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ORIGINAL RESEARCH

Direct and residual effect of various vermicompost on soil nutrient and nutrient uptake dynamics and productivity of four mustard Pak-Coi (*Brassica rapa* L.) sequences in organic farming system

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Abstract

Purpose To study the direct effect on the first mustard cropping and the residual effect of three kinds of vermicompost on the productivity of the second, third, fourth Pak-Coi mustard sequential cropping.

Method A field experiment was conducted for four sequential planting periods of mustard Pak-Coi in silty clay Inceptisol. The experiment used a factorial randomized block design with two factors. Factor I comprised three kinds of vermicompost with three types of bedding materials; V1—spent mushroom waste, V2—coconut husk, and V3—sugarcane trash, while factor II comprised four different application rates: 5, 10, 15, and 20 t ha^{-1}. From these two factors, there were 12 treatments plus one control treatment (without vermicompost application).

Results Application of vermicompost increased soil NPK content. The highest nutrient uptake was also found in the residual effect for the second cropping. Nutrient uptake of the third and fourth mustard cropping had a decreasing trend. The highest yield on the first cropping was found in the application of vermicompost V2 and V1 with the application rates of 10–15 t ha^{-1}. In the second cropping, the productivity increased, whereas the third and fourth sequential cropping decreased in the vermicompost V1 and V2, whereas in the vermicompost V3 the productivity of the third and fourth cropping was slightly increased.

Conclusion The application of vermicompost to organic farming provides nutrient availability in four mustard subsequent planting periods. Differences in the dynamics of nutrient availability, nutrient uptake and crop yields are affected by the vermicompost materials used.

Keywords Vermicompost · Soil nutrient · Nutrient uptake · Plant productivity

Introduction

The long-term overcropping and overuse of inorganic fertilizers without organic input degrade soil quality and health and cause environmental pollution as well (Albiach et al. 2000). Decreasing soil quality can be avoided by proper and careful soil management as practiced by organic farmers. The application of organic fertilizer is an important practice in organic farming to improve soil quality, enhance microbial activity and nutrient recycle to produce high-quality crops. Thus, organic farming system produces healthy plant (Knapp et al. 2010; Dimitri et al. 2012). Increase in microbial biomass activity also results changes in soil enzymes that play an important role in soil biochemical reactions (Garcia-Gil et al. 2000; Ros et al. 2006). Organic matter input into the soil gives a long-term positive effect due to humus production that can increase the soil cation exchange capacity and water retention (Weber et al. 2007).

One of the organic fertilizers often used by organic farmers is vermicompost. Vermicompost is a compost produced by earthworm activity. During the vermicomposting process, earthworms play an important role in degrading organic materials. This process gradually decreases C:N ratio and increases the surface area of organic matter, hence making it easier for microorganisms to decompose it. Castings produced by earthworms will be biochemically

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decomposed by microorganisms (Domínguez et al. 2010). Vermicompost is widely used in the cultivation of horticultural crops. Vermicompost has an extensive potential for use on agricultural crops to replace or, alternatively, combine with inorganic fertilizers. The yield of some horticultural crops on treatment using vermicompost and inorganic fertilizers was not significantly different, but the quality of yield was higher than that of the inorganic fertilizers (Nurhidayati et al. 2015, 2016). Other researchers have evaluated the effects of vermicompost on the growth of other plants through various greenhouse and field studies. Vermicompost have a positive effect on physico-chemical properties of soil hence improving growth and yield of tomato (Atiyeh et al. 2000a, b; Atiyeh et al. 2001; Hashemimajd et al. 2004; Gutiérrez-Miceli et al. 2007). Application of vermicomposts to the soil also increased soil humic and plant growth hormone hence enhanced the growth and yield of pepper (Arancon et al. 2004a, 2005). Soil improvement with vermicompost can increase growth and yield of the other crops such as garlic (Argüello et al. 2006), aubergine (Gajalakshmi and Abbasi 2004), strawberry (Arancon et al. 2004b), and sweet corn (Lazcano et al. 2011). The combined effects of vermicompost and vermiwash can also increase the yield of organic linseed crop (Makkar et al. 2017). The improvement of soil physicochemical and the addition of plant growth substances in the soil stimulated the development of roots and growth of shoots and plant leaf area (Edwards et al. 2004; Lazcano et al. 2009). Roy et al. (2010) showed that the plots using vermicompost treatment had higher plant height, shoot and root weight as compared to compost or soil plots.

Vermicompost is a natural organic fertilizer product by earthworm. It releases the nutrients gradually into the soil (Chaoui et al. 2003). Therefore, it has the residual effect on the succeeding plant. Jat and Ahlawat (2006) reported that vermicompost application enhanced soil nutrient status (N and P) in subsequent crops compared to no vermicompost application. However, the residual value was determined by the vermicompost quality and the application rate. The effect of vermicompost on plants was different. It is dependent on crop species and genotype (Lazcano et al. 2011). Nutrient dynamics in the soil and the availability of nutrients in the soil, especially the total N and P available in the soil due to vermicompost applications have been studied by Jat and Ahlawat (2006) on chickpea–maize cropping system. Where the dynamics of nutrient availability in soil and nutrient uptake in vermicompost application after chickpea increased and decreased after maize. However, little is known about the direct and residual effects of various vermicompost on one plant species with several planting periods associated with soil nutrient, nutrient uptake dynamics and crop yields. The main aim of this study was to determine the direct and residual effects of various vermicompost with different rates on soil nutrient, nutrient uptake dynamics and productivity of mustard Pak-Coi for four planting periods.

Materials and methods

Study site and soil characteristics

This study was a field experiment conducted at Landungsari village, Dau district, Malang regency in March–July 2017 with an altitude of 544 m above sea level, 07°55′42.1″S latitude, and 112°35′55.0″E longitude. The average temperature was 22–28 °C while the rainfall is 1750 mm/year. The field had a semi-technical irrigation system. The type of soil was an Inceptisol. The soil characteristic was silty clay comprising 46% clay, 46% silt, and 8% sand. The soil had bulk density of 1.23 g cm^{-3}. The soil was low in organic carbon (0,96%), with pH 5.7, low in total N (0.15%), high in phosphorus (228.26 mg kg^{-1}), and low in available K(0.33 cmol kg^{-1} soil).

Vermicompost preparation

Making of vermicompost was done in vermicomposting bin having a size of 80 × 120 × 30 cm. Materials used in making of the vermicompost were the spent mushroom waste, coconut husk, sugar cane trash, cow dung, dry leaf litter, and fresh vegetable waste. The vegetable wastes were collected from the traditional market and were cut into the size of vegetable wastes pieces of ± 5 cm. The dry leaf litter and sugar cane trash were grounded by a grinder. The spent mushroom waste, coconut husk and sugarcane trash served as bedding materials, while the mixture of cow dung, leaf litter and the vegetable waste were used as worm feeds. The amount of material needed to fill the bin was 40 kg of bedding materials and 20 kg of worm feed. This amount was adapted to the capacity of the worm to decompose organic matter on a daily basis. Vermicomposting process lasted for 28 days using the earthworm species, *Lumbricus rubellus.* Thereafter, composting was done for 14 days. The vermicompost is also added with fish meal and eggshell flour with a composition of 5% as the additive materials. The addition of eggshell flour and fish meal was done after vermicomposting process. During the vermicomposting process, moisture content was maintained at 80%. The vermicomposting bin is covered with a black cloth to avoid the sun. The chemical compositions of the resulting vermicomposts were analyzed (Table 1).

Experimental design

This experiment used a factorial randomized block design (RBD) which consisted of two factors. Factor I comprised

Table 1 Chemical compositions of three kinds of vermicompost on dry weight basis

No.	Chemical properties	V1	V2	V3
1	Organic-C (%)	17.39	34.66	19.09
2	Polyphenol (%)	0.79	0.67	1.58
3	Cellulose (%)	26.75	27.86	27.34
4	Lignin (%)	25.08	24.15	15.8
5	Total N (%)	2.04	2.28	2.22
6	C:N ratio	8.52	15.22	8.60
7	P (%)	10.63	0.73	8.08
8	K (%)	0.23	1.05	0.52
9	pH	7.4	7.2	7.1
10.	Ash (%)	4.66	4.73	3.86

three kinds of vermicompost (V) with three different bedding materials; V1: mixture of spent mushroom waste, cow dung, vegetable waste, and leaf litter, V2: mixture of coconut husk, cow dung, vegetable waste and leaf litter, and V3: sugarcane trash, cow dung, vegetable waste and leaf litter. Factor II comprised 4 different rates of vermicompost application: D1 = 5 t ha^{-1}, D2 = 10 t ha^{-1}, D3 = 15 t ha^{-1}, and D4 = 20 t ha^{-1}. From these two factors, there were 12 treatment combinations plus one control treatment (without vermicompost application). Each treatment was replicated 3 times to obtain 39 units of experimental plot, and each experimental plot had 5 samples of the observed plants.

Experimental procedures

Pak-Coi mustard seeds were planted in the medium mixture of cow dung and soil with a ratio of 1:1. This seedling takes 3 weeks (21 days) to be ready for transplanting. Land preparation was done by tilling the soil with a hoe and then making a bed of 2.5 m × 1.5 m. All experimental plots received the application of cow dung with a rate of 5 t ha^{-1}. Three kinds of vermicompost were weighed in accordance with the application rate. Then, the vermicompost was incorporated into the well-prepared beds evenly using the hoe 1 week before planting. Mustard seedlings were planted at a spacing of 20 cm × 20 cm, 21 days after seeding and a week after vermicompost application. Watering and manual weeding was done. The mustard was harvested 28 days after transplanting. After harvesting the first crop of mustard, the land was cleared for 1 week and planting the second crop of mustard and so on for up to the fourth mustard cropping, to test the residual effects on the second, third and fourth cropping. The observed variables were soil nutrient, nutrient uptake, fresh and dry weights of total biomass, and weight of marketable yield for the fourth mustard cropping period.

The nitrogen (N) content in leaves of these crops was measured using modified Kjeldahl's method (Jackson 1973). The P content was calculated by vanado-molybdo-phosphoric acid yellow colour method (Jackson 1973) and the K content was measured with a flame photometer. The N, P and K content in leaves was multiplied with the respective dry matter of total biomass to get N, P and K uptake in crop. The soil samples from the experimental plots were analyzed for total N (modified Kjeldahl's method, Jackson 1973) and available-P (Bray I method, Jackson 1973) and extractable-K content (flame photometer) at 2 weeks after transplanting during the first mustard cropping and after harvesting the first, second and the third mustard cropping.

Statistical analysis

The collected data were statistically confirmed using analysis of variance (*F* Test) at $P \leq 0.05$ and the differences between each treatment were determined by Tukey test ($P \leq 0.05$) using Minitab Version 14.12. Dunnett's test at 5% level was used to compare all treatments with control. For statistical analysis of data, Microsoft Excel was used.

Results and discussion

Soil nutrient content

Based on the results of the analysis of variance at $P = 5\%$, variables of the soil nutrients content at the fourth soil sampling showed that the tested treatment significantly ($P < 0.05$) influenced the soil nutrient content of soil. The soil nutrient dynamics of each treatment on the fourth soil sampling is presented in Fig. 1. The dynamics of N and K nutrients in soils up to the fourth soil sampling had a similar pattern, where the increased availability of N and K occurs on the second soil sampling (after harvesting mustard 1). On the third and fourth soil sampling, soil N and K decreased (Fig. 1a, c). Nutrient dynamics of P in soils differ from N and K, where the highest P nutrient availability was found in the first soil sampling (2 weeks after transplanting). The succeeding soil sampling P tended to decrease (Fig. 1b).

Figure 1a also illustrated that the direct effects of application of three vermicompost treatments, on soil N was found highest in vermicomposts V2 and V3 at application rates of 15–20 t ha^{-1}. On the second and third soil sampling (after harvesting mustard 1 and 2) the same pattern of nutrient availability was still observed. However, at the fourth soil sampling (after harvesting mustard 3), the soil nutrients in the plots treated with vermicompost V3 at an application rate of 20 t ha^{-1} were higher than the other treatments. This suggests that the different bedding materials affected the release of nutrients into the soil. Bedding derived from the spent mushroom waste had the highest lignin content providing a low nutrient release although the vermicompost had a high

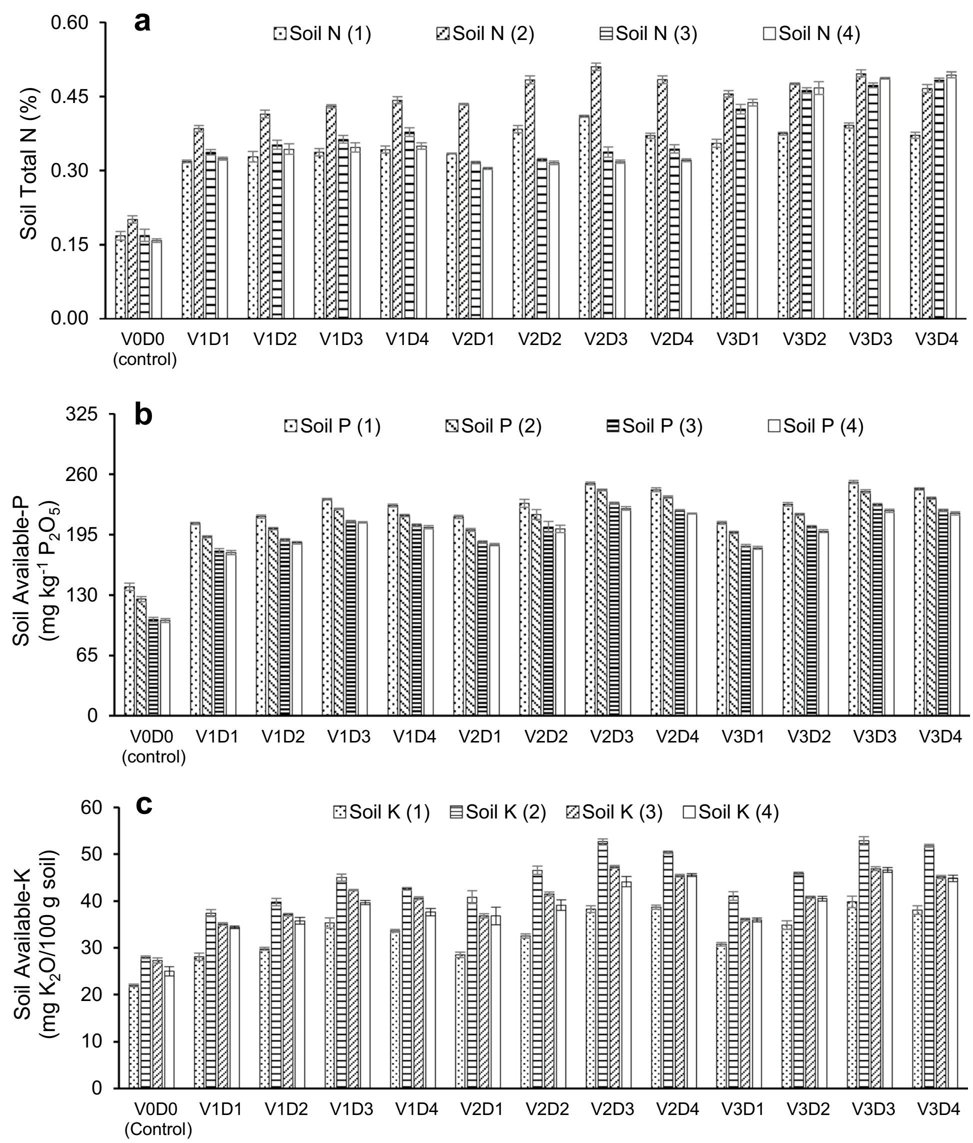

Fig. 1 The dynamics of soil N, P and K nutrient (**a**–**c**) due to direct and residual effect of three kinds of vermicompost on various application rates and the fourth soil sampling. (remarks: V1, V2, and V3 = kind of vermicompost, D1, D2, D3, and D4 = application rate (5, 10, 15, and 20 t ha^{-1}), (1), (2), (3), and (4) = time of soil sampling)

P content. Vermicompost V2 and V3 had a higher soil N content than V1. Thus, it released a higher N (Fig. 1b).

The highest soil N and K were found in the second soil sampling (after harvesting mustard 1), while the highest soil P was found at the first soil sampling (2 weeks after transplanting). In the next soil sampling, the soil P content decreased until the fourth soil sampling. The highest soil K was found on the plot treated with vermicompost V2. Vermicompost V2 contains bedding derived from coconut husk that has the highest K content. The chemical composition of vermicompost V2 had the highest K content (Table 1).

The dynamics of nutrient release for the fourth mustard cropping showed different patterns due to the application of three kinds of vermicompost. These results indicated that nutrient release is influenced by nutrient content in vermicompost. Yadav et al. (2010) showed that the characteristics of the raw material of vermicompost influenced the quality of vermicompost such as the total nutrient contents. Vermicompost V2 and V3 showed the highest nutrient availability especially N and K content on the second soil sampling. While vermicompost V3 still showed the highest N nutrient availability on the last soil sampling. Vermicompost V3 contained bedding derived from sugarcane trash which has a high N and the lowest lignin content (Table 1), which can increase the availability of N in the soil, while Vermicompost V1 contained the highest lignin. Differences in chemical composition of raw materials of organic matters such as organic-C, total N and lignin content as well as C:N and Lignin:N ratio affected the rate of decomposition and release of nutrients into the soil (Wardle et al. 2009; Moore et al. 2011).

De Araújo et al. (2010)reported that organic materials are mostly composed of carbon. The release of nutrient vermicompost was determined by the carbon quality and C:N ratio of the organic matters used. Thus, C:N ratio was an indicator of vermicompost maturity (Pattnaik and Reddy 2010). In addition to C:N ratio, the lignin content of organic matter affected the dynamics of N in the soil. Lignin was one of the most slowly decomposing components (Rahman et al. 2013). The three kinds of vermicompost had a C/N ratio < 20. This suggested that vermicomposts have high maturity and stability. An organic material with C:N ratio < 20 will be mineralized in soil releasing nutrients that can be absorbed by the plant. Among the three kinds of vermicompost, vermicompost V2 (bedding derived from coconut husk) had the highest C/N ratio of 15.22. Vermicompost V2 has the highest K content, because the coconut husk has a high K content.

Plant nutrient uptake

N, P and K uptake of the first mustard cropping was directly affected by three vermicompost applications, where vermicompost V1 and V2 provided the highest N uptake at an application rate of 10 t ha^{-1}, while the residual effect on the second plant, the highest N uptake was found in vermicompost V2 with application rate of 20 t ha^{-1}. Residual effects on the third and fourth mustards, vermicompost V2 and V3 at application rates of 15–20 t ha^{-1} gave the highest N uptake (Table 2).

The P uptake of mustard was not influenced by the direct effects of three vermicompost applications. However, the different rate significantly affect P uptake of the mustard where the highest P uptake was found at an application rate of 10 t ha^{-1}. The residual effect of three kinds of vermicompost on the P uptake of the second mustard was found on the plot treated with vermicompost V1 at application rates of 15–20 t ha^{-1}, while on the third and fourth mustard cropping, the highest P uptake was found in vermicompost 3 with an application rate of 15–20 t ha^{-1} (Table 2).

K uptake of the first mustard cropping was influenced by the direct effects of three vermicompost applications where the vermicompost V2 provided the highest K uptake at an application rate of 10–15 t ha^{-1}. The highest residual effect of the three kinds of vermicompost on K uptake of the second mustard was found in vermicompost V1 with application rate of 15–20 t ha^{-1}, while the highest residual effect on the third and fourth mustard was found in the plot treated with vermicompost V3 with application rate of 15–20 t ha^{-1}. These results demonstrated that the vermicompost derived from bedding of sugarcane trash gave the best residual effect on nutrient uptake until the fourth mustard cropping (Table 2).

Plant nutrient uptake highly depends on the nutrient release from the soil solid phase in the form of mineral and organic materials to the soil solution. The release of nutrients from organic matter occurs biochemically through the balance of mineralization and immobilization processes, while from mineral materials occurs physicochemically through adsorption and desorption, and precipitation and dissolution. The mineralization controls the soil solution concentration directly when the soil mineral does not release nutrient into the soil solution (Comerford 2005). Vermicompost as an organic fertilizer also undergoes mineralization releasing nutrients into the soil solution. The three kinds of vermicompost used in this study had a C/N ratio < 20. Thus, the vermicomposts had a high mineralization rate. Chaoui et al. (2003) reported that the vermicompost had a lower C/N ratio and indicated that it is more suitable for use as a soil amendment. It is due to the high NH_4^+ content released and converted into NO_3^- through the nitrification process during vermicomposting (Prabha 2009). Vermicompost contains high available nutrients, allowing not only a short supply of plant nutrient but also increasing reserves for the succeeding crops (Jat and Ahlawat 2006).

Crop yield

The fresh weight of total biomass differed significantly ($P < 0.05$) between the tested treatment combinations from either the direct effect for the first mustard cropping or the residual effect for the second, third and fourth mustard cropping (Table 3). The plots treated with vermicompost V2 at a rate of 10 t ha^{-1} had higher fresh weight of total biomass and weight of marketable yield than the other treatments though not significantly different with the treatment of vermicompost V1 at a rate 10–15 t ha^{-1} for direct effect of vermicompost (Tables 3 and 4). For the second mustard cropping, the treatments with vermicompost V1 at the rate of 10–20 t ha^{-1} significantly had the highest yield, but not significantly different with the vermicompost V3 at the rate of 20 t ha^{-1}. For the third mustard cropping, the treatments with vermicompost V3 at the rate of 15–20 t ha^{-1} significantly had the highest yield, but not significantly different with the vermicompost V1 at the rate of 20 t ha^{-1}. The fourth mustard cropping treated by vermicompost V3 at the rate of 15–20 t ha^{-1} significantly had the highest fresh weight of total biomass and weight of marketable yield (Tables 2, 3). All of the plots treated with three kinds of vermicompost significantly ($P < 0.05$) had higher yield than control (without vermicompost). Application of vermicomposts improved soil physicochemical and biological properties and added plant growth substance. Hence, it had a positive effect on the vegetative growth of plants and improved the yield and quality of horticultural crops (Atiyeh et al. 1999, 2000a, b, 2001; Hashemimajd et al. 2004; Gutiérrez-Miceli et al. 2007; Arancon et al. 2004b; Nurhidayati et al. 2016; Nurhidayati et al. 2017).

There was a trend of increased yield on the plots treated with three kinds of vermicompost for the residual effect

Table 2 Nutrient uptake of the first, second, third, and fourth mustard cropping as influenced by direct and residual effect of three kinds of vermicompost at various application rate

Treatments	Plant N-uptake (kg ha^{-1})			
	Mustard 1	Mustard 2	Mustard 3	Mustard 4
Kinds of vermicompost				
Vermicompost 1	160.31b	195.43b	100.63a	88.37a
Vermicompost 2	168.20b	166.29a	104.58ab	96.44a
Vermicompost 3	142.46a	169.37a	117.70b	131.59b
HSD 5%	14.15	20.63	14.49	12.56
Application rate				
5 t ha^{-1}	147.14a	150.40a	80.48a	84.09a
10 t ha^{-1}	184.79c	165.55a	105.62b	103.66b
15 t ha^{-1}	159.24b	193.17a	118.58bc	116.11b
20 t ha^{-1}	136.79a	199.00b	125.86c	118.01b
HSD 5%	19.76	28.80	20.22	17.53
Treatments	Plant P-uptake (kg ha^{-1})			
	Mustard 1	Mustard 2	Mustard 3	Mustard 4
Kinds of vermicompost				
Vermicompost 1	33.39a	34.96b	11.86a	10.65a
Vermicompost 2	32.69a	28.92a	12.18a	11.50a
Vermicompost 3	31.13a	30.01a	13.90b	14.55b
HSD 5%	3.06	3.64	1.60	1.37
Application rate				
5 t ha^{-1}	29.04a	26.09a	9.09a	9.40a
10 t ha^{-1}	37.57b	29.28a	12.20b	11.81b
15 t ha^{-1}	33.18ab	34.39b	14.13b	13.71c
20 t ha^{-1}	29.83a	35.43b	15.16c	14.00c
HSD 5%	4.27	5.08	2.23	1.91
Treatments	Plant K-uptake (kg ha^{-1})			
	Mustard 1	Mustard 2	Mustard 3	Mustard 4
Kinds of vermicompost				
Vermicompost 1	102.00ab	145.62b	72.82a	31.29a
Vermicompost 2	109.38b	123.11a	74.92ab	33.78a
Vermicompost 3	91.85a	131.92a	84.75b	43.06b
HSD 5%	11.33	17.14	9.90	4.04
Application rate				
5 t ha^{-1}	78.93a	100.07a	57.70a	26.72a
10 t ha^{-1}	120.68b	120.91a	75.31b	34.60b
15 t ha^{-1}	112.93b	159.52b	85.54bc	40.74c
20 t ha^{-1}	91.77a	153.70b	91.45c	42.12c
HSD 5%	15.81	23.92	13.83	5.64

Means followed by different letters in the same column are statistically significant different at Tukey test, $P=0.05$

of the second mustard cropping. The highest increase was found on the vermicompost V1 as 41% and followed by V3 as 26% and V2 as 0.5% as compared with the same treatments on the direct effect of the first mustard cropping. The next residual effect for the third and fourth mustard cropping had a trend to decrease yield on the plots treated with the vermicompost V1 and V2, while on the plots treated with the vermicompost V3 had a trend to increase yield slightly (Fig. 2a, b).

The results of this study corroborated with those reported by Jat and Ahlawat (2006) that the application of vermicompost had a positive effect on dry matter production directly

Table 3 Crop yield of the first, second, third, and fourth mustard cropping as influenced by direct and residual effect of interaction of three kinds of vermicompost and at various application rate

Treatments	Fresh weight of total biomass (t ha^{-1})			
	Mustard 1	Mustard 2	Mustard 3	Mustard 4
V0D0 (control)	37.31	47.65	42.48	45.07
V1D1	*47.81a	*60.35bcd	^{ns}44.00ab	^{ns}40.10a
V1D2	*54.00ab	*71.11ef	*51.97bc	^{ns}47.67abc
V1D3	*54.34ab	*79.96f	*54.77bcd	^{ns}50.54bcd
V1D4	*51.01a	*73.11ef	*58.50cde	^{ns}46.25abc
V2D1	*44.13a	^{ns}49.21a	^{ns}37.74a	^{ns}42.10abc
V2D2	*64.53b	*55.78abc	*51.59bc	^{ns}45.64abc
V2D3	*54.49ab	*59.96bc	*57.39cd	*50.98cd
V2D4	*52.80ab	^{ns}52.50ab	^{ns}48.05abc	^{ns}40.99ab
V3D1	*48.16a	^{ns}52.73ab	^{ns}47.84abc	^{ns}48.35bc
V3D2	*50.04a	*55.89abc	*57.56cd	*59.11de
V3D3	*51.62a	*64.79cde	*65.43de	*68.61ef
V3D4	*46.38a	*70.90def	*71.01e	*73.24f
HSD 5%	11.247	10.72	13.39	9.1
Dunnet 5%	6.09	5.80	7.24	5.20

Means followed by different letters in the same column are statistically significant different at Tukey test, $P=0.05$; *=significant; ns=non-significant at Dunnet test, $P=0.05$

Table 4 Marketable yield of the first, second, third, and fourth mustard cropping as influenced by direct and residual effect of interaction of three kinds of vermicompost and at various application rate

Treatments	Marketable yield (t ha^{-1})			
	Mustard 1	Mustard 2	Mustard 3	Mustard 4
V0D0 (control)	33.92	45.10	28.52	27.88
V1D1	*43.15ab	*57.55ab	*40.76ab	*37.01a
V1D2	*47.51ab	*68.39bcd	*48.92bc	*44.51abc
V1D3	*50.64abc	*77.48d	*51.58bcd	*47.40cd
V1D4	*47.95ab	*70.22cd	*55.09cde	*43.24abc
V2D1	*41.17a	*46.33a	*35.10a	*39.28abc
V2D2	*60.20c	*47.98a	*47.79bc	*42.65abc
V2D3	*51.90bc	*57.67ab	*54.44cde	*47.83cd
V2D4	*48.00ab	*50.25ab	*44.84abc	*37.54ab
V3D1	*45.20ab	*49.99ab	*44.65abc	*45.53bc
V3D2	*46.26ab	*53.32ab	*54.10cd	*55.96d
V3D3	*47.78ab	*59.67bc	*62.08de	*65.78e
V3D4	*42.56ab	*68.42bcd	*67.26e	*70.50e
HSD 5%	9.85	11.32	13.13	9.81
Dunnet 5%	5.33	6.13	7.10	5.31

Means followed by different letters in the same column are statistically significant different at Tukey test, $P=0.05$; *=significant; ns=non-significant at Dunnett test, $P=0.05$

on the first crop and gave residual effects on the succeeding crop. Chaoui et al. (2003) showed application of slow release fertilizer increased the synchrony between the plant's nutrient requirements and nutrient availability hence to increase plant biomass. The favorable response of vermicompost might be due to relatively higher nutrient content of vermicompost, thereby enriching the supply of the entire essential macro- and micronutrients and increasing plant nutrient uptake (Gupta and Garg 2008; Nath et al. 2009; Chauhan and Joshi 2010; Shak et al. 2014). Increase in crop yield, however, was not only caused by the availability of adequate nutrients and synchrony of plant's requirements, but also due to the improvement of soil physical properties affected by vermicompost application. Azarmi et al. (2008) reported that vermicompost applications can improve the bulk density and total porosity of the soil. Horticultural crops require soil conditions that are crumb due to shallow rooting. Vermicompost could also improve the soil aeration and infiltration (Arancon et al. 2008), thus providing a better medium for root growth (Chaoui et al. 2003). Improvement of soil physical conditions can create a good growth medium for crops hence the growth and crop yields increase (Manivannan et al. 2009).

Conclusion

Application of three kinds of vermicompost significantly increased soil nutrient availability, nutrient uptake and crop yield as compared with the control (without vermicompost application) for four mustard cropping sequences. The application of vermicompost provided the highest availability of N and K in soils on the second soil sampling (after harvesting mustard 1). While the highest P nutrient availability was found on the first soil sampling (2 weeks after transplanting the first mustard cropping). Application of vermicompost directly affected nutrient uptake and mustard yield, where the highest was found in vermicompost with bedding derived from coconut husk with dose of 10 t ha^{-1} but not significantly different with vermicompost using bedding of spent mushroom waste. The residual effect of vermicompost on the second mustard gave an increase in nutrient uptake and yield as compared with the direct effect, where the highest was found in vermicompost with bedding derived from the spent mushroom waste at rates of 10–15 t ha^{-1} and sugarcane trash at a rate of 20 t ha^{-1}. Vermicompost with bedding sugarcane trash with a rate of 20 t ha^{-1} provided the best residual effect on the third and fourth mustard sequential cropping. These results suggest that vermicompost application is required in organic farming systems to provide the best direct and residual effect on the availability of soil nutrient, plant nutrient uptake and crop yields.

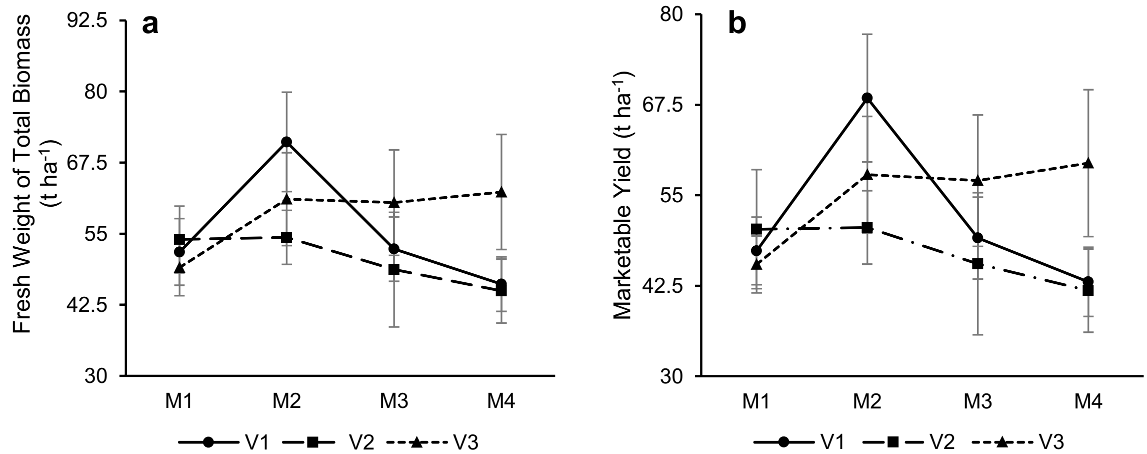

Fig. 2 The productivity of mustard due to direct and residual effect of three kinds of vermicompost at various application rates and the fourth planting periods of mustard. (remarks: M1, M2, M3 and M4 = The first, second, third and fourth mustard cropping)

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References

Albiach R, Canet R, Pomares F, Ingelmo F (2000) Microbial biomass content and enzymatic activities after the application of organic amendments to a horticultural soil. Bioresour Technol 75(1):43–48. https://doi.org/10.1016/S0960-8524(00)00030-4

Arancon NQ, Edwards CE, Atiyeh RM, Metzger JD (2004a) Effects of vermicompost produced from food waste on the growth and yields of greenhouse peppers. Bioresour Technol 93(2):139–144. https://doi.org/10.1016/j.biortech.2003.10.015

Arancon NQ, Edwards CA, Bierman P, Welch C, Metzger JD (2004b) Influences of vermicomposts on field strawberries: 1. Effects on growth and yields. Bioresour Technol 93(2):145–153. https://doi.org/10.1016/j.biortech.2003.10.014

Arancon NQ, Edwards CA, Bierman P, Metzger JD, Lucht C (2005) Effects of vermicomposts produced from cattle manure, food waste and paper waste on the growth and yield of peppers in the field. Pedobiologia 49(4):297–306. https://doi.org/10.1016/j.pedobi.2005.02.001

Arancon NQ, Edwards CA, Babenko A, Cannon J, Galvis P, Metzger JD (2008) Influences of vermicomposts, produced by earthworms and microorganisms from cattle manure, food waste and paper waste, on the germination, growth and flowering of petunias in the greenhouse. Appl Soil Ecol 39:91–99. https://doi.org/10.1016/j.apsoil.2007.11.010

Atiyeh RM, Subler S, Edwards CA, Metzger J (1999) Growth of tomato plants in horticultural potting media amended with vermicompost. Pedobiologia 43:1–5

Atiyeh RM, Subler S, Edwards CA, Bachman G, Metzger JD, Shuster W (2000a) Effects of vermicomposts and compost on plant growth in horticultural container media and soil. Pedobiologia 44(5):579–590. https://doi.org/10.1078/S0031-4056(04)70073-6

Atiyeh RM, Arancon NQ, Edwards CA, Metzger JD (2000b) Influence of earthworm-processed pig manure on the growth and yield of greenhouse tomatoes. Bioresour Technol 75(3):175–180. https://doi.org/10.1016/S0960-8524(00)00064-X

Atiyeh RM, Edwards CA, Subler S, Metzger JD (2001) Pig manure vermicompost as a component of a horticultural bedding plant medium: effects on physicochemical properties and plant growth. Bioresour Technol 78(1):11–20. https://doi.org/10.1016/S0960-8524(00)00172-3

Azarmi R, Giglou MT, Taleshmikail RD (2008) Influence of vermicompost on soil chemical and physical properties in tomato (*Lycopersicum esculentum*) field. Afr J Biotechnol 7(14):2397–2401

Chaoui HI, Zibilske LM, Ohno T (2003) Effects of earthworm casts and compost on soil microbial activity and plant nutrient availability. Soil Biol Biochem 35:295–302. https://doi.org/10.1016/S0038-0717(02)00279-1

Chauhan A, Joshi PC (2010) Composting of some dangerous and toxic weeds using *Eisenia foetida*. J. Am Sci 6 (3):1–6. http://www.americanscience.org

Comerford NB (2005) Soil factors affecting nutrient bioavailability. In: Bassiri Rad H (ed), Ecological studies, vol. 181. Nutrient acquisition by plants an ecological perspective. ISBN: 978-3-540-24186-7. Springer, Berlin, 7 pages

De Araújo ASF, De Melo WJ, Singh RP (2010) Municipal solid waste compost amendment in agricultural soil: changes in soil microbial biomass. Rev Environ Sci Biotechnol 9(1):41–49. https://doi.org/10.1007/s11157-009-9179-6

Dimitri C, Kemp L, Sooby J, Sullivan E (2012) Organic farming for health and prosperity. Organic Farming Research Foundation. Washington, D.C. Ofrf.org. 75 pages. https://www.ofrf.org/sites/ofrf.org/files/docs/pdf/HP-report-web.pdf

Domínguez J, Aira M, Gómez Brandón M (2010) Vermicomposting: earthworms enhance the work of microbes. In: Insam H, Franke-Whittle I, Goberna M (eds) Microbes at work: from wastes to resources. Springer, Berlin Heidelberg, pp 93–114

Edwards CA, Domínguez J, Arancon NQ (2004) The influence of vermicomposts on plant growth and pest incidence. In: Shakir SH, Mikhaïl WZA (eds) Soil zoology for sustainable development in the 21st century, Cairo, pp 397–420

Garcia-Gil JC, Plaz C, Soler-Rovira P, Polo A (2000) Long-term effects of municipal solid waste compost application on soil enzyme activities and microbial biomass. Soil Biol Biochem 32(13):1907–1913. https://doi.org/10.1016/S0038-0717(00)00165-6

Gajalakshmi S, Abbasi SA (2004) Neem leaves as a source of fertilizer-cum-pesticide vermicompost. Bioresour Technol 92(3):291–296. https://doi.org/10.1016/j.biortech.2003.09.012

Gupta R, Garg VK (2008) Stabilization of primary sewage sludge during vermicomposting. J Hazard Mater 153(3):1023–1030. https://doi.org/10.1016/j.jhazmat.2007.09.055

Gutiérrez-Miceli FA, Santiago-Borraz J, Molina JAM, Nafate CC, Abdud-Archila M, Llaven MAO, Rincón-Rosales R, Dendooven L (2007) Vermicompost as a soil supplement to improve growth, yield and fruit quality of tomato (*Lycopersicum esculentum*). Bioresour Technol 98(15):2781–2786. https://doi.org/10.1016/j.biortech.2006.02.032

Hashemimajd K, Kalbasi M, Golchin A, Shariatmadari H (2004) Comparison of vermicompost and composts as potting media for growth of tomatoes. J Plant Nutr 27(6):1107–1123. https://doi.org/10.1081/PLN-120037538

Jackson ML (1973) Soil chemistry analysis, 2nd edn. Prentice Hall of India Pvt. Ltd, New Delhi

Jat RS, Ahlawat IPS (2006) Direct and residual effect of vermicompost, biofertilizers and phosphorus on soil nutrient dynamics and productivity of chickpea-fodder maize sequence. J Sustain Agric 28(1):41–54. https://doi.org/10.1300/J064v28n01_05

Knapp BA, Ros M, Insam H (2010) Do composts affect the soil microbial community? In: Insam H, Franke-Whittle I, Goberna M (eds) Microbes at work: from wastes to resources. Springer, Berlin, pp 93–114

Lazcano C, Arnold J, Tato A, Zaller JG, Domínguez J (2009) Compost and vermicompost as nursery pot components: effects on tomato plant growth and morphology. Span J Agric Res 7(4):944–951

Lazcano C, Revilla P, Malvar RA, Domínguez J (2011) Yield and fruit quality of four sweet corn hybrids (*Zea mays*) under conventional and integrated fertilization with vermicompost. J Sci Food Agric 91(7):1244–1253. https://doi.org/10.1002/jsfa.4306

Makkar C, Singh J, Parkashi C (2017) Vermicompost leachate reduces some negative effects of salt stress in pomegranate. Int J Recycl Org Waste Agric 6:255–263. https://doi.org/10.1007/s40093-017-0168-4

Manivannan S, Balamurugan M, Parthasarathi K, Gunasekaran, G, Ranganathan LS (2009) Effect of vermicompost on soil fertility and crop productivity – beans (*Phaseolus vulgaris*). J Environ Biol 30(2):275–281

Moore TR, Trofymow JA, Prescott CE, Titus BD (2011) Nature and nurture in the dynamics of C, N and P during litter decomposition in Canadian forest. Plant Soil 339:163–175. https://doi.org/10.1007/s11104-010-0563-3

Nath G, Singh K, Singh DK (2009) Chemical analysis of vermicomposts/vermiwash of different combinations of animal, agro and kitchen wastes. Aust J Basic App Sci 3(4):3671–3676. http://www.ajbasweb.com/old/ajbas_oct-dec_2009.html

Nurhidayati, Ali U, Murwani I (2015) Influence of the kind of vermicompost material and earthworm *Pontoscolex corethrurus* population on the yield and quality of phak-coi mustard (*Brassica rapa* L.) with organic potting media. In: Proceeding of the first international conference on life science and biotechnology exploration and conservation of biodiversity. ISBN: 978-602-9030-98-3.p.168-176

Nurhidayati, Machfudz M, Murwani I (2017) Combined effect of vermicompost and earthworm Pontoscolex corethrurus inoculation on the yield and quality of broccoli (*Brassica oleracea L*) using organic media. JOBARI 22(4):148–156

Nurhidayati N, Ali U, Murwani I (2016) Yield and quality of cabbage (*Brassica oleracea* L.var.Capitata) under organic growing media using vermicompost and earthworm *Pontoscolex corethrurus* inoculation. Agric Agric Sci Proc 11:5–13. https://doi.org/10.1016/j.aaspro.2016.12.002

Pattnaik S, Reddy MV (2010) Nutrient status of vermicompost of urban green waste processed by three earthworm species: *Eisenia fetida*, *Eudrilus eugeniae*, and *Perionyx excavatus*. App Environ Soil Sci article ID 967526 (2010). 13 pages. http://dx.doi.org/10.1155/2010/967526

Prabha ML (2009) Waste management by vermitechnology. Indian J Environ Prot 29(9):795–800

Rahman MM, Tsukamoto J, Rahman MM, Yoneyama A, Mostafa KM (2013) Lignin and its effects on litter decomposition in forest ecosystems. Chem Ecol 29(6):540–553. https://doi.org/10.1080/02757540.2013.790380

Ros M, Pascual JA, García C, Hernández MT, Insam H (2006) Hydrolase activities, microbial biomass and bacterial community in a soil after long-term amendment with different composts. Soil Biol Biochem 38(12):3443–3452. https://doi.org/10.1016/j.soilbio.2006.05.017

Roy S, Arunachalam K, Dutta BK, Arunachalam A (2010) Effect of organic amendments of soil on growth and productivity of three common crops viz. *Zea mays*, *Phaseolus vulgaris* and *Abelmoschus esculentus*. App Soil Ecol 45:78–84. https://doi.org/10.1016/j.apsoil.2010.02.004

Shak KPY, Wu TY, Lim SL, Lee CA (2014) Sustainable reuse of rice residues as feedstocks in vermicomposting for organic fertilizer production. Environ Sci Pollut Res 21(2):1349–1359. https://doi.org/10.1007/s11356-013-1995-0

Wardle DA, Bardgett RD, Walker LR, Bonner KI (2009) Among- and within-species variation in plant litter decomposition in contrasting long-term chronosequences. Funct Ecol 23:442–453. https://doi.org/10.1111/j.1365-2435.2008.01513.x

Weber J, Karczewska A, Drozd J, Licznar M, Licznar S, Jamroz E, Kocowicz A (2007) Agricultural and ecological aspects of a sandy soil as affected by the application of municipal solid waste composts. Soil Biol Biochem 39(6):1294–1302. https://doi.org/10.1016/j.soilbio.2006.12.005

Yadav KD, Tare V, Ahammed MM (2010) Vermicomposting of source separated human faeces for nutrient recycling. Waste Manag 30(1):50–56. https://doi.org/10.1016/j.wasman.2009.09.034