Original Research Article

Advanced Vermicomposting Modality: Microbial Acceleration to Improve Micronutrient Profile of Agricultural Residue derived compost

ABSTRACT

Advancing circular economies and self-reliant agricultural systems will critically depend on innovative strategies in the optimization of resource utilization and agro-waste recycling for food production sustainability. The present study is focused on the potential of vermitechnology with diverse substrate compositions in bioconverting lignocellulosic agricultural residues into nutrient-rich amendments. Trials of vermicomposting were carried out exploiting *Eudriluseugeniae* and a fungal decomposer consortium, Pusa Decomposer. Treatments included T1: *Gliricidia sepium* leaves (GL), T2: Banana pseudostem (BP), T3: Rice straw (RS), T4: Rice husk (RH), T5 (RS + BP – 8:1 w/w), T6 (RH + BP - 8:1 w/w), T7 (RH + RS + BP – 4:4:1 w/w) and T8 (RH + RS + BP + GL – 4:4:0.5:0.5 w/w) with 3 replications in CRD.T2 expressed peak Mn, Zn and Cu values at 418.40 mg kg^{-1}, 247.50 mg kg^{-1} and 55.12 mg kg^{-1}, respectively. T3 reported summit Fe and B at 8669.50 mg kg^{-1} and 37.00 mg kg^{-1}, respectively. It was found that the combination of RS along with BP reported excellent nutrient solubilization and enhanced EC, which ratiocinates the role of substrate mix in determining vermicompost quality. These findings underline the importance of substrate selection and microbial augmentation with fungal decomposer consortia such as Pusa decomoposer, which optimize the vermicomposting process for nutrient recovery and improved soil health.

Keywords: Vermicompost, Eudriluseugeniae, Pusa decomposer, Sustainability, Micronutrient, Paddy stubble, Organic farming.

1 INTRODUCTION

Developing circular economies and self-relying systems that focus on resource utilization optimization and recycling is crucial for creating sustainable ecosystems in terms of food production endeavours. Sustainability can be achieved with proficiency when the direct dependence on conventional nutrient sources can be reduced to certain degrees by exploiting other feasible opportunities as far as crop growth is concerned. Efficient and maximum utilization of agri-waste via bio-conversion to nutrient rich amendments is one of the best modes of mitigating multiple issues simultaneously. Human health, climate and ecosystems are in progressing state of threat of deterioration as higher demands for agricultural products necessitates rapid growth of the agriculture sector health (Duque-Acevedo et al. 2020; Cai et al. 2021). Recent surveys depicts that 1 billion tonnes of agricultural waste is produced on a global scale, annually which contributes to 1/5th of total greenhouse gas emissions (Karić et al. 2022). Out of which global rice production yields over 750 million tons annually, generating substantial biomass waste like straw, husk, and bran (Zhang et al., 2023). While, approximately 114.08 million metric tons of banana cultivation residues are globally produced (Acevedo, 2021). Lignocellulose forms a major proportion of the structural component of agricultural wastes such paddy stubble. Lignocellulose components primarily consist of cellulose, hemicellulose and lignin. Lignin is strongly attached to hemicellulose molecules via covalent and hydrogen bonding, making it highly resistant to enzymatic hydrolysis (Veluchamy et al., 2017). Hence, a need for microbial colonies capable of degradation of lignocellulytic polymers efficiently, that can be exploited on a practical scale persists. Morphologically, three distinct fungal species phyla are able to degrade lignin complexes (brown-rot fungi, white-rot fungi, and soft-rot fungi). Other fungi, such as coprophilic fungi growing on dung and litter-degrading fungi, are also effective lignin degraders (Liers et al. 2011; Blanchette 1995). Among the entire roster of viable biomass conversion methods, implementation of vermitechnology is the most dynamic one. Earthworms aerate, crush, mix, chemically degrade and biologically stimulate the decomposition of organic matter. Moreover, conjoint action of earthworm foraging and nutrient metabolization along with the hydrolytic action of microbial decomposer consortiums, especially against structurally non-reactive derivatives can allow enrichment of VC with nutrients on a larger magnitude and with nutrients possessing lower solubility.

2 MATERIALS AND METHODS

2.1 EXPERIMENTAL SETUP

It was ascertained that the vermicomposting as an activity is carried out in complete adherence to the 2016 Kerala Agricultural University's protocol. Specialized vermicomposting reactors (VR) were constructed. Every VR had a gravel bottom, covered with plastic mesh and coconut fibre layer. The reactors were loaded with 5 kg pre-decayed biomass which included GL, BP, RS, and RH in varying ratios with 100 g bonemeal and 1 litre cow dung in (2:1 v/v). 120 adult*Eudriluseugeniae* and 20 ml of a fungal decomposer consortium (Pusa Decomposer) developed at the Indian Agricultural Research Institute, which contains seven fungal strains were the primary composting agents of the study. The pattern of the experiment was completely randomized in design with eight treatments replicated three times to make up a total of twenty four VR units. Optimal moisture conditions were maintained during the course of the study.

Treatment details:

T1 :*Gliricidia sepium* leaves

T2 : Banana pseudostem

T3 : Rice straw

T4 : Rice husk

T5 :Rice straw + Banana pseudostem (ratio - 8:1 w/w)

T6 : Rice husk + Banana pseudostem (ratio - 8:1 w/w)

T7 : Rice straw + Rice husk + Banana pseudostem (4:4:1 w/w)

T8 :Rice straw + Rice husk + Banana pseudostem+ *Gliricidia sepium* leaves(4:4:0.5:0.5 w/w)

2.2 PHYSICO-CHEMICAL ANALYSIS OF SUBSTRATES AND VERMIWASH

pH and EC of the samples were noted by glass electrode (Jackson, 1958) and graphite electrode (Jackson, 1973) method respectively.Boron concentrationwere determined using a UV-1800 UV-Spectrophotometer by Shimadzu using the techniques described by Wolf (1974). Concentrations of iron, zinc, manganese, and copper were determined using an atomic absorption spectrophotometer, novAA-350 from Analytik Jena, described by Piper (1966).

2.3 STATISTICAL ANALYSIS

All statistical analysis were carried under theKAU-GRAPES “R-package” ecosystem (Gopinath, 2021). In which, significant difference was determined at 95% confidence level by analysis of variance followed by Least Significant Difference test.

Table 1. Physico-chemical characteristics of major substrates.

Characteristics	**Rice straw**	**Banana pseudostem**	***Gliricidia sepium* leaves**	**Rice husk**	**FYM**
pH	7.2	7.81	6.87	7.65	6.20
EC (ds/m)	1.01	0.55	1.52	0.423	2.38
B (mg kg^{-1})	19.71	39.88	31.53	11.88	21.22
Fe (mg kg^{-1})	1125.76	457.65	197.26	174.98	1163.43
Cu (mg kg^{-1})	11.58	8.7	20.11	2.24	3.74
Mn (mg kg^{-1})	464.22	207.86	105.36	85.81	301.83
Zn (mg kg^{-1})	41.53	116.60	54.37	54.47	96.85

3 RESULTS AND DISCUSSION

pH value, electrical conductivity, and micronutrient composition of VC is essential in determining the effectiveness of the material as an amendment. Accordingly, the pH was recorded to understand its role with regard to the solubility and bioavailability of other nutrients. The electrical conductivity was assessed to find out the ionic nature or possible salinity levels which could affect the soil adversely. Finally, the concentration of trace elements within the vermicompost was analysed in order to determine the extent to which vermicompost would be able to provide the required micronutrients for adequate plant growth. Such thorough understanding brings forward detailed information on the extent to which the use of vermicompost would help in enhancing soil fertility.

3.1 pH and EC

The pH of the final vermicompost did not differ significantly within treatments. It spanned between slightly acidic in some treatments to neutral in majority treatments, which were well within the optimal range for earthworm survival (Wu et al., 2020). Hence, the selected substrates and subsequent combinations were suitable for earthworm multiplication under controlled micro-climate. Initial reduction in pH during vermicomposting is due to increased microbial degradation action that is associated with release of organic acids, primarily humic acid. This acid production is further enhanced under the presence of secretions and vermicasts of E. eugeniae which act as foci of microbial proliferation (Mapile and Obusan, 2020). Humic acid thus formed is stabilized by the presence of lignin decomposed derivatives during vermicomposting process (Dariellys, et al., 2014). It is during the later stages of composting that pH moves towards neutrality as microbial diversity improves allowing buffering action via multiple organic secretions. Similar results were interpreted by

Xue-Jian et al., (2023), Vinay and Charanjit, (2021) and Syed et al., (2024). Victor et al., (2013) linearly related the release of H^+ ions to rate of nitrification during the composting of Gliricidia sepium. This could explain the lowest pH recorded in T1 (gliricidia leaves) which possessesrelatively higher nitrogen levels in gliricidia leaves.

Substrate composition exerts influence on the EC of the vermicompost produced from the respective substrates. Water content of vermicomposts shows positive correlation with EC. (Karla et al., 2013). Furthermore, the process of vermicomposting itself impacts EC, as the microbial conversion of organic waste results in elevated levels of macronutrients and micronutrients, leading to changes in EC levels. Improved catalytic action of fungal strains specializing in lignocellulose derived compounds via Pusa decomposer incorporation further accelerates dissolution of soluble nutrients. This may explain the relatively higher EC value in T5 (Table 2.) which could be a combined result of high mineral solublization and presence of highly succulent water banana pseudostem. Chen at al., (2023) argued that increase in EC of vermicompost samples can be due to high rate of carbon mineralization during degradation process.

Table 2. pH and EC values of VC as influenced by varying substrate combinations

Treatments	**pH**	**EC (ds/m)**
T1	6.43	1.77^{b}
T2	6.96	0.71^{d}
T3	6.65	2.11^{ab}
T4	7.17	0.68^{d}
T5	6.68	2.61^{a}
T6	7.23	0.84^{cd}
T7	7.09	1.53^{bc}
T8	6.88	1.79^{b}
SEm (±)	0.228	0.231
CD (0.05)	0	0.692

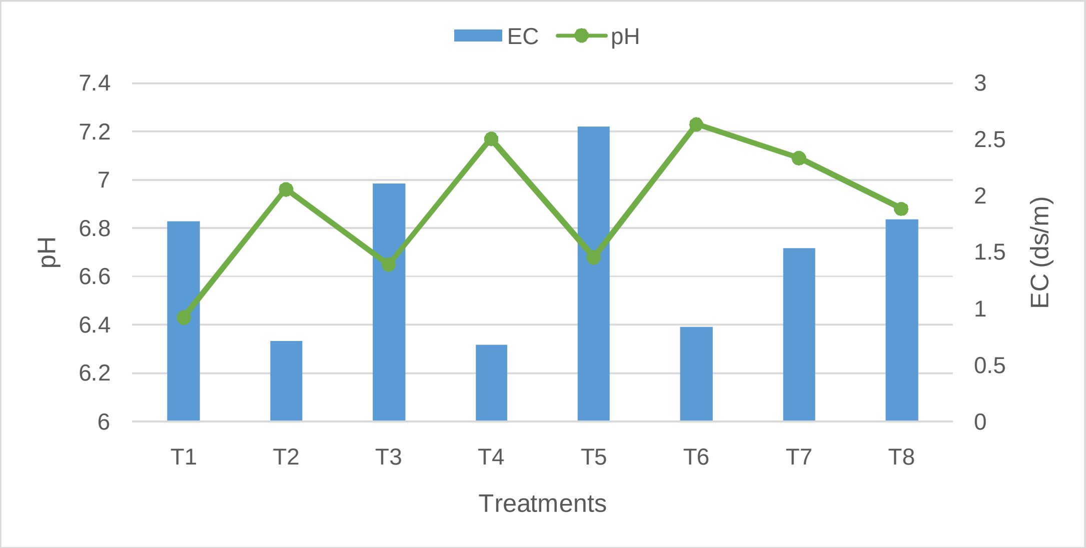

Fig. 1. pH and EC characteristics of vermicompost as propagated by varying substrate combinations.

3.3 MICRONUTRIENT CONTENT

Significant difference within treatments was observed for Fe, Zn, Cu, B and Mn. Complexing properties of organic matter plays a crucial role in determining the micronutrient availability. Micronutrient stability dictating availability follows the order: Cu^{2+}> Fe^{2+}> Zn^{2+}> Mn^{2+} and Cu^{2+}> Zn^{2+}> Fe^{2+}> Mn^{2+} for humic acid and fulvic acid, respectively (Relan et al., 1990). Also, plant available micronutrient release could be due to high rate of mineralization of partially digested earthworm faecal matter by detritus microflora, which is further enhanced by the modification of the physical structure of the ingested material due to muscular action of the foregut which causes increase in net surface area for microbial action (Suthar, 2008). T3 reported highest Fe and B readings at 8669.50mg kg^{-1} and 37.00 mg kg^{-1}, respectively, which were on par with T2. Similar results were obtained by Jusoh (2013) and Shak et al., (2013) via comparative studies. *T. harzanium* and *T. asperellum* which form a constituent of Pusa decomposer microbial load, are capable of efficient iron mineralization and further augmenting Fe concentration (Tagyan et al., 2023). *T. asperellum* is efficient in iron mineralization by increasing available Fe levels via siderophore production (Zhao et al., 2014). Moreover, relatively higher Fe content reported in RS (Table 1), could further enhance total soluble iron accumulation with the biomass matrix. Pusa decomposer also consists of *A. niger,* which has been reported to express high B mineralization capacities (Bayat et al., 2011; Anwar et al., 2023). Increased activity of the aforementioned fungal strains can be attributed to increase in organic acid production via lignocellulytic degradation processes occurring during RS decomposition. B contentin T3 was in accordance with experiments conducted by Sharma and Garg (2018) and Yan et al., (2012). Peak Mn, Zn and Cu concentrations were detected in T2 at 418.40 mg kg^{-1}, 247.50 mg kg^{-1} and 55.12 mg kg^{-1}, respectively. This could be due to enhanced enzymatic activity, greater organic matter breakdown to simpler molecules allowing efficient solublization and complexation of micronutrients via interaction with humic substances (Harrison, 2008). Microbial activity stimulated by earthworms along with biomass colonization by a diverse spectrum of microflora due to Pusa decomposer augmentation duringvermicomposting leads to production of various organic acids, such as citric and acetic acids, which can solubilize micronutrients like Cu, Zn, and Mn, thereby, increasing bio-availability (Domínguezand Gómez-Brandón, 2012). Similar results for Mn, Zn and Cu were obtained by Vidya et al., (2020) by vermicomposting of BP via *E. eugeniae*vermiconversion.

Table 3. Micronutrient constituents of VC as propagated by different substrate combinations

Treatments	**Fe** **(mg kg^{-1})**	**Mn** **(mg kg^{-1})**	**Zn** **(mg kg^{-1})**	**Cu** **(mg kg^{-1})**	**B** **(mg kg^{-1})**
T1	4052.50^{b}	280.85^{c}	155.50^{bc}	34.74^{b}	31.60^{a}
T2	7715.75^{a}	418.40^{a}	247.50^{a}	55.12^{a}	34.60^{a}
T3	8669.50^{a}	336.30^{b}	159.60^{b}	32.84^{bc}	37.00^{a}
T4	3315.00^{bc}	133.02^{ef}	94.92^{ef}	22.37^{de}	15.90^{b}
T5	2983.00^{bc}	295.12^{bc}	154.60^{bc}	27.70^{bcde}	18.65^{b}
T6	2065.25^{c}	84.81^{f}	89.60^{f}	20.46^{e}	16.55^{b}
T7	2768.00^{bc}	208.60^{d}	133.75^{cd}	23.32^{cde}	19.95^{b}
T8	2439.00^{bc}	163.25^{de}	114.89^{de}	31.47^{bcd}	16.45^{b}
SEm (±)	594.218	17.145	7.81	3.415	1.842
CD (0.05)	1781.463	51.4	23.413	10.239	5.524

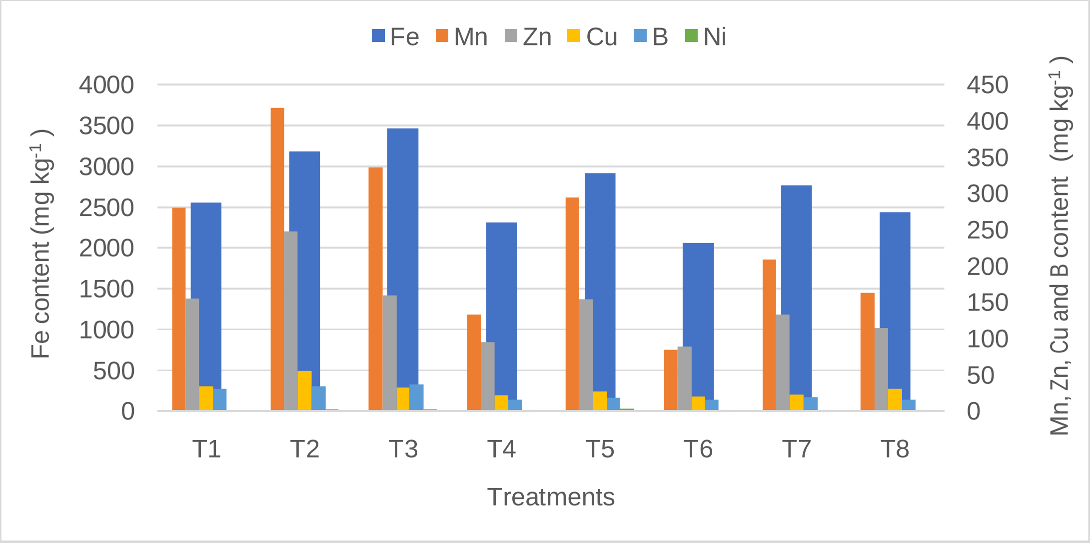

Fig. 2. Micronutrient profile of vermicompost as influenced by different substrate combinations.

CONCLUSIONS

In the present study, RS and BP proved to be exemplary substrates in vermicomposting, showing optimal improvement in nutritional profiles in vermicomposts. Thus, RS VC as a major substrate, increases the Fe and B content of the final vermicomposts similar to BP VC. While, BP is a very good substrate for maximum availability of Mn, Zn, and Cu. Innate nutrient rich constitution of RS and high rate of decomposition of BP under vermiconversionwhen subjected to the conjoined decomposing action of voracious *E. eugeniae* foraging and biomass breakdown via Pusa decomposer, yields VC with enhanced micronutrient dissipating capacity. The interaction of microbial activity with the digestion process of earthworms further enriched the vermicompost with nutrient elements essential for improving the agronomic value of vermicompost.Substrate composition had a significant influence electrical conductivity of the vermicompost. These findings suggest that the choice of substrate is a critical determinant of nutrient profile and quality of vermicompost. The acidic to neutral pH recorded in the vermicomposts represents the best condition for earthworm activities and microbial proliferation, hence enhanced decomposition and release of nutrients. Moreover, utilization of microbial decomposer consortium such as Pusa decomposer, further intensifies the composting process and allows for a wider microflora to colonize and proliferate within the composting micro-climate. Improved nutrient release in T2 and T3 proves potential to optimize nutrient content in vermicompost through modified allocation of substrates in various proportions. These findings provide valuable insights into the microbial augmentation of vermicomposting practices with respect to potent organic manure production with micronutrient fortification within reduced maturity period while simultaneously managing exploitation of agricultural waste such as paddy stubble and banana pseudostem with an ecologically responsible approach. Thus, bolstering the practical possibilities for achieving sustainable food production systems.

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