EO content, and yield of MAPs.

The EO content and composition of MAPs such as the Lamiacee family are influenced by the EO channels, secretory channels, EO gland cells, and glandular trichomes (Fallah et al. 2018). On the other hand, the synthesis of these compounds needs elements such as N and P. Therefore, the facilitation of N uptake by biological N-fixing and the role of N and P in EO synthesis pathways were likely to increase the EO composition in basil in the intercropping systems with the application of vermicompost (Duchene et al. 2017; Ostadia et al. 2020).

In addition, in this study, we reported that the vermicompost application could change the EO composition of basil. Scientific reports on EO composition of sweet basil affected by intercropping with vermicompost application are scarce. Hence, this report is one of the few studies reporting on the effect of vermicompost on sweet basil EO composition. Therefore, it seems that one of the strategies for producing EOs in low-input and organic farming is the use of vermicompost, because it provides the conditions for the absorption of nutrients by modifying the soil structure and increasing the biological activity of the soil.

Results showed that in all intercropping patterns, the partial LER of basil was greater than that of common bean, indicating that the former was the dominant plant in intercropping patterns. In this study it was also found that the LER values were greater than the ones in all intercropping patterns of common bean and basil (except 1B:1CB ratio). Similarly, parallel with our hypothesis, previous studies showed that the higher LER of the intercropping system can be related to the correct arrangement and better supplementary use of environmental resources (Kassam and Brammer 2013; Duchene et al. 2017; Martin-Guay et al. 2018).

5 Conclusions

The use of sustainable agriculture for the improvement and production of medicinal and aromatic plants is a crucial challenge nowadays. Notably, the need of replacing chemical fertilizers with more environmentally friendly substances is an important priority for farmers in order to reduce the environmental impact. Our findings showed the advantage of combining the intercropping of sweet basil and common bean with application of vermicompost in order to achieve a better quality and productivity of basil essential oil. Notably, the intercropping pattern of 3 rows of basil + 2 rows of common bean under vermicompost application revealed to be the best strategy to improve the essential oil productivity and quality of basil. At the same time, this treatment allowed to increase the crop nutrient uptake and Land equivalent ratio. Thus, it can be introduced to basil growers as an alternative and sustainable strategy for replacing chemical fertilizer and plant monoculture.

Data Availability The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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