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# Organic source on productivity of pomegranate–lemongrass-based agroforestry system in central India

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**Abstract** The present study was conducted to assess the response of organic sources of nutrition on productivity of pomegranate (*Punica granatum* L.) and lemongrass (*Cymbopogon flexuosus* Stapf.) under agroforestry system in central India. The experiment was designed in Factorial Randomized Block Design with two cultivars of pomegranate ($V_1$—Ganesh and $V_2$—Bhagwa) and four levels of nutrient management [$T_1$—vermicompost (30 kg/plant), $T_2$—farm yard manure or FYM (30 kg/plant), $T_3$—vermicompost (30 kg/plant) + FYM (30 kg/plant) and $T_4$—recommended doses of chemical fertilizers (RDF)]. A control of pure lemongrass was also maintained separately. The lemongrass was intercropped in a 4-year-old pomegranate orchard, and the observations were recorded consecutively for 3 years (2017, 2018 and 2019). Findings revealed that vermicompost either alone or in combination with FYM was more effective than the chemical fertilizer in influencing almost all the studied plant characters. Maximum collar diameter of pomegranate was found in $T_1$ during 2017 (6.31 cm) and 2018 (6.96 cm), and in $T_4$ during 2019 (7.13 cm). Maximum number of fruits/plant was in $T_3$ during 2017 (22.45) and 2018 (21.81), and in $T_1$ during 2019 (24.26). Average fruit weight was maximum in $T_2$ during 2017 (231.67 g) and 2018 (261.67 g) while in $T_4$ during 2019 (260.36 g), which was at par with $T_2$ (253.78 g) and $T_1$ (242.75 g). Average fruit yield was maximum in $T_3$ during 2017 (4.70 kg/plant), in $T_2$ during 2018 (5.51 kg/plant) and in $T_1$ during 2019 (5.85 kg/plant). When intercropped with pomegranate, lemongrass's fresh biomass yield was maximum in $T_3$ while oil recovery in $T_1$ during period of investigation. The minimum fresh biomass and oil recovery were observed in $T_2$. Pure lemongrass (control) plot yielded highest fresh biomass as well as oil recovery in all the 3 years of the study period. In nutshell, it is concluded that organic sources of nutrition in general and vermicompost in particular proved to be more effective than the chemical sources of nutrition for sustainable productivity from the pomegranate–lemongrass-based agroforestry system in rainfed conditions. Further, this system holds great promise for boosting farmers' economy by providing extra income from lemon oil in drought stricken semi-arid regions of central India.

**Keywords** Aromatic plant · Chemical fertilizer · *Cymbopogon flexuosus* · Farm yard manure · *Punica granatum* · Vermicompost

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## Introduction

Pomegranate (*Punica granatum* L.) is an ancient and important fruit crop of tropical and subtropical regions of the world. It belongs to family Punicaceae with two species, namely *P. granatum* and *P. protopunica*. The origin of pomegranate is in South-West Asia probably in Iran (De Candolle 1967). It is commercially cultivated in Iran, Afghanistan, Russia, Israel, North and Latin American countries, Africa and India. India ranks first in the world with area of 0.234 million ha and production of 2.85 million tonnes (GOI 2018). In India, it is commercially cultivated in states of Maharashtra, Karnataka, Gujarat, Rajasthan, Uttar Pradesh, Andhra Pradesh and Tamil Nadu. Maharashtra is the main pomegranate producing state and accounts 78% of total production of the country. It is also cultivated in semi-arid and arid regions but requires irrigation for better quality fruits. Bundelkhand region of central India is suitable for pomegranate cultivation, as climatic conditions are almost similar to pomegranate growing areas of the Maharashtra. The harmful effects of inorganic fertilizers and chemicals are well known not only on human health but also on health of soil and on environment. Organic production systems are based on specific standards precisely formulated for food production and aim at achieving agro-ecosystems that are socially and ecologically sustainable. A diet based on organic products provide more health benefits compared to conventional ones due to the higher concentration of nutritional compounds and the absence of pesticide residues (Oates et al. 2014).

The present challenge of feeding the world's population requires new strategies to ensure food security based on its availability and access including food safety and nutritional quality. Organic production systems may be a way to ensure sustainability of the food production, conservation of natural resources for present and future generation and also provide a high-quality and long shelf life to the product (Rembialkowska 2007).

The impact of organic agriculture on natural resources favors interactions within the agro-ecosystem that is vital for both agricultural production and nature conservation. The environmental costs of conventional agriculture are substantial, and the evidences for significant environmental amelioration via conversion to organic agriculture are overwhelming (Kler et al. 2001, 2002). There are also high pre-consumers human health costs to conventional agriculture, particularly in the use of pesticides (Conway and Pretty 1991). Nowadays, people are more conscious about their health and consuming less fruits due to more use of chemicals (fertilizers and pesticides). To overcome harmful effects of these chemicals on human health, an attempt has been made to use organic manure in place of inorganic fertilizers for managing pomegranate orchard. Also, meagre information is available on integration of aromatic plants with fruit trees on the same land management unit under the organic regime as compared to the other forms of agroforestry. Integration of aromatic plants provides another opportunity to study diversification of existing landuse systems for beneficial environmental impacts and higher returns as compare to sole cropping systems (Chaturvedi 1991). In this study, the lemongrass (*Cymbopogon flexuosus* Stapf.) Will. Watson has been intercropped with pomegranate. Lemongrass produces bright or pale yellow color essential oil with a thin consistency and a lemony scent. Essential oil is highly demanded in the market, as it is used in perfume industry. Besides, lemongrass is used as traditional medicine for pain relief, stomach problems and fever. Its antioxidant, anti-inflammatory and antifungal properties make it more beneficial (Beth Sissons, 2019). In present study, an attempt has been made to see the response of organic sources of nutrition (farm yard manure (FYM) and vermicompost) on growth and production of pomegranate (cultivars Ganesh and Bhagwa) fruits and biomass yield and oil recovery in lemongrass under agroforestry system in central India.

## Materials and methods

### Environmental settings

The study was carried out at central research farm of ICAR-Central Agroforestry Research Institute (CAFRI), Jhansi, Uttar Pradesh, India. The soil of the experimental farm is inter-mixed black and red soil, which represent '*parawa*' group of soil of Bundelkhand region, covered under the order of Alfisol. The ICAR-CAFRI farm is situated at 25° 27′ N and 78° 35′ E, at 271 m above mean sea level in the semi-arid tract of central plateau of India. Annual rainfall ranges from 700 to 1150 mm with a mean value of 958 mm of which about 80% is received during southwest monsoon. The potential evapotranspiration is quite high in the range of 1400–1700 mm with moisture index value of − 40 to − 50. The pattern of the rainfall is highly erratic and more than 90% of the total rainfall occurs within 10 weeks between the months of July to mid-September accompanied by intermittent long dry spells. The entire rainfall is received in less than 50 rainy days. Winter showers are rare and uncertain. The frequent drought occurs in entire region. Usually, monsoon commences by the last week of June but sometimes delayed to the first week of July. The active monsoon often withdraws up to the mid of September. Mean annual temperature of the Jhansi is generally high with high degree of variation between 5.8 °C in January (minimum) and 39.8 °C in June (maximum). Sometimes, maximum temperature in the summer months of May and June touches 48 °C, and minimum drops to 1.5 °C in winter month of January.

## Experimental setup

The experiment was conducted in a 4-year-old pomegranate orchard at central research farm of ICAR-CAFRI, Jhansi during 2017 to 2019. For establishing pomegranate orchard, the seeds of two cultivars of pomegranate, namely Ganesh and Bhagwa, were collected from ICAR-National Research Centre on Pomegranate, Solapur, Maharashtra, India. The seedlings were raised in the nursery, and healthy plants of 45 cm height were planted in the field at 5 × 3 m spacing during February 2013. Drip system was installed during 2016 to irrigate pomegranate plants. The experiment was designed in Factorial Randomized Block Design with two cultivars of pomegranate ($V_1$—Ganesh and $V_2$—Bhagwa) and four levels of nutrient management viz. $T_1$—vermicompost (30 kg/plant), $T_2$—FYM (30 kg/plant), $T_3$—vermicompost (30 kg/plant) + FYM (30 kg/plant) and $T_4$—recommended doses of chemical fertilizers (RDF). One-third of organic nutrition along with 0.5 kg neem (*Azadirachta indica*) cake per plant was applied just after pruning in the month of July, and remaining two-third was applied in three split doses in the month of September, October and November. In September, 1.0 kg neem cake per plant was also applied. The RDF included 625 g nitrogen (N), 250 g phosphorus (P) and 250 g potassium (K) for all 3 years (Sheikh 2006). Similar to organic nutrition, inorganic nutrition was also applied in split doses along with neem cake in the same months. The treatments were applied in pomegranate plants only for all the three consecutive years. The experiment was replicated thrice, and each treatment was having four plants of each cultivars. A control of pure lemongrass was also maintained separately. The Krishna variety of lemongrass, procured from CSIR-Central Institute of Medicinal and Aromatic Plants (CIMAP), Lucknow, Uttar Pradesh, India, was planted during July–August 2016 at spacing 50 × 40 cm in all treatments, except treatment $T_4$ in a plot size of 56 m$^2$ excluding area covered by pomegranate plants. The lemongrass was grown purely in rainfed conditions and without application of any fertilizer. Data on monthly distribution of rainfall at experimental site for the period from 2013 to 2019 are given in Table 1. During July–August 2018, due to increase in tussock size, lemongrass spacing was converted in to 100 × 80 cm by removing one tussock in between the two tussocks. The treatments of organic nutrition were applied in pomegranate plants during month of July.

## Characteristics of experimental soil, FYM and vermicompost

Characterization of experimental soil, FYM and vermicompost was done at the beginning of the experiment. Soil organic carbon (SOC) was determined by dichromate oxidation (Walkley and Black 1934) and available N by the alkaline potassium permanganate distillation method (Subbiah and Asija 1956). Available P in soil was determined by extracting samples with 0.5 M $NaHCO_3$ and determined P colorimetrically using molybdate (Olsen et al. 1954). Available K was determined using 1 N ammonium acetate extraction, followed by emission spectrometry (Jackson 1973). Available micro-nutrients viz. copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) were extracted with DTPA extractant (Lindsay and Norvell 1978) and estimated with the help of atomic absorption spectrophotometer (Make: ECIL; Model: AAS4141). The soil pH of experimental field ranged from 6.46 to 6.98 in surface (0–15 cm) and from 6.48 to 6.66 in sub-surface layer (15–30 cm). Similarly, electrical conductivity (EC) in surface and sub-surface

**Table 1** Distribution of rainfall (mm) during 2013–19 at ICAR-CAFRI, Jhansi

| Year | Rainfall (mm) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 2013 | 1.4 | 118.8 | 5.0 | 0.8 | 0.0 | 156.6 | 430.3 | 473.2 | 29.0 | 139.7 | 0.6 | 19.4 |
| 2014 | 51.6 | 69.2 | 3.4 | 15.2 | 8.5 | 82.8 | 179.5 | 76.2 | 119.5 | 0.2 | 0.0 | 23.4 |
| 2015 | 33.0 | 15.0 | 43.0 | 3.1 | 0.0 | 74.6 | 199.8 | 348.8 | 14.0 | 0.0 | 0.0 | 0.0 |
| 2016 | 0.0 | 0.0 | 7.2 | 0.0 | 27.6 | 118.1 | 336.0 | 168.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2017 | 17.4 | 0.0 | 0.0 | 0.0 | 28.8 | 116.2 | 241.4 | 152.8 | 90.4 | 0.0 | 0.0 | 0.0 |
| 2018 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 58.6 | 378.8 | 264.4 | 419.1 | 0.0 | 0.0 | 0.0 |
| 2019 | 0.0 | 25.2 | 0.1 | 0.0 | 0.0 | 40.8 | 302.1 | 137.3 | 227.7 | 37.9 | 0.0 | 3.0 |

layers ranged from 0.154 to 0.218 and 0.151 to 0.191 dS/m, respectively. The SOC ranged from 0.51 to 0.68% in surface and 0.42 to 0.64% in sub-surface layer. In surface soil, the available N, P and K ranged from 236 to 255 kg/ha, 9.4 to 13.6 kg/ha and 117.8 to 127.5 kg/ha, respectively, while in sub-surface layer, the values ranged from 212.2 to 254.3 kg/ha, 7.1 to 10.8 kg/ha and 115.4 to 125.6 kg/ha, respectively.

The vermicompost used in the experiment contained 8.42% organic carbon, 7.81 pH and 1.99 dS/m electrical conductivity (EC). The contents of N, P and K were 2.97, 0.96 and 1.01%, respectively. The DTPA extractable Zn, Fe, Cu and Mn were 7.44, 17.85, 2.28 and 20.49 ppm, respectively. The FYM used in the study contained 6.94% organic carbon, 8.70 pH and 3.41 dS/m EC. The contents of N, P and K were 1.10, 1.01 and 1.20%, respectively. The DTPA extractable Zn, Fe, Cu and Mn was 6.87, 10.75, 1.57 and 20.57 ppm, respectively.

### Observations and statistical analysis

Observations on plant growth and yield characteristics of pomegranate viz. height (m), collar diameter (cm), canopy spread (m) in East–West and North–South directions, number of fruits/plant, average fruit weight (g) and average fruit yield (kg/plant) were recorded every year (i.e., during 2017, 2018 and 2019). Hast Bahar crop (September flowering) was allowed for study purpose. The Bahar treatment was given by withholding of irrigation for two months prior to the Bahar. Thereafter, the treatments were imposed immediately after medium pruning and resumed irrigation. All quality parameters of the pomegranate fruits could not be assessed systematically, however, total soluble solids (TSS) and acidity in juice of both the cultivars viz. Ganesh and Bhagwa were estimated to perceive general fruit quality. In lemongrass, two cuts (May and October) in each year were taken and fresh yield (t/ha) was recorded. Simultaneously, the samples from each treatment were collected for both the cuts and sent to CSIR-CIMAP, Lucknow, Uttar Pradesh, India for oil estimation. The oil estimation through steam extraction using Clevenger apparatus was carried out in the laboratory after keeping the samples in shade for 24 h.

The statistical analysis of the data was done using online software OPSTAT (two-factor analysis) developed by Sheoran et al. (1998). For statistical analysis of lemongrass data, fresh yield and estimated oil (kg/ha) of both the cuts were clubbed together for each year and analyzed through OPSTAT. Since lemongrass was not planted in treatment $T_4$, only three treatments were used for data analysis and pure lemongrass (control) data were used for comparison.

## Results

### Plant growth and yield characters of pomegranate

Data pertaining to plant growth characteristics of pomegranate is presented in Table 2. The height and canopy spread of pomegranate remained unaffected by fertilizer treatments during all the years as indicated by non-significant variations. However, treatments of organic fertilizer caused significant variation in collar diameter throughout the study period, i.e., 2017, 2018 and 2019. The treatment $T_1$ recorded maximum collar diameter in 2017 (6.31 cm) and 2018 (6.96 cm) which was statistically at par with $T_2$ and $T_4$ in both the years, whereas in 2019, it was maximum in $T_4$ (7.13 cm) and at par with $T_1$ (7.03 cm). The order of the rank was

**Table 2** Effect of organic sources of nutrition on plant growth characters in pomegranate based agroforestry system

| Treatment | Collar diameter (cm) | | | Height (m) | | | Canopy spread (m) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | East–West | | | North–South | | |
| | 2017 | 2018 | 2019 | 2017 | 2018 | 2019 | 2017 | 2018 | 2019 | 2017 | 2018 | 2019 |
| Main plot ($V$) | | | | | | | | | | | | |
| $V_1$ | 6.68 | 7.36 | 7.58 | 3.01 | 2.57 | 3.29 | 1.87 | 1.41 | 2.41 | 1.83 | 1.44 | 2.33 |
| $V_2$ | 5.17 | 5.93 | 5.99 | 2.33 | 2.04 | 2.53 | 1.55 | 1.18 | 1.84 | 1.57 | 1.18 | 1.78 |
| CD 5% | 0.484 | 0.302 | 0.306 | 0.282 | 0.251 | 0.402 | 0.237 | 0.203 | 0.471 | 0.188 | 0.215 | 0.513 |
| Sub-plot ($T$) | | | | | | | | | | | | |
| $T_1$ | 6.31 | 6.96 | 7.03 | 2.78 | 2.33 | 3.13 | 1.81 | 1.33 | 2.15 | 1.78 | 1.32 | 2.15 |
| $T_2$ | 5.92 | 6.60 | 6.67 | 2.67 | 2.35 | 2.99 | 1.71 | 1.23 | 2.39 | 1.71 | 1.22 | 2.27 |
| $T_3$ | 5.36 | 6.25 | 6.32 | 2.60 | 2.13 | 2.70 | 1.65 | 1.22 | 1.89 | 1.60 | 1.27 | 1.93 |
| $T_4$ | 6.12 | 6.77 | 7.13 | 2.65 | 2.42 | 2.82 | 1.67 | 1.41 | 2.07 | 1.74 | 1.41 | 1.88 |
| CD 5% | 0.684 | 0.428 | 0.432 | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| $V \times T$ | | | | | | | | | | | | |
| $T_1V_1$ | 7.33 | 7.77 | 7.84 | 2.95 | 2.45 | 3.38 | 1.82 | 1.39 | 2.44 | 1.87 | 1.41 | 2.43 |
| $T_1V_2$ | 5.28 | 6.14 | 6.22 | 2.60 | 2.20 | 2.88 | 1.79 | 1.26 | 1.86 | 1.68 | 1.24 | 1.88 |
| $T_2V_1$ | 7.14 | 7.72 | 7.83 | 3.25 | 2.75 | 3.62 | 2.05 | 1.42 | 2.85 | 1.99 | 1.43 | 2.63 |
| $T_2V_2$ | 4.69 | 5.48 | 5.51 | 2.09 | 1.94 | 2.36 | 1.36 | 1.03 | 1.92 | 1.43 | 1.02 | 1.90 |
| $T_3V_1$ | 5.47 | 6.65 | 6.75 | 2.74 | 2.33 | 2.82 | 1.78 | 1.30 | 1.95 | 1.67 | 1.35 | 2.04 |
| $T_3V_2$ | 5.24 | 5.84 | 5.88 | 2.45 | 1.93 | 2.57 | 1.53 | 1.14 | 1.83 | 1.52 | 1.19 | 1.81 |
| $T_4V_1$ | 6.79 | 7.30 | 7.90 | 3.10 | 2.76 | 3.33 | 1.82 | 1.54 | 2.41 | 1.80 | 1.56 | 2.23 |
| $T_4V_2$ | 5.46 | 6.24 | 6.35 | 2.19 | 2.07 | 2.32 | 1.52 | 1.27 | 1.72 | 1.67 | 1.26 | 1.52 |
| CD 5% | 0.967 | 0.605 | 0.611 | NS | NS | NS | NS | NS | NS | NS | NS | NS |

$V_1$—cv. Ganesh, $V_2$—cv. Bhagwa; $T_1$—vermicompost @ 30 kg/plant, $T_2$—FYM @ 30 kg/plant, $T_3$—$T_1 + T_2$, $T_4$—recommended dose of fertilizer

$T_1 > T_4 > T_2 > T_3$ in 2017 and 2018, and $T_4 > T_1 > T_2 > T_3$ in 2019. The minimum diameter was obtained in $T_3$ during all the years. Irrespective of fertilizer treatments, better collar diameter, plant height and canopy spread were exhibited by cultivar $V_1$ (Ganesh) than $V_2$ (Bhagwa) throughout the investigation. The interactive effect of fertilizer treatments and cultivars was non-significant for plant height and canopy spread; however, significant for collar diameter during entire study period. Maximum collar diameter was recorded in $T_1V_1$ during 2017 (7.33 cm) and 2018 (7.77 cm) and were at par with $T_2V_1$ (7.14 and 7.72 cm, respectively) and $T_4V_1$ (6.79 and 7.30 cm, respectively) in both the years; however, in 2019, it was recorded maximum in $T_4V_1$ (7.90 cm) which was at par with $T_1V_1$ (7.84 cm) and $T_2V_1$ (7.83 cm). The minimum diameter was obtained in $T_2V_2$ in all three years of the study period. In general, it was observed that irrespective of fertilizer treatments, $V_1$ was superior over $V_2$.

Data pertaining to yield parameters of pomegranate revealed that significant variations were observed in yield attributes of pomegranate due to fertilizer treatments, cultivars and interactions, except number of fruits/plant in the year 2019, if only cultivars were concerned (Table 3). In general, cultivar $V_1$ recorded more numbers of fruits; average fruit weight and mean fruit yield/plant than cultivar $V_2$ in all the years of study period, except fruit numbers in the year 2018 wherein $V_2$ was superior over $V_1$. In general, fruit weight and yield increased with passage of growing period from 2017 to 2019. Irrespective of cultivars, fertilizer treatment had shown significant effects on all yield parameters during period of investigation. The treatment $T_3$ yielded maximum number of fruits in 2017 (22.45) and 2018 (21.81), while $T_1$ during 2019

**Table 3** Effect of organic sources of nutrition on yield and yield attributes in pomegranate based agroforestry system

| Treatment | Number of fruits/plant | | | Average fruit weight (g) | | | Average fruit yield (kg/plant) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2017 | 2018 | 2019 | 2017 | 2018 | 2019 | 2017 | 2018 | 2019 |
| Main plot (V) | | | | | | | | | |
| $V_1$ | 22.02 | 19.92 | 22.64 | 228.86 | 275.11 | 273.51 | 5.04 | 5.48 | 6.18 |
| $V_2$ | 17.00 | 21.95 | 22.59 | 202.25 | 222.25 | 221.39 | 3.43 | 4.88 | 5.00 |
| CD 5% | 0.931 | 0.677 | NS | 14.256 | 13.456 | 12.512 | 0.393 | 0.283 | 0.283 |
| Sub-plot (T) | | | | | | | | | |
| $T_1$ | 18.62 | 20.61 | 24.26 | 204.06 | 234.06 | 242.75 | 3.82 | 4.82 | 5.85 |
| $T_2$ | 17.82 | 21.09 | 21.96 | 231.67 | 261.67 | 253.78 | 4.24 | 5.51 | 5.58 |
| $T_3$ | 22.45 | 21.81 | 22.45 | 207.99 | 244.66 | 232.91 | 4.70 | 5.28 | 5.26 |
| $T_4$ | 19.16 | 20.22 | 21.80 | 218.50 | 254.33 | 260.36 | 4.18 | 5.12 | 5.68 |
| CD 5% | 1.317 | 0.957 | 1.801 | 20.162 | 19.029 | 17.695 | 0.556 | 0.401 | 0.400 |
| $V \times T$ | | | | | | | | | |
| $T_1V_1$ | 21.50 | 20.76 | 22.75 | 216.46 | 256.46 | 271.52 | 4.64 | 5.30 | 6.18 |
| $T_1V_2$ | 15.73 | 20.46 | 25.77 | 191.67 | 211.67 | 213.98 | 3.00 | 4.33 | 5.51 |
| $T_2V_1$ | 21.34 | 20.92 | 21.92 | 263.33 | 303.33 | 265.80 | 5.62 | 6.34 | 5.83 |
| $T_2V_2$ | 14.29 | 21.26 | 22.01 | 200.00 | 220.00 | 241.77 | 2.85 | 4.67 | 5.32 |
| $T_3V_1$ | 24.11 | 20.17 | 23.98 | 220.98 | 274.31 | 255.37 | 5.34 | 5.52 | 6.12 |
| $T_3V_2$ | 20.78 | 23.45 | 20.92 | 195.00 | 215.00 | 210.46 | 4.05 | 5.04 | 4.40 |
| $T_4V_1$ | 21.12 | 17.82 | 21.92 | 214.67 | 266.33 | 301.36 | 4.54 | 4.74 | 6.61 |
| $T_4V_2$ | 17.20 | 22.63 | 21.68 | 222.33 | 242.33 | 219.37 | 3.82 | 5.49 | 4.75 |
| CD 5% | 1.862 | 1.354 | 2.547 | 28.514 | 26.912 | 25.025 | 0.786 | 0.567 | 0.565 |

$V_1$—cv. Ganesh, $V_2$—cv. Bhagwa; $T_1$—vermicompost @ 30 kg/plant, $T_2$—FYM @ 30 kg/plant, $T_3$—$T_1 + T_2$, $T_4$—recommended dose of fertilizer

(24.26) which was at par with $T_3$ (22.45); whereas minimum fruits were counted in $T_2$ during 2017 (17.82), and in $T_4$ during 2018 (20.22) and 2019 (21.80). Similarly, average fruit weight was found maximum in $T_2$ during 2017 (231.67 g) and 2018 (261.67 g), which was at par with $T_4$ in the same years (218.50 and 254.33 g, respectively), while in 2019, it was maximum in $T_4$ (260.36 g) which was found at par with $T_2$ (253.78 g) and $T_1$ (242.75 g). Minimum fruit weight was recorded in $T_1$ during 2017 (204.06 g) and 2018 (234.06 g), and in $T_3$ during 2019 (232.91 g). Maximum average fruit yield was recorded in $T_3$ during 2017 (4.70 kg/plant), in $T_2$ during 2018 (5.51 kg/plant) and in $T_1$ during 2019 (5.85 kg/plant). Its minimum value was recorded in $T_1$ during 2017 (3.82 kg/plant) and 2018 (4.82 kg/plant), and in $T_3$ during 2019 (5.26 kg/plant). The interactive effects of cultivars and fertilizer treatments were also significantly different from each other. Maximum number of fruits was counted in treatment combination of $T_3V_1$ in 2017 (24.11), $T_3V_2$ in 2018 (23.45) and $T_1V_2$ in 2019 (25.77). Likewise, maximum fruit weight was recorded in $T_2V_1$ in 2017 (263.33 g) and 2018 (303.33 g), and in $T_4V_1$ in 2019 (301.36 g), whereas minimum weight was noticed in $T_1V_2$ during 2017 (191.67 g) and 2018 (211.67 g), and in $T_3V_2$ during 2019 (210.46 g). Similar trend was observed for fruit yield of pomegranate. In general, interactive effects were more pronounced in treatment combination of $T_2V_1$. As far as quality of pomegranate fruit is concerned, TSS ranged from 11.8 to 14.4°B in cultivar $V_1$ while in cultivar $V_2$, value varied between 13.2–15.1°B. Acidity in fruit juice of cultivars $V_1$ and $V_2$ varied from 0.35 to 0.45% and 0.33 to 0.44%, respectively. Both the cultivars appear to be on equal footings.

### Biomass production and oil recovery from lemongrass

Data presented in Table 4 revealed that fresh weight of lemongrass biomass was significantly influenced by tested cultivars in different years of the study period. Cultivar $V_1$ recorded significantly higher biomass during 2017 (8.01 t/ha) and 2018 (9.95 t/ha) than $V_2$ while reverse was true during 2019. In case of oil recovery, $V_1$ superseded $V_2$ during 2017 (38.34 kg/ha) and 2018 (53.23 kg/ha), while $V_2$ (130.41 kg/ha) gave higher value of oil recovery during 2019 in comparison with $V_1$ (98.32 kg/ha). Irrespective of cultivars, fertilizer treatment had significant effects on fresh biomass yield and oil recovery. During all the years of investigation, maximum fresh biomass yield was obtained in $T_3$ while minimum in $T_2$. Oil recovery was maximum in $T_3$ (38.52 kg/ha) during 2017; however, $T_1$ gave maximum oil recovery in 2018 (54.74 kg/ha) and 2019 (127.38 kg/ha). Treatment $T_2$ gave minimum oil recovery in all 3 years of the study period. The interaction effects between fertilizer treatments and cultivars significantly influenced lemongrass fresh biomass weight and oil recovery during period of investigation. In comparison with pure lemongrass plot (control), fresh weight was significantly reduced in all treatment combinations during all 3 years of investigation. Same trend was also noticed in case of oil recovery. In the year 2017, treatment combination $T_1V_1$ yielded maximum fresh weight (10.15 t/ha) as well as oil recovery (49.15 kg/ha), whereas $T_3V_2$ recorded maximum fresh weight (12.65 and 19.32 t/ha) and oil recovery (64.61 and 118.80 kg/ha) during 2018 and 2019.

## Discussion

### Plant growth and yield characters of pomegranate

Close perusal of the data presented in Table 2 reveals that wherever organic fertilizer was used either alone or in combination, the results were better than the application of chemical or inorganic fertilizers.

**Table 4** Fresh yield and oil recovery of lemongrass cv. Krishna in pomegranate based agroforestry system

| Treatment | Lemongrass fresh yield (t/ha) | | | Lemongrass oil recovery (kg/ha) on fresh weight basis | | |
|---|---|---|---|---|---|---|
| | 2017 | 2018 | 2019 | 2017 | 2018 | 2019 |
| Main plot (V) | | | | | | |
| $V_1$ | 8.01 | 9.95 | 15.02 | 38.34 | 53.23 | 98.32 |
| $V_2$ | 7.00 | 9.70 | 16.99 | 35.65 | 52.42 | 130.41 |
| CD 5% | 0.632 | 0.226 | 1.670 | 2.003 | 0.795 | 10.351 |
| Sub plot (T) | | | | | | |
| $T_1$ | 7.64 | 10.28 | 17.03 | 37.85 | 54.74 | 127.38 |
| $T_2$ | 6.94 | 8.50 | 13.92 | 34.62 | 50.74 | 104.68 |
| $T_3$ | 7.94 | 10.70 | 17.07 | 38.52 | 53.00 | 111.04 |
| CD 5% | 0.774 | 0.277 | 2.045 | 2.454 | 0.973 | 12.677 |
| $T$ x $V$ | | | | | | |
| $T_1V_1$ | 10.15 | 12.26 | 17.49 | 49.15 | 62.20 | 115.37 |
| $T_1V_2$ | 5.14 | 8.30 | 16.57 | 26.54 | 47.28 | 139.39 |
| $T_2V_1$ | 7.15 | 8.85 | 12.76 | 33.54 | 56.12 | 76.33 |
| $T_2V_2$ | 6.73 | 8.15 | 15.08 | 35.71 | 45.37 | 133.04 |
| $T_3V_1$ | 6.73 | 8.74 | 14.82 | 32.32 | 41.38 | 103.27 |
| $T_3V_2$ | 9.14 | 12.65 | 19.32 | 44.71 | 64.61 | 118.80 |
| CD 5% | 1.095 | 0.392 | 2.892 | 3.470 | 1.377 | 17.928 |
| Control | 11.68 | 15.39 | 25.90 | 131.18 | 173.41 | 265.53 |

$V_1$—cv. Ganesh, $V_2$—cv. Bhagwa; $T_1$—vermicompost @ 30 kg/plant, $T_2$—FYM @ 30 kg/plant, $T_3$—$T_1 + T_2$

Further, between two organic sources, vermicompost proved to be more beneficial than the FYM which may be attributed to the better nutritional status of the formers and also other factors such as soil microbial activity, mineralization, soil enzymatic factors and the presence of some phyto-hormones in worm-processed materials. These results are in the conformity with the findings of Gautam et al. (2012) who had worked on mango cv. Sunderja and reported maximum vegetative growth with application of FYM and vermicompost over chemical fertilizers. The improvement in growth might be due to increased photosynthetic rate and accumulation of carbohydrate as a result of multifarious role of FYM and vermicompost that allows most favorable conditions of soil with increased availability of plant nutrients responsible for better plant growth (Tiwari et al. 1999; Dutta et al. 2009). Improved vegetative growth in guava was also reported by Goswami et al. (2012) and Pathak and Ram (2005) with the application of different organic manures and biofertilizers. The increase in growth might be attributed to the stimulative activity of micro-flora in the rhizosphere leading to increased nutrient availability (Singh et al. 2000; Aseri et al. 2008). Suthar (2009) reported excellent plant growth and yield in *Allium sativum* with the application of vermicompost. Arancon et al. (2006) reported two major contributions of vermicompost to the field viz. increased in microbial populations and its activities, and production of plant growth influencing materials which ultimately enhance growth and production of the crops. Kumar et al. (2018) reported the efficacy of vermicompost in improving soil health, which resultantly improved the growth and productivity in initial stage of the growth of *Zizyphus mauritiana* cv. Seo in semi-arid region; and advocated that use of vermicompost could be an efficient plant growth medium that can ensure sustainable productivity. Sangeeta et al. (2017) recorded maximum growth by the application of 100% recommended dose of nitrogen through vermicompost in pomegranate cv. Super Bhagwa. Better growth and development with the application of 100% dose of nitrogen through vermicompost might be due to increased microbes in rhizosphere which might have helped in enhancing release of growth factors like auxins, gibberellins and cytokinins in pomegranate (Mir et al. 2015). Choudhary (2016) reported that vermicompost altered various enzymatic activities in plant such as peroxidase, catalase which promotes cell elongation, root and shoot growth and carbohydrate metabolism in *Z. mauritiana*.

In the present study, the vigorous growth in $V_1$ (Ganesh) can be assigned to the varietal characteristics exhibited due to application of organic fertilizers. Prasad et al. (2013) reported that cv. Bhagwa was highly vigorous in nature, whereas cv. Ganesh was medium in vigor that might be due to hybrid vigor reflection by the cv. Bhagwa as it is multi-hybrid variety. In our case, the result was reverse and the reasons could be the seedling population of both the cultivars which failed to exhibit their original characters despite same environmental condition and application of organic fertilizers. Similar to pomegranate plant growth characteristics, use of different sources of plant nutrition had caused significant variations in yield attributes of pomegranate. In general, use of organic sources yielded better results. These results are in conformity with the results of Marathe et al. (2017) who reported maximum fruit weight and fruit yield in FYM-treated plants as compared to vermicompost pronouncing that organic manures release nutrients slowly and make them available throughout the growing period resulting in better uptake of nutrients and yield. Increased microbial population and better soil physical environment due to organic fertilizers might have facilitated easy absorption of nutrients in balanced form and translated into increased yield. Higher residual effect of FYM was also reported in litchi (Sharma et al. 2005) and kinnow mandarin (Garhwal et al. 2014). In terms of pomegranate fruit quality, both the cultivars seem to be at par with $V_1$ having slight edge over $V_2$ in TSS. The assessed values of TSS and acidity in fruit juice were in agreement with findings of Prasad et al. (2013) and Marathe et al. (2017). However, detailed investigation is required on this aspect.

## Biomass production and oil recovery from lemongrass

Production of lemongrass biomass as well as its oil recovery was significantly influenced by cultivars of pomegranate and different treatments of plant nutrition. In comparison with pure lemongrass plot (control), fresh weight was significantly reduced in all the pomegranate and lemongrass treatment combinations during all 3 years of investigation. This trend also continued in case of oil recovery. Reduction in lemongrass fresh biomass and oil recovery might be attributed to shade effects of pomegranate plants. In general, fresh yield of lemongrass and oil recovery increased with progression in time from minimum in 2017 to maximum in 2019. We harvested 7–17 t/ha biomass of lemongrass producing 34–127 kg/ha oil on fresh weight basis from our experimental field. As far as productivity of lemongrass is concerned, the findings of present study are in conformity of results reported by Valtcho et al. (2011) who harvested 8–19 t/ha dry biomass yielding 23 to 139 kg/ha oil at different locations of Mississippi with the application of 80 kg/ha nitrogen and irrespective of the use of sulfur in irrigated condition. In contrast, our study was conducted in rainfed conditions that too without application of any fertilizer. Despite these constraints, the production of fresh biomass and oil recovery was quite satisfying, and farmers adopting this landuse system are likely to earn more income than the sole pomegranate orchard.

## Conclusion

The findings of the study, apart from its scientific value, have significant practical implications in phasing out use of inorganic fertilizers by organic source of nutrition without compromising productivity of agricultural land on sustainable basis. The study concluded that both the organic sources of plant nutrition viz. vermicompost and FYM were beneficial for the pomegranate plant as compared to chemical fertilizers. Out of the two organic sources, vermicompost was more effective than FYM in respect to sustainable crop production. Further, integration of lemongrass with pomegranate in rainfed conditions has shown potential for boosting farmers' economy by providing extra income from lemon oil in drought stricken semi-arid regions.

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