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A valorisation approach in recycling of organic wastes using low-grade rock minerals and microbial culture through vermicomposting

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ABSTRACT

A study was steered to explore the effect of rock mineral addition (i.e., rock phosphate (RP), dolomite (DM) and mica (MC)) in organic wastes (e.g., water hyacinth and paddy straw) along with microbial inoculums on vermicompost quality. Different amalgamations of four microbial inoculums viz., *Trichoderma viride, Azotobacter chroococcum, Bacillus polymixa* and *Bacillus firmus,* and three rock minerals i.e., RP, DM, and MC were used during vermicomposting process to access their effect on the quality of mature vermicompost. A significant reduction in pH, organic carbon, C/N ratio, while significant increase in humic acid, total nitrogen, available phosphorus and exchangeable potassium was observed in each of the vermibeds. Furthermore, enzymatic activities were also boosted considerably due to Vermi-stabilization. Application of rock minerals at 10% (200 g in 2 kg organic waste mixture) along with microbial inoculants in the vermicomposting process promoted the availability of macronutrients as compared to control treatment. The results showed that the combination of rock minerals and microorganisms along with earthworms facilitated the decomposition and reduced the overall time required for composting besides producing a nutrient-enriched vermicompost product.

1. Introduction

Wastes originating from animals and plants are one of the major under-utilized resources globally (Balaman, 2019). Lack of viable technology is a major restraint in the way to recycle and reuse such wastes at full potential (Chander et al., 2018). The essence of sustainability in agricultural sector lies in recycling of organic wastes and ensuring availability of good-quality organic manure at comparably cheaper rate (Chatterjee et al., 2017). Reusing organic wastes has realized momentum in the current years due to pricey fertilizers and consumer preference for quality (healthy) products (Chew et al., 2019). Although, composting is a meticulous biological oxidative decomposition of organic matter, it is a prevalent process for recycling organic (waste) materials. However, it has some obvious disadvantages like, loss of nutrients during the process, requirement of infrastructure (e.g., land, equipment and labour), and bad odor associated with the composting process. In this perspective, vermicomposting can be a path-breaking technology to achieve sustainability goals in agriculture (Lazcano and Domínguez, 2011). Vermicomposting being an eco-friendly technology for converting organic wastes into high-value organic manure can overcome the shortcomings of traditional composting process and can be a more valuable tool after value addition (Singh et al., 2020).

However, the selection of feedstock plays a major role in quality of compost/vermicompost (Fuchs and Cuijpers, 2016). Although, India is opulent in production of on-farm residues; using alternative sources like aquatic weeds, may return higher benefits at ecosystem level. Among such wastes, water hyacinth (*Eichhornia crassipes*), a free-floating macrophyte is abundant in wetlands, especially in north-eastern part of India (approximately 23.15%). Despite being controlled by natural predators, water hyacinth has caused havoc in the whole area (north-eastern part of India) (Degaga, 2018). For instance, diminution of fishes due to its rapid growth and the robustness of its seeds is a major problem for aquatic ecosystem. Water hyacinth is also known as the world's rapid-growing aquatic weed, as it double sits biomass within 14 days. Aversion of river traffic and chocking of irrigation canals due to formation of dense mats of such macrophytes adversely affect hydro-power projects, and also destroys rice fields (Gupta et al., 2007). As of its intrinsic nature, water hyacinth is now considered a potential threat to the aquatic environment in many countries; especially if it is not well managed for sustainable production of value-added products (e.g., vermicomposting) (Ojo et al., 2019). Nevertheless, it could generate additional economic advantages in agrarian economies. On the other hand, environmental problems originating from on-field burning of agro-residues at a very large scale to save time, labor and enable farm machinery to work efficiently for the next cropping season can be efficiently addressed using the vermicomposting technology (Singh, 2021) (Kuttippurath et al., 2020). However, burning of paddy straw in fields can be prevented by adopting prac-

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tices for its alternative use and appropriate mechanism to handle such large quantities of the crop residues (Abbhishek, 2021) (Timsina, 2005). The basic challenge in efficient utilization of such aquatic and agro feed stocks is value addition to them through technological interventions.

Vermicomposting is a bio-chemical process that transforms organic matter into a stabilized humus like product (Ali and Nazir, 2021), which have relatively high contents of readily available plant nutrients, growth promoting substances, enzymes, and a number of beneficial and active microorganisms (Olle, 2019). However, a major limitation of traditional vermicompost prepared from on-farm wastes lies in its inherent low nutrient content, particularly macro-nutrients (Sannigrahi, 2016). Nevertheless, these nutrients might be augmented by adopting different ways to prepare a good-quality product by treating the aquatic and on-farm waste with certain efficient micro-flora in the pre-decomposition state (Shalaby, 2011). Valorization of organic wastes through vermicomposting might be an efficient way to recycle nutrient-rich biomass back to the field (Lim and Wu, 2016). However, new interventions might help in reducing the time period of vermicomposting processes.

Trichoderma viride (TV) is the best-known hemi-cellulose and cellulose degrading micro flora apart from being N_2 fixer, phosphorus solubilizing, and potassium solubilizing bacteria (Tang et al., 2020). Inoculation of TV during the vermicomposting process may enhance the vermicompost quality by increasing nitrogen, phosphorus and potassium content of the vermicompost. Besides microbial inoculation, vermicompost can also be enriched with specific nutrients using less important natural rock minerals.

India has an estimated stock of 296 million tons of rock phosphate (RP), out of which most of that are not suitable for commercial use due to inherent low P content (Indian Minerals Year book 2013). The commercial production of phosphatic fertilizers requires high P-content as well as high reactivity of RP (Narayanasamy and Biswas, 1998). On the other hand, India spends a larger portion of its foreign exchange in importing the potash fertilizers as muriate of potash or sulphate of potash, which are not available indigenously. However, mines of mica (MC) which is another K-rich mineral are opulent in east-central part of India (e.g., Koderma, Giridih and Hazaribagh districts of Jharkhand), and can also be considered as nature's gift to this country (Nishanth and Biswas, 2008). This also provides an opportunity to explore the possibilities for its use as a source of plant available K, through adopting different processes of chemical or biological mobilization. In this perspective, use of *Bacillus mucilaginous* could be an alternative and viable technology to solubilize insoluble K-fertilizer for sustaining crop production and maintaining soil potassium (Basak and Biswas, 2009).

Similarly, about 738 million tons of dolomite (DM) are available in India (UNFC (2014) 2012), which contain the substantial amount of Ca (18–22%) and Mg (8–12%). Addition of these natural minerals in vermicomposting process may influence the pH of the medium and lead to production of enriched vermicompost. However, there is a dearth of knowledge on the preparation of enriched vermicompost using natural rock minerals such as low-grade rock phosphate, dolomite, and mica along with microbial consortium using aquatic vis-a vis on-farm crop residue and its effects on changes in soil fertility in intensive cropping system.

Nevertheless, available literature definitely indicates that the production technology of traditional vermicompost could be molded with efficient utilization of such intermediaries. Furthermore, the plenty of research related to the addition of rock minerals in the composting process is available. As per best of our knowledge, this is for the first time where we have attempted addition of rock minerals (DM and MC, except RP) in the vermicomposting process for higher solubility of nutrients. We couldn't find much reference regarding rock mineral addition in the vermicomposting process. Nonetheless, there is very less information available regarding optimal doses of rock minerals required during vermicomposting to obtain a better-quality organic fertilizer (i.e., based on earthworm tolerance capacity). However, technology up-gradation aimed to enrich the vermicompost using different rock minerals and microbial combinations need to be evaluated comparatively to provide a new direction for value addition and production of a high-quality organic fertilizer.

Table 1
Chemical properties of organic wastes. The results are expressed as Mean± Standard deviation.

Parameters	Cow dung	Water Hyacinth	Paddy straw
pH	6.2 ± 0.03	7.3 ± 0.03	7.8 ± 0.04
EC (dSm^{-1})	1.3 ± 0.011	0.6 ± 0.02	0.7 ± 0.02
Organic C (%)	20.3 ± 1.11	29.6 ± 1.04	52.6 ± 1.31
Total N (%)	0.68 ± 0.04	0.62 ± 0.04	0.78 ± 0.04
C/N ratio	30	48	67
Total P (%)	0.40 ± 0.03	0.35 ± 0.03	0.27 ± 0.03
Total K (%)	0.65 ± 0.04	0.82 ± 0.05	0.62 ± 0.05

Therefore, we propose a hypothesis that vermicomposting using different combination of less valuable rock minerals (low-grade rock phosphate, dolomite and mica) and microbial inoculum would enhance the dissolution of mineral nutrients into their respective available forms through chemical and physical weathering, enzymatic action and intestinal grinding of the materials as they pass through the earthworm's gut. Consequently, we design an experiment to test the specific objective of assessing the quality of vermicompost prepared from two different organic wastes (i.e., Paddy straw and Water hyacinth) enriched with rock minerals (Rock phosphate, dolomite and mica) at varying levels in presence and absence of microbes.

Material and methods

Organic wastes and earthworm species used for vermi-conversion

Two plants based organic wastes such as water hyacinth, WH (aquatic weeds), paddy straw, PS (a by-product of rice), along with one animal waste, (i.e., cow dung) were used in this study. Quality of these organic wastes differed with respect to C/N ratio (i.e., 48:1 for water hyacinth, 67:1 for paddy straw and 32:1 for cow dung). These biodegradable organic wastes were evaluated for their effect on, nutrient status and maturity of vermicompost (VC). In the vermicomposting process, exotic epigeic earthworm '*Eisenia foetida*', weighing about 300–350 mg were used. The stock cultures of around 500–2000 earthworms, were maintained in the laboratory with cow dung as culturing material. The waste materials, paddy straw and water hyacinth were collected from the research farm of the Institute, and fresh cow dung was procured from adjacent cattle dairy farm. The chemical properties of organic wastes are given in Table 1.

Rock minerals

The rock minerals such as rock phosphate (RP), dolomite (DM), and mica (MC) minerals were used for enriching the VC with phosphorus (P), calcium-magnesium (Ca-Mg), and potassium (K) respectively. RP and DM were collected from West Bengal Mineral Development and Trading Corporation Limited, Purulia, West Bengal and mica waste was collected from Prakash Pvt. Ltd., Jharkhand. The nutrient composition of the mineral element is given in Table 2.

Microbial source

Pure cultures of microbial inoculants used in the composting process were *Trichoderma viride, TV* (cellulolytic and lignolytic fungi), *Azotobacter chroococcum, AZC* (free- living nitrogen-fixing bacteria, for enriching nitrogen), *Bacillus polymixa, PSB* (phosphate-solubilizing bacteria, for enriching phosphorus), and *Bacillus firmus, KSB* (potassium-releasing bacteria for enriching potassium). The microbial inoculants, *TV, AZC* and *PSB* were procured from Institute of Microbial Technology,

Table 2
Nutrients composition of the rock minerals (rock phosphate, dolomite and mica powder). The results are expressed as Mean± Standard deviation.

Nutrients	Rock phosphate	Dolomite	Mica
pH	7.2 ± 0.34	7.5 ± 0.31	7.1 ± 0.42
Total N (%)	nd	nd	nd
Total P (%)	8.5 ± 0.43	0.01	0.01
Total K (%)	0.3 ± 0.04	nd	10.1 ± 0.67
Total Ca (%)	8.1 ± 1.21	19.2 ± 1.12	0.1
Total Mg (%)	4.8 ± 1.33	12.8 ± 1.13	4.5 ± 0.37
Available N (mg kg^{-1})	nd	nd	nd
Available P (mg kg^{-1})	35.2 ± 2.45	nd	nd
Available K (mg kg^{-1})	55.6 ± 3.54	nd	140 ± 4.68

Note: nd means not detected.

Chandigarh, India. Other bacteria *KSB* was collected from Department of Agricultural Microbiology, Indian Agricultural Research Institute, New Delhi, India. The fungal cultures were maintained with Potato Dextrose Agar Media, while bacterial inoculations were sub-cultured on Jensen's Agar Media.

Experimental design

Three sets of experiments were conducted for three respective rock minerals such as RP, DM and MC addition along with two feed stocks, i.e., WH and PS. The RP, DM and MC were used at varying doses for preparation of VC with an aim to enrich the prepared vermicompost with P, Ca-Mg and K respectively. Furthermore, the microbial inoculums such as TV, AZC, PSB, and KSB were used in combinations with each rock minerals for the analysis of combined effect of rock minerals and microbes on enrichment of VC made from organic wastes. Each set comprised 12 treatment combinations (Table 3) and was laid in complete randomized design with three replications.

Treatment details

Factor 1: Rock Minerals (Three) at three doses 0% (no addition), 10% and 20% (dry weight basis)

a. Rock phosphate (RP)
b. Dolomite (DM)
c. Mica (MC)

Factor 2: Organic Waste (Two)

a. Water Hyacinth (WH)
b. Paddy Straw (PS)

Factor 3: Microbial inoculation (Two)

a. No microbes (M0)
b. Microbes (TV+ AZC+ PSB+ KSB) (M1)

Experiment set I (Preparation of RP enriched VC): No. of treatments = [{2(rock phosphate doses) × 2 (wastes)} + 2 organic wastes alone without minerals] × 2 (microbes) = 12

In the experiment set-II and set-III, aimed at preparation of DM and MC enriched vermicompost, every factor was same as in experiment set-I (explained above), except type of rock mineral (i.e., RP was replaced by DM and MC respectively) (Supplementary Table 1)

Preparation of rock mineral enriched vermicompost

One kilogram of the organic wastes (WH and PS) were mixed with fresh cow dung in 1:1 ratio (w/w; dry weight basis) and taken in separate earthen pots (diameter: 15 cm and depth: 15 cm). Rock minerals (RP, DM and MC) were added as per the treatment doses to both organic wastes. There was no hole for draining water from the pots therefore, calculated quantity of water was added to maintain moisture (60–70%) after weighing the pots. Then after, the calculated quantities of rock minerals (RP, DM and MC) as per the treatment doses were added to both organic wastes. The microbes such as *TV, AZC, PSB* and *KSB* in combinations were inoculated as 50 mL of seven-day old broth culture per kg (10^6 cells per mL) of organic waste with the rock minerals in both treatments. Fifteen days after addition of the rock minerals and microbes, 50 young non-clitellated hatchling earthworms, each weighing 316–440 mg, were introduced in each pot. Regular turning of the material and sprinkling of water was done manually to eliminate volatile toxic gasses and maintain temperature in the range of 30–35 °C suitable for mesophillic aerobic digestion. The total duration of the vermicomposting process was 90 days.

Chemical and biological properties

Vermicompost samples were oven-dried at 70 °C and ground to pass through a 20-mesh sieve size before chemical and biological characterization. The pH was determined using a double distilled water suspension of VC in the ratio of 1:10 (W/V) that was agitated mechanically for 30 min and filtered through Whatman no. 1 filter paper (Page et al., 1982). Organic C content in samples was determined by the dichromate oxidation method in the acid mediums (Nelson and Sommers, 1982). One-gram VC was first digested in 25 mL of concentrated HNO_3 followed by addition of 20 mL of 60% $HClO_4$, and total P content was determined by spectrophotometer after developing the vanadomolybdo-phosphoric yellow color complex in the nitric acid medium (Jackson, 1973). For the estimation of olsen P (available P), 2.5 g of sample was extracted with 50 mL of 0.5 M $NaHCO_3$ (pH 8.5) for 30 min (Olsen et al., 1954), and phosphate content was determined spectrophotometrically using ascorbic acid as the reductants (Watanabe and Olsen, 1965). Ammonium acetate K (available K) was determined by extracting 5 g sample with 25 mL 1 N NH_4OAc (pH 7.0) reagent (Hanway and Heidel, 1952). Potassium concentration in the extract was then estimated by a flame photometer. Inorganic N (NH_4^+-N and NO_3^--N) was determined by first extracting the samples with 2 M KCl (sample solution ratio of 1:10) followed by determination of NH_4^+-N by steam distillation with MgO in a micro-Kjeldahl distillation unit (Keeney and Nelson, 1982). The same procedure was used for NO_3^--N after reduction with Devarda's alloy. Enzymes such as urease and phosphatase activities of soils were estimated by spectrophotometric method (Tabatabai, 1994). Humic acids in vermicomposts were extracted using classic alkali/acid fractionation procedure (Valdrighi et al., 1996).

Statistical analysis

A three-way ANOVA and post-hoc test (Gomez and Gomez, 1984) was performed using SPSS statistical software to analyze the results obtained during the experiment. All tests were carried out at 5% level of significance to determine the differences between the treatment means.

Results

Earthworm growth rate of rock mineral enriched VC

The data on earthworm growth rate is presented in Fig. 1. Among the RP enriched VC, the earthworm growth rate in T4 (13.93 mg worm^{-1}day^{-1}) and T6 (13.60 mg worm^{-1}day^{-1}) treatments were comparable, and they were significantly higher than no application of RP (T1:11.65 mg worm^{-1}day^{-1}). However, in case of DM enriched VC, the highest growth rate of the earthworm was noted in T4 (15.14 mg worm^{-1}day^{-1}), which was significantly higher than DM0 doses (T1:10.78 mg worm^{-1}day^{-1}) and 20% DM doses (10.58 mg worm^{-1}day^{-1}). Among MC-based treatments, no addition of MC (T1) gave the maximum earthworm growth rate (11.99 mg worm^{-1}day^{-1}),

Table 3
Experimental details specifying the treatments composition is given as the combination of different factors in three sets (I, II, III) each performed in triplicate.

Treatment	SET	Factors												
		Organic waste		Microbial Inoculum		Rock Mineral 1 (Rock Phosphate)			Rock Mineral 2 (Dolomite)				Rock Mineral 3 (Mica)	
T. No.		PS§	WH¥	M0£	M1	RP0 (0%)	RP10 (10%)	RP20 (20%)	DM0 (0%)	DM10 (10%)	DM20 (20%)	MC0 (0%)	MC10(10%)	MC2 (20%)
T1	I	√		√		√								
T2		√		√			√							
T3		√		√				√						
T4			√	√		√								
T5			√	√			√							
T6			√	√				√						
T7		√			√	√								
T8		√			√		√							
T9		√			√			√						
T10			√		√	√								
T11			√		√		√							
T12			√		√			√						
T1	II	√		√					√					
T2		√		√						√				
T3		√		√							√			
T4			√	√					√					
T5			√	√										
T6			√	√							√			
T7					√				√					
T8		√			√					√				
T9		√			√						√			
T10			√		√				√					
T11			√		√					√				
T12			√		√						√			
T1	III	√		√								√		
T2		√		√									√	
T3		√		√										√
T4			√	√								√		
T5			√	√									√	
T6			√	√										√
T7		√			√							√		
T8		√			√								√	
T9		√			√									√
T10			√		√							√		
T11			√		√								√	
T12			√		√									√

Note: PS§ refers to Paddy straw; WH¥ refers to Water hyacinth; M0£ refers to no microbes; M1¶ refers to addition of Microbes (TV+ AZC+ PSB+ KSB); 'Ö'sign represents the presence of respective factor in given treatment.

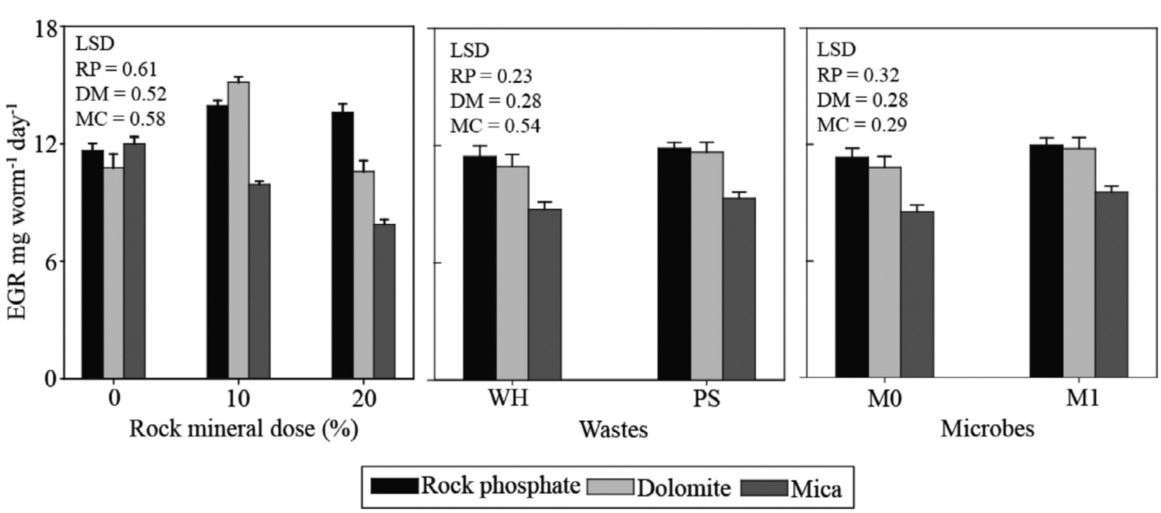

Fig. 1. Effect of rock mineral doses and microbial inoculation in organic wastes such as water hyacinth (WH), paddy straw (PS) on earthworm growth rate (EGR) in the vermicompost; M0: without microbial inoculants; M1: with microbial inoculants; RP: rock phosphate; DM: dolomite; MC: mica; the vertical lines indicate standard deviation. LSD: least significance difference at $P = 0.05$.

Table 4
Effect of rock minerals doses and microbial inoculation in organic wastes such as water hyacinth (WH) and paddy straw (PS) on pH of vermicompost. The results are expressed as Mean± Standard Deviation.

Treatment	Rock phosphate		Dolomite		Mica	
	WH	PS	WH	PS	WH	PS
Control	6.7 ± 0.17	7.32 ± 0.09	6.7 ± 0.11	7.32 ± 0.21	6.7 ± 0.15	7.32 ± 0.12
Microbes	6.72 ± 0.11	7.3 ± 0.07	6.72 ± 0.13	7.3 ± 0.17	6.72 ± 0.20	7.3 ± 0.15
10% mica	6.62 ± 0.09	7.1 ± 0.12	6.98 ± 0.11	7.4 ± 0.11	6.98 ± 0.21	7.4 ± 0.18
10% mica + microbes	6.6 ± 0.13	7.1 ± 0.11	6.92 ± 0.13	7.48 ± 0.16	6.92 ± 0.16	7.48 ± 0.21
20% mica	6.82 ± 0.14	7.15 ± 0.14	7.98 ± 0.16	8.1 ± 0.15	7.98 ± 0.14	8.1 ± 0.16
20% mica + microbes	6.75 ± 0.11	7.1 ± 0.10	8.05 ± 0.15	8.2 ± 0.14	8.05 ± 0.13	8.2 ± 0.13

which was significantly higher than rest mica doses (T3 and T5). Each successive addition of mica doses decreased the earthworm growth rate significantly. Between the organic wastes, paddy straw (9.31 mg worm^{-1}day^{-1}) showed significantly higher earthworm growth rate than water hyacinth (8.77 mg worm^{-1}day^{-1}).

Changes in chemical and bio-chemical properties of enriched VC

The chemical properties viz. OC, total N, ammonium-N, nitrate-N, total P, olsen-P, total K, ammonium acetate-K and humic acid content were analysed during vermicomposting period of enriched VC and the results are represented below. The organic wastes such as WH and PS had slightly alkaline pH, whereas after vermicomposting, the pH shifted towards neutrality (Table 1 and 4). Microbial inoculants showed variable influence on pH of the VC depending on the nature of microbes and the organic wastes used.

Organic carbon content

The time series analysis of OC content during composting period is presented in Fig. 2. Irrespective of RP doses, OC content of VC decreased sharply from day 0 to 90 days of composting. T1 treatment (control) gave the maximum OC content throughout the vermicomposting periods and minimum was in T6. The OC content was higher in PS than WH-based VC throughout the vermicomposting period. Use of microbial inoculants brought changes in OC content after 30 days of vermicomposting and showed lower OC content compared to respective control (i.e., without microbial inoculant). The maximum OC content was noted in T1, which decreased significantly with progressive increase in RP doses from 10% (T3) to 20% (T5). Further, OC content was significantly reduced when the VC was prepared with microbial inoculants (186 g kg^{-1}) than without inoculants (204 g kg^{-1}). Between the organic wastes, significantly lower OC content of VC was recorded in WH (168 g kg^{-1}) than in PS (223 g kg^{-1}) (Fig. 2).

In case of DM addition, OC content during vermicomposting period is presented in Fig. 3. The OC content declined with the period of vermicomposting process. Among the DM doses, the T1 treatment (control) gave the maximum OC content throughout the composting periods and minimum was in T2 treatment. Between the organic wastes, PS had significantly higher OC content than WH throughout the vermicomposting period. Use of microbial inoculants brought changes in OC content after 60 days of composting, while showing lower value as compare to without microbial inoculants. In matured VC, the OC content was significantly reduced under different DM treatments than control. Increasing addition of DM at 10% (T3) and 20% (T5) decreased the OC content of final VC significantly as compared to no DM application (T1). Further addition of DM (at 20%) resulted significant increase in OC content of the final VC. Between the organic wastes, the OC content in matured VC was recorded significantly lower in WH (199 g kg^{-1}) than in PS (283 g kg^{-1}) (Fig. 3). Microbial inoculation into the organic waste reduced the OC content significantly. Increasing addition of DM doses from 10 to 20%, decreased the OC content of final VC by 3 to 25% in WH and 4 to 28% in PS as compared to no application of DM (T1).

However, addition of MC, declined the OC content with the period of vermicomposting process. Among the MC doses, T1 treatment recorded the maximum OC content (268 mg g^{-1}), which decreased significantly with progressive addition of MC doses from 10% (T3) to 20% (T5) (Fig. 4). Between the organic wastes, the OC content in matured VC was significantly lower in WH (191 g kg^{-1}) than in PS (208 g kg^{-1}). Also, the VC prepared from microbial inoculants had significantly lower OC content (197 g kg^{-1}) than without inoculants (202 g kg^{-1}).

Total nitrogen content

Total N content increased steadily with duration of vermicomposting process and attained the maximum values at 90 days (Fig. 2). Among the RP doses, the T1 gave the maximum total N content throughout the vermicomposting period, which was significantly reduced with increasing dose of RP. Use of microbial inoculants significantly increased the total N content after 30 days of vermicomposting as compared to without microbial inoculants. The total N content of VC prepared from WH was significantly higher as compared to PS throughout the vermicomposting period.

Progressive addition of DM from 0 (T1) to 10% (T4) resulted significant increase in total-N content of prepared VC (Fig. 3). However, further addition of DM at 10% or higher, decreased the total N content significantly. Hence, the maximum total N content was noted in T4 (16.4 g kg^{-1}), which was significantly higher than the rest DM doses. Between the organic wastes, total N content in matured VC was recorded significantly lower in WH (14.6 g kg^{-1}) than in PS (13.7 g kg^{-1}). Furthermore, total N content was significantly increased in VC when prepared with microbial inoculants (14.5 g kg^{-1}) than without inoculants (13.7 g kg^{-1}).

However, total N content in MC increased steadily with duration of vermicomposting process and attained the maximum value towards maturity (105 days). T1 recorded the maximum total N content (13.7 g kg^{-1}), which was comparable with T2 and both were significantly higher than rest mica doses (Fig. 4). Between the organic wastes, WH showed significantly higher total N content (12.0 g kg^{-1}) than PS (10.9 g kg^{-1}) in the matured VC. However, use of microbial inoculants had no effect on total N content of the VC.

Ammonium-N and Nitrate-N content

Ammonium-N content increased steadily with duration of the vermicomposting up to 30 days and decreased thereafter with lower dose of RP (0 to 20%) i.e., T1 to T6 (Fig. 2). Ammonium-N content of VC prepared from WH was higher than PS throughout the vermicomposting period. Similarly, inoculation of microbes resulted in higher ammonium-N content than without inoculation. The ammonium-N content of the matured VC is represented in Fig. 2. Among the RP doses, the maximum ammonium-N content was noted in T1 (646 mg kg^{-1}) treatment and both were significantly higher than rest RP doses.

In case of DM addition too, ammonium-N content steadily increased with the duration of the vermicomposting process up to 30 days and decreased thereafter up to maturity. In matured VC, the

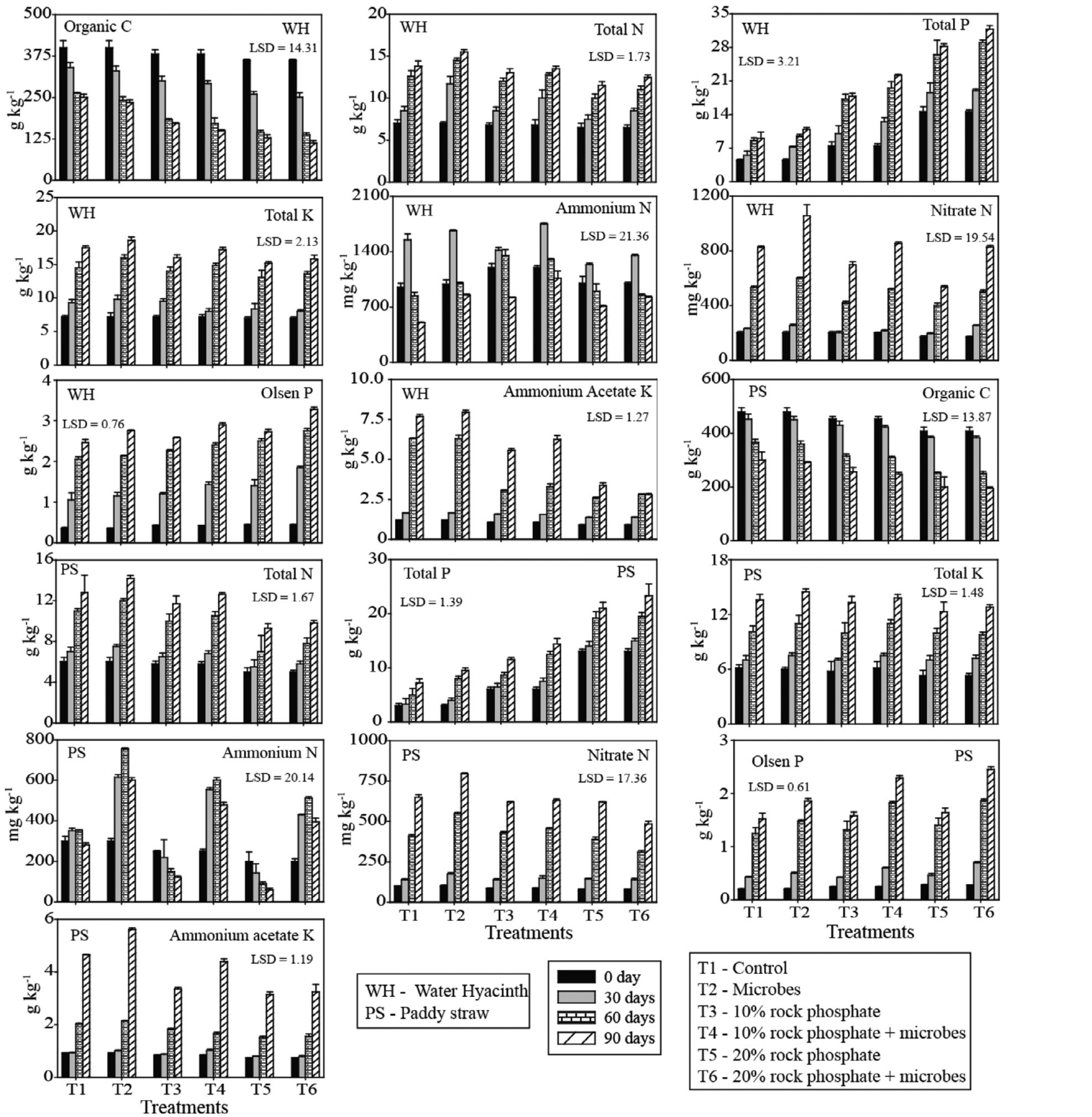

Fig. 2. Organic C, Total N, Total P, Total K, Ammonium N, Nitrate N, Olsen P and Ammonium acetate K in different organic wastes i.e., water hyacinth (WH) and paddy straw (PS) during vermicomposting by using different rock phosphate (RP) doses and microbes (Error bars represent standard deviation; LSD = least significant difference at $p = 0.05$).

highest ammonium-N content was noted in T4 (Fig. 3). Although, further increase in DM addition at 20% resulted in significant decrease in ammonium-N content of VC. Between the organic wastes, significantly higher ammonium-N content value was recorded in WH than in PS with DM addition. The VC prepared from microbial inoculants reflected significantly higher ammonium-N content than without inoculants.

Ammonium-N content steadily increased with the duration of the vermicomposting process up to 30 days with lower dose in case of MC (<10%) and decreased thereafter. Among the MC doses, the maximum ammonium-N content was noted in T1 (412 mg kg^{-1}), which was significantly reduced with successive addition of MC doses (Fig. 4). Between the organic wastes, significantly higher ammonium-N content of VC was noted in WH (330 mg kg^{-1}) than in PS (85 mg kg^{-1}). Also, the VC prepared from microbial inoculants had significantly higher ammonium-N content (235 mg kg^{-1}) than without inoculants (179 mg kg^{-1}).

Nitrate-N content

Nitrate-N content of VC sharply increased with the duration of the vermicomposting process from 30 to 60 days and thereafter remained stable up to the maturity. In final matured VC, among the RP doses, maximum nitrate-N was recorded under control treatment (T1), which was significantly reduced with increasing doses of RP (Fig. 2). Between the organic wastes, significantly higher nitrate-N content was recorded in WH (721 mg kg^{-1}) than in PS (598 mg kg^{-1}).

Nitrate-N content sharply increased with the duration of the vermicomposting process from 30 to 90 days and then slowly increased up

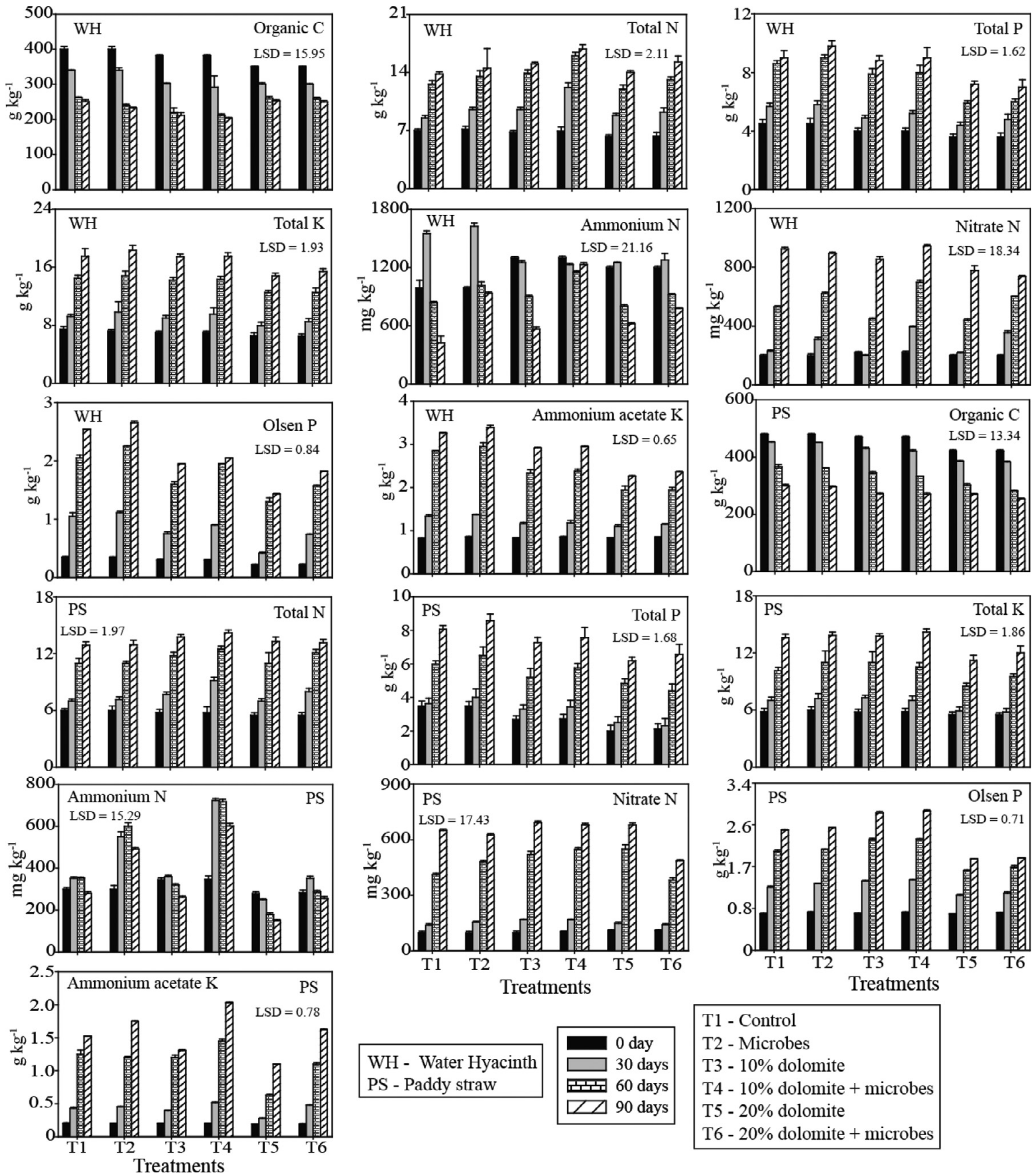

Fig. 3. Organic C, Total N, Total P, Total K, Ammonium N, Nitrate N, Olsen P and Ammonium acetate K in different organic wastes i.e., water hyacinth (WH) and paddy straw (PS) during vermicomposting by using different dolomite (DM) doses and microbes (Error bars represent standard deviation; LSD = least significant difference at p = 0.05).

to maturity in case of DM addition. Application of DM at 10% (T3) increased the nitrate-N content significantly in matured VC as compared to no DM (T1) addition. Further, increase in dose of DM by 10% led to significant decrease in nitrate-N content of the VC (Fig. 3). However, between the organic wastes, significantly higher nitrate-N content was recorded in WH than in PS. The VC prepared from microbial inoculants reflected significantly higher nitrate-N content than without inoculants.

Nitrate-N content steadily increased with the MC addition during the composting process up to 30 days and thereafter it tended to increase (Fig. 4). Among the MC doses, the maximum nitrate-N content was noted in MC0 (804 mg kg^{-1}), which was significantly reduced with further addition of MC doses. Between the organic wastes, significantly higher nitrate-N content of VC was in WH (622 mg kg^{-1}) than in PS (460 mg kg^{-1}). The VC prepared with microbial inoculants had significantly higher nitrate-N content (548 mg kg^{-1}) than without inoculants (535 mg kg^{-1}).

Total phosphorus content

Total P content steadily increased with the duration of vermicomposting process up to 60 days and thereafter marginally increased up to maturity in case of RP addition. In finally prepared VC, progressive increase in RP doses from 10 to 20% resulted in significant increase of

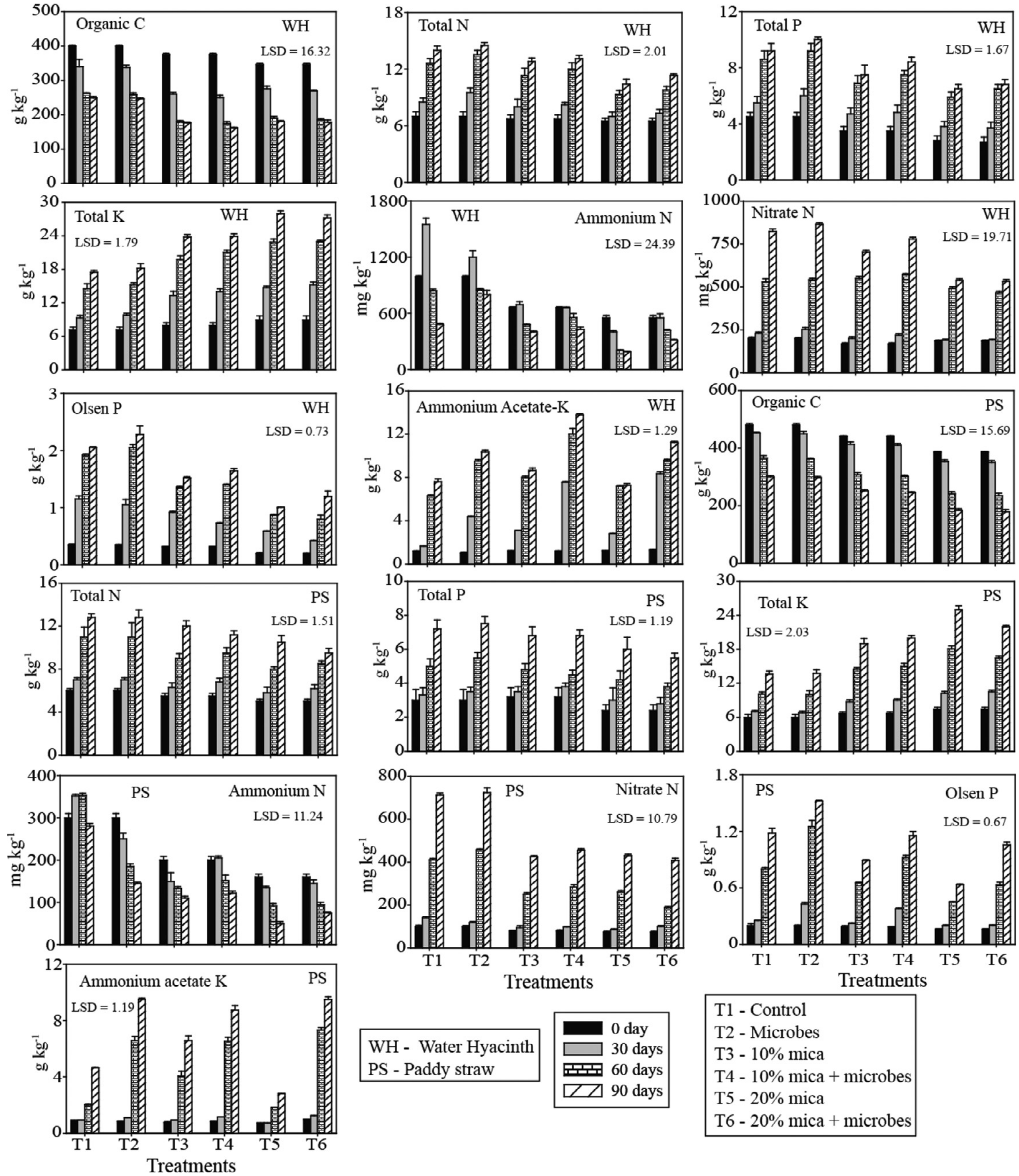

Fig. 4. Organic C, Total N, Total P, Total K, Ammonium N, Nitrate N, Olsen P and Ammonium acetate K in different organic wastes i.e., water hyacinth (WH) and paddy straw (PS) during vermicomposting by using different mica (MC) doses and microbes (Error bars represent standard deviation; LSD = least significant difference at $p = 0.05$).

total P content (Fig. 2). The P content of VC was lowest in T1 (9.2 g kg^{-1}) and highest in T6 (35.2 mg g^{-1}). However, among the organic wastes, significantly higher total P content of VC was recorded in WH (24.6 g $kg^{-1)}$ than in PS (19.5 g kg^{-1}). Also, the use of microbial inoculants in this case significantly enhanced total P content (22.4 g kg^{-1}) as compared to without inoculants (21.7 g kg^{-1}). The response of total P content of final VC to increasing doses of RP was higher in WH than in PS.

Total P content of VC steadily increased with the duration of vermicomposting process and attained the maximum values as matured at 90 days in case of DM and MC addition (Fig. 3). In the matured VC, among the DM doses, the maximum P content was noted in control (T1: 9.1 g kg^{-1} of P) and minimum in 20% DM dose (T5). Use of DM doses at greater than equal to 10% (≥10%) resulted significant decrease in P content of VC as compared to control (T1). Between the organic wastes, significantly higher total P content of VC was recorded in WH than in PS.

Among the MC doses, maximum total P was recorded under control treatment (T1), which was comparable with T2 and both were significantly higher than rest MC doses (Fig. 4). However, between the organic wastes, significantly higher total P content was noted in WH (7.7 g kg^{-1}) than in PS (6.5 g kg^{-1}) in case of MC addition. Use of microbial inoculants did not make any change in total-P content of the VC, when added with MC.

Olsen-P content

The Olsen–P content increased with the period of vermicomposting process. In final VC, maximum Olsen–P was noted in RP20 (2.5 g kg^{-1}) showed significantly higher Olsen–P content as compared to rest treatments. Between the organic wastes, significantly higher Olsen–P content of VC was recorded in WH (2.7 g kg^{-1}) than in PS (1.7 g kg^{-1}) (Fig. 2). Furthermore, the Olsen–P content was significantly increased when the VC was prepared with microbial inoculants (2.5 g kg^{-1}) than without microbial inoculants (1.9 g kg^{-1}).

In case of DM addition, maximum olsen-P was noted in control treatment (T1), which decreased significantly with progressive increase in DM doses from 10% to 20% (Fig. 3). Between the organic wastes, significantly higher olsen-P content of VC was recorded in WH than in PS. Similarly, olsen-P content was significantly increased when the VC was prepared with microbial inoculants than without microbial inoculants.

Similarly, in case of MC addition, maximum Olsen–P content was noted in control treatment (T1: 1.83 g kg^{-1}), which decreased significantly with progressive increase in MC doses from 10% (T3) to 20% (T6) (Fig. 4). Between the organic wastes, significantly higher Olsen–P content of VC was recorded in WH (1.3 g kg^{-1}) than in PS (9.9 g kg^{-1}). Similarly, Olsen–P content was significantly increased when the VC was prepared with microbial inoculants (1.3 g kg^{-1}) than without microbial inoculants (1.1 g kg^{-1}).

Total potassium content

Total K content increased steadily with the duration of vermicomposting process and attained the maximum values at maturity. Among the DM doses, T3 gave the maximum total K content in final VC, which was comparable with T1, but significantly higher than T5 (Fig. 3). The total K content of WH-based VC was 15.3 g kg^{-1}, which was significantly higher than the PS based VC. However, in case of MC addition, the maximum K content was found in T6 (28.6 g kg^{-1} of K) and minimum in T1 (16.7 g kg^{-1}) (Fig. 4). Between the organic wastes, significantly higher total K content was noted in WH (26.2 g kg^{-1}) than in PS (23.3 g kg^{-1}) for MC addition.

Ammonium acetate-K content

Ammonium acetate-K content steadily increased with the duration of vermicomposting process and attained the maximum values at 90 days (Fig. 2). The T1 (7.0 g kg^{-1}) gave the maximum ammonium acetate-K content of final VC, which was significantly reduced with increasing doses of RP. Ammonium acetate-K content of the VC in WH (5.1 g kg^{-1}) was significantly higher as compared to PS (4.7 g kg^{-1}). Use of microbial inoculants resulted significantly higher ammonium acetate-K content than without inoculants.

However, in case of DM additions, ammonium acetate-K content of VC steadily increased after 30 days of composting process and attained the maximum values at 90 days (Fig. 3). As compared to control (T1), addition of DM at higher doses (>10%) brought significant reduction in ammonium acetate-K content of final VC. Between the organic wastes, WH showed significantly higher ammonium acetate-K content than PS in final VC. Use of microbial inoculants significantly increased the ammonium acetate-K content. For the wastes, PS added with DM from 0 to 10% increased the ammonium acetate-K content of VC significantly. However, further addition of DM at >10% resulted a significant decrease in the ammonium acetate-K content. On contrary, for WH-based organic waste the DM addition at any dose caused significant reduction in ammonium acetate-K content of the VC.

In case of MC addition, the maximum ammonium acetate-K content was noted in T4 (9.5 g kg^{-1}) treatment, which was significantly higher than rest MC doses (Fig. 4). However, between the organic wastes, significantly higher ammonium acetate-K content was recorded in WH (9.5 g kg^{-1}) than in PS (7.2 g kg^{-1}). Similarly, the VC prepared with microbial inoculants (10.7 g kg^{-1}) reflected significantly higher ammonium acetate-K content than without microbial inoculants (5.8 g kg^{-1}) in case of MC addition.

Humic acid content

Humic acid content of final VC is represented in Table 5. Among the RP doses, 10% RP doses gave the maximum humic acid content (0.59 mg g^{-1}) in the final VC, which was significantly higher than rest of the doses (0% RP and 20% RP doses). Between the organic wastes, significantly higher humic acid content of VC was recorded in PS (0.54 mg g^{-1}) than in WH (0.48 mg g^{-1}). Use of microbial inoculants with RP did not cause any significant changes in humic acid content of the VC. The interaction effect of organic wastes, RP doses and microbes were not significant for humic acid content in final VC. Similarly, incase of DM and MC, no significant change was observed in humic acid content of final VC.

Urease activity

Among the RP doses, T3 was resulted the maximum urease enzyme activity (UA) (129 μg NH_4 g^{-1} h^{-1}) in final VC, which was significantly higher than rest of RP doses (Fig. 5). Among the organic wastes, WH had significantly higher UA (116 μg NH_4 g^{-1} h^{-1}) as compared to PS (112 μg NH_4 g^{-1} h^{-1}). However, addition of microbial inoculants in RP (117 μg NH_4 g^{-1} h^{-1}) significantly increased the UA as compared to without microbial inoculants (111 μg NH_4 g^{-1} h^{-1}). The interaction effect of organic wastes and RP doses was significant for UA in final VC.

Although, progressive increase in DM doses like at 10% brought significant increase in urease activity (UA) of matured VC however, any further increase in DM doses, (like 20%) reduced the UA significantly (Fig. 5). Furthermore, the use of microbial inoculants did not cause any significant change in urease activity in case of DM addition.

The data in Fig. 5 shows that increasing doses of MC from 0 to 20% (T1 to T6) brought significant reduction in urease enzyme activity (UA) of VC. The organic wastes, WH and PS had comparable UA in the final VC when added with MC. However, the VC prepared with microbial inoculants had significantly higher UA (99 μg NH_4 g^{-1} h^{-1}) as compared to without microbial inoculants (92 μg NH_4 g^{-1} h^{-1}) in case of MC addition.

Acid phosphatase activity

The data shown in Fig. 5 indicates that increasing doses of RP from 0 to 10% (RP0 and RP10) did not make any significant changes in acid phosphatase activity (APA) of the VC. However, addition of RP at 20% brought significant reduction in acid phosphatase activity of VC. Among the organic wastes, significantly higher APA of VC was recorded in WH (211 μg pnp g^{-1} h^{-1}) than in PS (192 μg pnp g^{-1} h^{-1}). The APA of VC added with microbial inoculant was 211 μg pnp g^{-1} h^{-1}, which was significantly higher than without inoculants (192 μg pnp g^{-1} h^{-1}). The interaction effect of organic wastes, RP doses and microbes were not significant on APA of final VC.

In case of DM addition, as compared to control (DM0), 10% DM did not bring any change in acid phosphatase activity (APA), whereas, the higher dose of DM addition (>10%) brought significant reduction in APA of final VC (Fig. 5). Between the organic wastes, WH showed significantly higher APA than PS in final VC. Also, the introduction of microbial inoculants significantly increased the APA of final VC in case of DM addition.

Similarly, in case of MC addition, maximum acid phosphatase activity (APA) was noted in control treatment (MC0), which decreased significantly with progressive increase in MC doses from T3 to T6 (Fig. 5). The organic wastes, WH and PS had comparable effects on APA in case of MC addition. However, use of microbial inoculants resulted significant increase in APA in both the organic wastes.

Table 5
Effect of rock minerals and microbial inoculation in organic wastes such as water hyacinth (WH) and paddy straw (PS) on humic acid content (mg *g* - 1) of vermicompost. The results are expressed as Mean± Standard Deviation.

Treatment	Rock phosphate		Dolomite		Mica	
	WH	PS	WH	PS	WH	PS
Control	0.5 ± 0.03	0.6 ± 0.04	0.5 ± 0.02	0.69 ± 0.05	0.51 ± 0.04	0.62 ± 0.04
Microbes	0.51 ± 0.03	0.61 ± 0.04	0.6 ± 0.05	0.72 ± 0.05	0.53 ± 0.04	0.64 ± 0.05
10% mica	0.55 ± 0.02	0.62 ± 0.03	0.6 ± 0.05	0.81 ± 0.06	0.56 ± 0.03	0.66 ± 0.05
10% mica + microbes	0.56 ± 0.03	0.63 ± 0.04	0.65 ± 0.03	0.82 ± 0.06	0.59 ± 0.05	0.69 ± 0.04
20% mica	0.48 ± 0.04	0.52 ± 0.03	0.62 ± 0.03	0.76 ± 0.03	0.54 ± 0.05	0.63 ± 0.05
20% mica + microbes	0.56 ± 0.02	0.55 ± 0.03	0.64 ± 0.03	0.88 ± 0.04	0.57 ± 0.03	0.65 ± 0.03

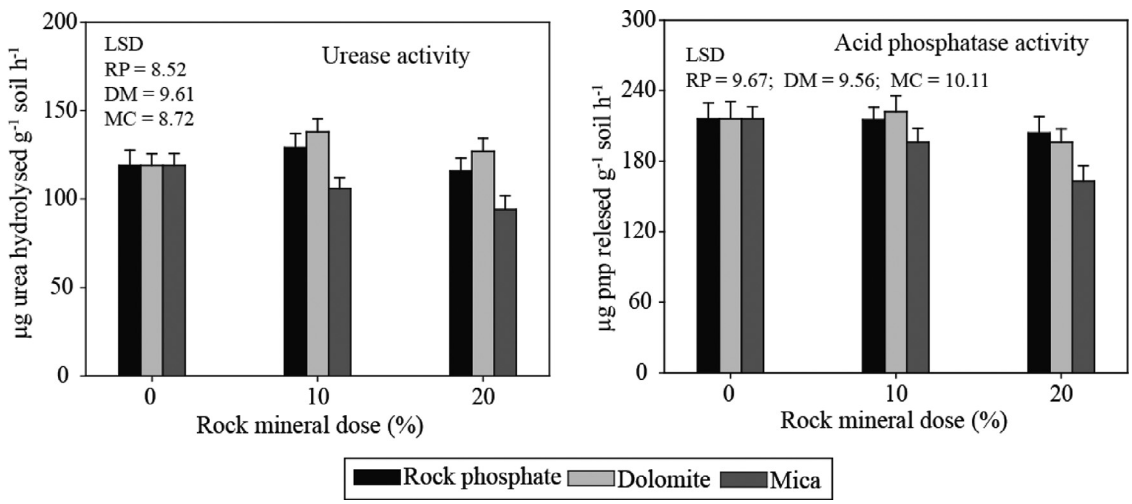

Fig. 5. Effect of Urease enzyme activity (UA) and Acid phosphatase enzyme activity (APA) in matured vermicompost by using different doses of rock minerals i.e., Rock phosphate (RP), Dolomite (DM) and Mica (MC). (Error bars represent standard deviation; LSD = least significant difference at p = 0.05).

Discussions

Chemical and biological properties of RP enriched VC

The survival and activity of the earthworms in the vermicomposting during the study were attributable to the proper combination of organic wastes and mineral addition. Increase in dose of RP up to 20% decreased the C/N ratio of VC. However, the difference in growth rates could be related to the nutrient quality of the wastes and C/N ratio, which are the important factor to favor the growth rate of earthworm (Edwards et al., 1998). In our experiment, WH had significantly enthused higher earthworm growth rate as compared to PS. This was possibly due to rapid and extensive decomposition of WH (larger loss of C and greater reduction in C/N ratio over the study period) than PS.

Stabilization of OC content in the present experiment varied between 60 and 90 days of vermicomposting. Stabilization in the OC content of wastes is considered as the completion of vermicomposting process. The loss of OC during vermicomposting process was mainly due to decomposition of organic wastes, resulting in the evolution of CO_2 in the process. Among the RP doses, maximum OC content was noted in RP0 and minimum in RP20. This might be due to the highest food consumption of earthworms and higher growth of micro-organism at 20% RP dose leading to the reduction of OC content. Among the wastes, lower OC content of VC was recorded in WH than PS. Similar decreasing trends in OC content was also reported during vermicomposting on different organic wastes in earlier studies (Das et al., 2016; Devi and Khwairakpam, 2020). The higher N content in WH might lead to greater food consumption of earthworm, thereby faster decomposition causing higher loss of OC as compared to PS. Inoculation of microorganisms in organic wastes enhanced the rate of carbon mineralization which in turn, led to the reduction of OC content in VC. This might be attributed to their ability to dissociate carbonaceous polymers (Gusain and Suthar, 2020).

Increase in N content of VC was noted up to 60 days that ultimately stabilized in 90 days of vermicomposting. The maximum increase in N content during 30–60 days concurred with the duration of maximum mineralization (loss of OC) during the vermicomposting. The increasing trend in the N content during the vermicomposting process was irrespective of microbial inoculation. The increase in total N might be due to net loss of organic matter as CO_2 and moisture loss by evaporation during the vermicomposting process. This might also be attributed to the mineralization of N with progress of vermicomposting process (Lv et al., 2018; Das et al., 2016). Increase in N content of VC was found to be higher when inoculated with AZC as compared to other microbes.

Increasing addition of RP dose into vermicomposting resulted to decrease in N content compared to control treatment. However, RP has negligible N content, thus decreasing N content with increasing dose of RP might be attributed to dilution of N in the vermicomposting process.

With the progress of vermicomposting, ammonium N content was increased up to 30 days due to maximum mineralization in the organic wastes. This might be because of earthworm growth rate which was higher up to 30 to 40 days, which possibly accelerated the mineralization of organic matter. After 30 days, decrease in ammonium-N content till maturity of VC was probably due to loss of N as ammonia and transformation of ammonium-N to nitrate-N by nitrifying bacteria in favorable aerobic conditions (Said-Pullicino et al., 2007; Biswas et al., 2009). In our experiment, it was found that nitrate-N content increased after 30 days of vermicomposting up to maturity. However, total-N, and ammonium-N content of VC decreased with increased addition of RP.

Total P content steadily increased with the duration of vermicomposting process up to 30 days and thereafter marginally increased up to maturity. In the vermicomposting process, organic matter decomposes to various types of organic acids like glycolic acid, fumaric acid, citric acid, carbonic acid etc., which solubilize tri-calcium phosphate of RP, hence release phosphate and calcium into the VC (Wei et al., 2012). Different organic wastes showed variable increase in total P content. WH-based VC showed higher total P content than PS-based VC. This might be due to greater mineralization of P in the former organic wastes (C/N ratio of WH<PS). Inoculation of microorganisms into organic wastes resulted in significant increase in rate of P-mineralization. Combined effect of PSB and TV enhanced the ability to solubilize P from RP. The presence of large number of micro-flora in the gut of earthworm might have played an important role in increasing total P content in the process of vermicomposting (Sharma, 2003). This increase in total P to direct action of worm gut enzymes and indirectly by stimulation of the micro flora (Ajibade et al., 2020).

The Olsen–P was increased with increasing RP dose up to 20% (T6). The reactions of released inorganic soluble P with the presence of other cation in the VC could be a reason for reduced availability of soluble P above 20% RP dose. Combined effect of inoculation of PSB and TV enhanced the solubilised P from RP. The PSB and fungi are well known to produce organic acids like citric acid, tartaric acid, oxalic acid, gluconic and lactic acid etc. which might be a reason for this.

Total K increased with duration of vermicomposting process, whereas ammonium acetate – K content increased up to 30 to 60 days of vermicomposting and thereafter stabilized. This could be attributed to mineralization of K with progress of vermicomposting up to 60 days, which got stabilized with stabilization of C/N ratio of the VC. However, with increase in doses of RP, the K content of VC decreased due to dilution of K in large vermicomposting mass. Among the wastes, WH had higher K content, consequently resulted higher total K content of VC as compared to PS. Inoculation of KSB and TV micro-organisms increased organic acid production through decomposition of organic matter, which enhanced ammonium acetate-K content in the VC.

Humic acids are formed during breakdown of organic wastes by earthworms (Singh et al., 2021). In this experiment, the humic acid content decreased with increasing rock minerals dose above 10% (Table 5). This was due to the decrease in organic matter and humification with decreasing growth rate of earthworm under high RP doses (>10% RP). The PS-based VC had higher humic acid content as compared to WH due to higher cellulose content of PS. The increased urease activity during vermicomposting might be explained with the greater extra-cellular enzyme activity of microorganisms during controlled biodegradation of the wastes, which lead to continuous accumulation of cell-released enzymes in humic substrates.

The positive and significant ($p<0.05$) correlation ($r = 0.73$) between urease activity and humic acids content was observed in VC enriched with RP. It suggests that humic acid gets stabilized and thus becomes resilient to physical and microbial degradation. Further, the inoculation of microorganisms amplified urease activity which indicates that the transit of organic wastes through the earthworm gut boosted the microbial activity. The greater acid phosphatase activities in WH-based VC might be due to higher N and P contents of the organic wastes, which resulted higher microbial activity as compared to PS-based VC. Earthworms mostly feed on microbes, particularly fungi, for their protein/ nitrogen requirement to maintain their growth and reproduction. The mucus produced in the gut of earthworms comprises gluco-proteins, small glucosidic and proteic molecules, which are consumed by the microbes entering in the worms' gut and they produce extra-cellular enzymes in turn to facilitate the digestive process in the gut of earthworm (Zeibich, 2019). This process leads to higher phosphatase activities in VC. Inoculation of microorganisms significantly increased acid phosphatase activities as compared to their un-inoculated VC. Humic acid, extracted from the enriched VCs registered positive correlation with acid phosphatase activities ($r = 0.87$). This positive correlation confirmed the fact that the enhanced acid phosphatase activity in the VC was due to presence of PSB (Liu et al., 2017).

Chemical and biological properties of DM enriched VC

The survival and activity of the earthworms in the vermicomposting with different organic wastes and DM addition showed that the activity of earthworm depends on C/N ratio and pH of the vermicomposting medium. Increasing earthworm growth rate with the increasing doses of DM up to 10% was due to the decreasing C/N ratio and favourable pH medium of the VC. Further increasing dose of DM (above 10%) resulted in increase of the C/N ratio (16.7 to 22.7) of the VC medium, thereby decreasing the earthworm growth rate. Higher doses of DM increased Ca and Mg content that might be responsible for increasing the pH which became toxic to the earthworm. In presence of water, $CaCO_3$ and $MgCO_3$ form hydroxides of Ca and Mg, which increase the pH of the vermicomposting process.

The OC content decreased significantly with advancement of the vermicomposting process both in the presence and absence of microbes and the decrease might be mainly due to decomposition of organic wastes into CO_2 by earthworms. Lowest OC content in DM10 treatment might be due to the favourable DM dose (10%) of earthworm for decomposition of the organic matter. In contrast, higher DM dose (>10%) increased the pH of the VC that caused slow mineralization and decomposition of organic wastes resulting in the higher OC content (Table 4). Microbial inoculation with DM enhanced the rate of decomposition of organic wastes due to synergistic effect of DM and microorganism on the VC.

Highest total N content of VC at DM10 might be due to the apparent neutral pH (Table 4) at this DM dose. In neutral pH range (~7.5), the free living N_2-fixing bacterial population and earthworm growth rate increased, which resulted in higher mineralization, hence increased N content of VC.

Ammonium N content was increased up to 30 days with the progress of vermicomposting and decreased thereafter up to maturity, which might be due transformation of ammonium-N to nitrate-N by nitrifying bacteria in favourable aerobic conditions as in the case of RP enriched VC (Said-Pullicino et al., 2007; Biswas et al., 2009).

Increasing rate of DM into vermicomposting mass resulted decrease in Olsen P content, which might be attributed the negligible amount of P in DM. Moreover, with higher DM doses, fixation and precipitation of P occurred in the form of calcium phosphate, iron phosphate and aluminium phosphate, thus decreasing Olsen–P content of the VC (Ajibade et al., 2020). Presence of PSB in microbial inoculant treatment increased the rate of P-mineralization, hence resulted into significant increase in Olsen–P content of the VC. Total K and ammonium acetate-K content of the VC was similar in case of DM addition which might be due to negligible amount of K in DM. DM enriched VC had significantly higher content of total Ca and Mg as compared to no DM addition (DM0). This was attributed due to contribution of Ca and Mg from DM.

Lignin decomposition is a key factor which influences the formation of humic substrates (Wang et al., 2017). DM at 10% dose showed higher humic acid content as compared to control treatment. This might be due to better digestion of organic wastes by the earthworms at 10% DM dose to convert humic acid through humification. The influence of PSB in microbial inoculant treatments increased humic acid content through increasing population of cellulolytic fungi in the vermicomposting process. Humic acid controlled the urease and phosphatase activity of the VC as explained earlier.

Chemical and biological properties of MC enriched VC

The survival and activity of the earthworms in the vermicomposting with different organic wastes with MC addition decreased with increasing MC dose above 10% (MC10) that becomes toxic to earthworm. Effect of the organic waste and microbial inoculations on earthworm growth rate and N content of VC in MC-based treatment was similar as in RP-based treatments. The MC-based and DM-based treatments had similar effect on P content of VC.

Increasing rate of MC addition into vermicomposting mass resulted increase in total K and ammonium actetate-K content, which can be attributed the secretion of various organic acids during the decomposition process. The K solubilisation from MC waste was also observed by Biswas et al. (2009) in farm yard manure. The WH based VC showed higher total K content, because of its better degradability over PS (C/N ratio of WH<PS) and higher K content of the native raw material. Microbial inoculated VC resulted higher ammonium acetate K content in the VC as compared to non-inoculated products. The use of KSB (*Bacillus firmus*) might be responsible for enhancing the solubility of K from mica in the VC. KSB and fungi are well known to produce various organic acids like citric acid, tartaric acid, oxalic acid, gluconic and lactic acid etc. which possibly increased the ammonium acetate-K content (Basak, 2018)

Breakdown of organic wastes by earthworms through humification results in the formation of humic acid; the content of which indicates the quality of the fertilizer. In this experiment, the humic acid content decreased with increasing MC dose above 10%. Addition of MC dose up to 10% favored the earthworm growth rate that resulted better decomposition of organic wastes, hence increasing content of humic acid through humification. The positive correlation between humic acid and urease activity ($r = 0.64^{**}$) in the VC suggests the stabilization of urease-humic complex up to 10% addition of MC, which showed resistant to microbial degradation above this dose.

Conclusions

The study revealed that addition of rock minerals such as RP, DM and MC at 10% along with microbial inoculants in organic wastes such as WH enhanced the earthworm growth rate, hence improved the quality of VC in terms of macronutrients availability through mobilization of nutrients to available forms than control (no rock mineral and no microbial inoculants). Additionally, application of rock minerals (RP or DM or MC) at 10% along with microbial inoculants in the vermicomposting process enhanced the bio-chemical properties of VC such as humic acid, urease activity and acid phosphatase activity content significantly compared to control. Interestingly, microflora in the gut of earthworms also had beneficial effects through microbial enrichment of the vermicompost.

Thus, the rock mineral based-VC could be a viable technology to utilize both low grade rock minerals, organic wastes and microbes at combining together for the upgrade of the vermicompost quality.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.envc.2021.100225.

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