http://www.pjbs.org

PJBS

ISSN 1028-8880

Pakistan Journal of Biological Sciences

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

OPEN ACCESS Pakistan Journal of Biological Sciences

ISSN 1028-8880
DOI: 10.3923/pjbs.2020.501.509

Research Article
Vermicomposting of Organic Waste with *Eisenia fetida* Increases the Content of Exchangeable Nutrients in Soil

El Jawaher A. Bin Dohaish

Department of Biology, Faculty of Science, University of Jeddah, Saudi Arabia

Abstract

Background and Objective: Vermicomposting is a green technique used to produce organic compost from organic waste with the aid of specific earthworm species. The resulting compost is rich in nutrients that can improve plant health and fertility. This study was conducted to produce organic compost using a developed vermicomposting technique. And that is to enhance and increase the exchangeable nutritional content in the soil for utilization in sustainable agriculture. **Materials and Methods:** The experiment was carried out with *Eisenia fetida* worms in a treatment technique using sugarcane straw, remnants of garden tree leaves, kitchen wastes and cow manure. The physiochemical parameters, namely temperature, moisture, acidity, electrical conductivity and 10 different nutrients, were assessed in vermicompost samples and garden soil sample (without earthworms). **Results:** The results revealed higher N, C and P content in the vermicompost than in the garden soil sample. **Conclusion:** This study confirms that vermicompost has a high nutrient value and can be considered a promising method for safely disposing organic waste, improving crop production and achieving long-term food security.

Key words: Eco-friendly products, *Eisenia fetida*, green technique, plant nutrients, vermicompost, waste management

Citation: El Jawaher A. Bin Dohaish, 2020. Vermicomposting of organic waste with *Eisenia fetida* increases the content of exchangeable nutrients in soil. Pak. J. Biol. Sci., 23: 501-509.

Corresponding Author: El Jawaher A. Bin Dohaish, Department of Biology, Faculty of Science, University of Jeddah, Saudi Arabia

Copyright: © 2020 El Jawaher A. Bin Dohaish. This is an open access article distributed under the terms of the creative commons attribution License, which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited.

Competing Interest: The author has declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Extensive use of chemical fertilizers and pesticides in agriculture negatively impacts the soil and plants as chemical and pesticide residues are present in nutritional products and they accumulate in the food web and environment. Therefore, developing innovative agricultural practices that employ organic composts and environmentally friendly products will navigate the agricultural sector toward a greener future and production of wholesome and nontoxic food products at affordable prices year-round. In addition, innovative agriculture is required to meet the demands of governments and companies[1].

Vermicomposting is a green technique that produces vermicompost from different types of organic wastes using specific earthworm species. It helps farmers to reduce their use of chemical fertilizers and the overall production costs. Vermicompost is considered an alternative to chemical additives in agricultural crop production that reduces economic costs, while producing healthier organic products for consumers and enriching the environment[2]. Therefore, organic agriculture is rapidly becoming a common theme among scientists and the agricultural society.

Vermicompost plays a vital role in non-artificial systems such as organic agriculture, sustainable agriculture, or environmentally friendly agriculture, owing to its potential to improve the nutritional value of crops and enhance soil fertility[3]. Vermicompost is an essential element in organic agricultural systems, as it contains beneficial and useful properties for plants. It enhances the physical, chemical and biological properties of the soil and increases its organic content[4,5]. Lléo *et al*.[6] verified that vermicomposting is the best option for treating an organic fraction of municipal solid waste, compared with traditional composting procedures, it released lower amounts of pollutant gases (such as CH_4, NH_3, etc.).

Earthworms are considered one of the primary tools for treating solid organic wastes, which consist of domestic, agricultural and animal-based wastes. Approximately 15 million t of agricultural waste is produced yearly in Saudi Arabia[7] and food wastes hold the highest percentage of economic losses owing to excessive squandering, infection via pests, or deposition in municipal waste dumpsters, which causes pungent odors due to high biological decomposition[8]. *Eisenia fetida* is one of the earthworm species that works efficiently in breaking down and decaying natural remains and turning these scraps into high-quality organic compost. It is capable of eating as much as half of its weight daily. The behavioral activity of earthworms (feeding, burrowing and casting) enhances the physical, chemical and biological properties of organic matter and soil, thereby augmenting the growth of agricultural crops naturally and safely[9].

During the process of vermicomposting, vermiworms are used to transform organic wastes into a high-quality product from degraded organic matter and the dead bodies of vermiworms[10,11]. This technique of vermicomposting helps to transform various organic wastes (agricultural waste, animal manure and domestic wastes) into a nutrient-rich compost for the soil and plants[12]. In addition, because of the humic acids in vermicompost, significant amounts of nutrients such as N, P, K, Ca and Mg accumulate in the shoots, roots and leaves of plants[13].

Vermicompost is a brownish black substance with high porosity, aeration and water retention capacity[14]. It is rich in micronutrients and soil beneficial microbes (nitrogen-fixing and phosphate-solubilizing bacteria and actinomycetes) and it is a sustainable alternative to chemical composts, as well as an excellent growth enhancer and plant crop protector[5,15]. This study was conducted to (1) apply a developed vermicomposting technique to produce vermicompost from locally available organic waste products with the help of *Eisenia fetida* (vermiworms) and (2) enhance the nutrient content of the vermicompost produced for use in sustainable agriculture.

MATERIALS AND METHODS

Vermicomposting station setup

Study area: This study was conducted at a vermicomposting station at the Southeast of Jeddah, Kingdom of Saudi Arabia. The total duration of the research conducted was from December, 10th 2018 till March, 25th 2019. Physical and chemical analysis was conducted at the laboratory of the University (in 2-3 weeks).

The vermiworms (*Eisenia fetida)* (Fig. 1) were obtained from the Egyptian Center of Agriculture and Research for the purpose of producing vermicompost using sugarcane straw, remnants of garden tree leaves, cow manure (an organic fertilizer obtained from Proteina Farms, Riyadh, Saudi Arabia) and kitchen wastes (excluding acidic or spicy fruits and vegetables, egg shells, meat, chicken, fish and dairy products). The vermicompost station was constructed with dimensions $3\times15\times15$ m (width×length×height). Shade was created overhead using plantation fabric[10]. The vermicompost was prepared in three red brick tanks with dimensions $70\times300\times120$ cm (width×length×height). All dry matter used in the experiment was minced thoroughly using a GR-650R1 Multi-Purpose Shredder (Kainitz Corporation, Bowa, Manila, Philippines).

Fig. 1: A photograph of *Eisenia fetida*, a vermiworm species used in vermicomposting, captured by the author in 2019

The 1st layer was composed of a 5 cm thick layer of broken bricks mixed with sand to prevent the earthworms from moving into the soil. The 2nd layer consisted of a 10 cm layer of muddy soil. The 3rd, 4th, 5th and 6th layers were each 10 cm thick and composed of sugarcane straw, tree leaves, sugarcane straw and tree leaves, respectively. The 7th layer was made of 15 cm of cow manure and the 8th layer of 5 cm of palm tree waste. Moisture was maintained in each layer at 70% by sprinkling water. The 9th layer was composed of 1000 worms of *Eisenia fetida* (Fig. 1) that were then left for 4 weeks, while sprinkling them with water in the morning when needed to maintain moisture.

After 4 weeks, the bedding was mixed by hand and meals of kitchen waste were added every 2 weeks or as needed. The level of pH was measured weekly and adjusted to neutral by adding agricultural lime whenever needed. The temperature was also measured weekly during the decomposition process (Fig. 2). After 2 months, watering was terminated and the bedding was collected into a pyramid-like pile on a concrete floor and left for 15 days to allow the worms to descend to the bottom of the pile to facilitate collection of the product. The vermicompost was then sieved through metal sieves of different sizes (3 and 4 mm mesh sizes) to separate the worms and cocoons from the vermicompost (Fig. 3).

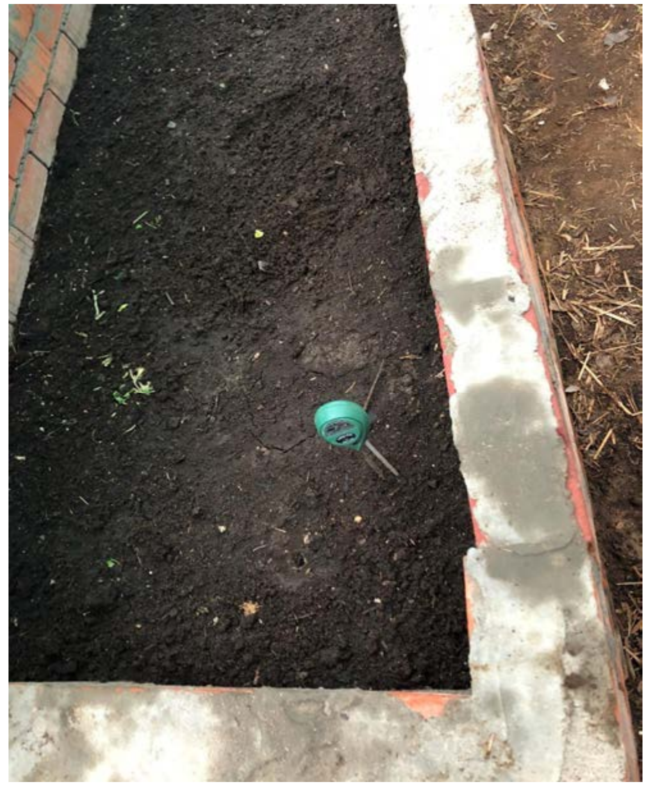

Fig. 2: Vermicomposting tank used in the experiment conducted in Jeddah, Saudi Arabia

Physical and chemical analysis: Three samples were taken from each of the three experimental vermicompost tank replicas along with samples from a separate garden soil tank. Subsequently, the physical and chemical parameters were analyzed to assess the nutrient quality in the vermicompost and garden soil.

Moisture content and pH were measured using a tensiometer (B07R4RPS54; Atree). To determine electrical conductivity, 1 g of each sample was dissolved in 100 mL of double distilled water (Milli-Q) and analyzed using a multiparameter meter (InoLab-IDS Multi 9430; WTW, Weilheim, Germany). One gram of each sample was extracted and oven-dried at 120°C for 24 h until they turned to powder. The samples were transferred into Pyrex flasks and 10 mL of aqua-regia (HNO_3/HCl) was added to each flask and heated at 100°C. This process was repeated thrice until the residue dissolved completely and total digestion was achieved.

The solution was then filtered through Whatman filter paper No. 42, transferred into a 100 mL volumetric flask and diluted with Milli-Q water. Blank samples were prepared using the same technique but without the sample. Digestion and quantification of the metal content (Mg, Cu, Zn, Fe, Ca and Mn

Fig. 3: Final vermicompost harvested after 2 months of the vermicomposting experiment

from three samples) was performed in triplicate by inductively coupled plasma optical emission spectrometry using an inductively coupled plasma spectrometer (ICPE-9000; Shimadzu Scientific Instruments [Oceania], Kyoto, Japan). Before analyzing the samples, the instrument was calibrated with a standard blank and the multi-element calibration standard. The analysis was conducted after the best linear regression correlation coefficient ($r^2 \geq 0.9998$) was obtained from the calibration plot.

To analyze the total nitrogen, 13 mL of H_2SO_4 and one Kjeltabs Cu-3.5 catalyst tablet (3.5 g K_2SO_4+0.4 g $CuSO_4 \times 5\ H_2O$) were added to 1 g of each sample and then digested at 420°C for 30 min. After digestion, the samples were left to cool at 30°C. The tray with samples was then loaded into the automatic sample analyzer (ASC-6100 Auto Sampler; Shimadzu Corporation, Japan) and their total organic carbon (TOC) was measured using a TOC-VCPH total carbon analyzer attached to the ASI-V autosampler supplied by Shimadzu Corporation, Japan. An experimental blank was prepared using the same technique, but the samples were replaced with distilled water. Titration was automatically performed by the instrument and the values displayed on the screen were recorded. Total phosphorus (TP) was analyzed using the colorimetric method with molybdenum in H_2SO_4, while total potassium was analyzed using the method described by Tandon[16].

Statistical analysis: Data were calculated by Independent T student test using SPSS program version 13. The results were expressed as Mean±SE.

RESULTS AND DISCUSSION

Organic waste management is considered a basic component in developing sustainable agriculture as it assists with maintaining the natural balance of N, P, K, Mg, Fe and other nutrients in the soil. In addition, vermicompost is an essential part of the comprehensive system of waste management because it recycles waste using eco-friendly agricultural techniques and is an alternative to chemical fertilizers. Treating organic waste requires low-cost technology[17] and vermicompost provides the soil with macro and micronutrients needed for optimum plant growth[18]. The vermicompost harvested after 60 days of composting was blackish-brown in color (Fig. 3) and with a mull-like soil odor, similar to that described by Domínguez and Edwards[19]. Microorganisms generate heat during organic matter decomposition. A temperature between 20 and 35°C is considered sufficient to facilitate the production of vermicompost in a tank. An increase in temperature of more than 35°C may activate many essential microorganisms and further degradation, which will occur when enough oxygen is provided. The mean temperature in the vermicompost tank was 25°C and mean pH was 7.2, which fell within the normal range according to the standard values (Table 1). A study[20] has found that most vermiworm species prefer a neutral pH of 7.0. The average moisture content in the tank was 60-80%, which was slightly lower than that reported by Domínguez and Edwards[19]. The electrical conductivity of the samples from the vermicompost tank and garden soil was 0.283 and 0.0942 mS cm^{-1}, respectively (Table 1), indicating that the vermicompost contained more soluble salts compared with the garden soil. The physical and chemical analysis revealed that the nutrient values varied widely between the vermicompost and garden soil.

Nitrogen (N): The total nitrogen content showed significant increase in the vermicompost (0.600% or 6 mg g^{-1} or 6000 ppm) than in the garden soil (0.102%) at $p<0.05$ (Table 2). Similar results were shown in previous studies on vermicompost (Table 3), where N content in vermicompost

Table 1: Physical properties of soil samples and vermicompost samples harvested after 2 months of vermicomposting

Physical parameters	Mean±SD of vermicompost samples	Mean±SD of soil samples
Electrical conductivity, EC (mS cm^{-1})	0.283±0.050	0.0942±0.047
pH	7.2±0.2	ND
Temperature (°C)	25.0±2.64	ND
Moisture (%)	80.0±3	ND

Table 2: Elements in soil sample (%) compared with vermicompost harvested after 2 months of preparation

Chemical parameters	Mean±SD of vermicompost samples (%)	Mean±SD of soil samples (%)
Nitrogen	0.600±0.114	0.102±0.005
Total organic carbon	4.408±0.379	0.142±0.116
Phosphorous	2.008±0.004	1.122±0.057
Potassium	1.488±0.089	3.396±0.168
Magnesium	1.764±0.192	13.007±0.265
Copper	0.042±0.005	0.074±0.016
Zinc	0.076±0.013	0.275±0.017
Iron	2.35±0.571	28.90±3.265
Calcium	9.26±0.650	28.90±1.309
Manganese	0.022±0.005	0.018±0.002

All data were expressed as Mean±SE of 3 samples, *Significance differences between groups at p<0.05

ranged from 0.51-1.61%[21-27]. Broz *et al.*[28] mentioned that the microbial content of organic compost and vermicompost is responsible for changing the dynamics of N in the soil. Suthar[29] suggested that earthworms increase the levels of N in the vermicompost through their excretory products, mucus and body fluids and through the decaying tissues of dead worms in the vermicomposting system. The N levels in the vermicompost could be related to the quality of the substrate used to feed the worms[30] or due to the mineralization of organic matter[31].

Total organic carbon (TOC): The chemical and physical properties of the substrate are important for assessing the quality of the nutrients in the final product. Carbon is a major component of the organic molecules in the vermicompost; it is a source of energy and thus a building block for all organisms[4,10,32]. In the present study, the mean TOC content in the vermicompost was 4.408% (or 44.08 mg g^{-1} or 44080 ppm), which was significantly higher than that in the garden soil (mean 0.142%) (Table 2). When compared with previous studies on vermicompost (Table 3), TOC was lower in the present study than in the study by Manyuchi *et al.*[23] (5.21-5.25%), Maheswari and Priya[21] (9.8-13.4%), Jaybhaye and Bhalerao[24] (17.38%) and Ramnarain *et al.*[22] (18.53%). The reduced TOC concentration found in the present study may be due to insufficient tree leaves and straw supplied to the worms.

Phosphorous (P): The TP content in the vermicompost (2.008% or 20.08 mg g^{-1} or 20080 ppm) recorded significant increase than that in the garden soil (1.122%) (Table 2). It was also greater compared with the values recorded by Oluseyi *et al.*[26] (1.78%), Maheswari and Priya[21] (0.19-1.02%), Ramnarain *et al.*[22] (0.58%), Jaybhaye and Bhalerao[24] (0.30%), Manyuchi *et al.*[23] (796.3-838.1 ppm) and Singh[25] (0.137 mg g^{-1}) (Table 3), which may be contributed to the differences in the waste material used to feed the worms or the different vermicomposting protocols such as decomposition time. Marlin and Rajeshkumar[33] also recorded a high percentage of TP (2.68-3.61%) in vermicompost obtained from different waste products, such as sawdust, city waste, sugarcane, weeds, pressed mud and slaughterhouse waste. The release of P during vermicomposting is attributed partly to the activity of phosphatases in the earthworm gut and partly to the P-solubilizing microorganisms present in the worm casts, which convert P into a form more readily available to the plants[30,34].

Potassium (K): The mean concentration of total K in the vermicompost showed significant decrease (1.448% or 14.48 mg g^{-1} or 14480 ppm) as compared with soil sample (3.396%) at p<0.05 as shown in Table 2. This value was similar to the K values of 0.54-1.72% reported in earlier studies[35-41], but much higher than those reported by Maheswari and Priya[21] (0.15-0.73%), Ramnarain *et al.*[22] (0.56%), Jaybhaye and Bhalerao[24] (0.56%), Manyuchi *et al.*[23] (1915.8-2384.7 ppm) and Singh[25] (0.176 mg g^{-1}) (Table 3). Oluseyi *et al.*[26] recorded a higher percent of potassium (6.27%) than the current study. Vermicompost contains high concentrations of exchangeable K due to the enhanced microbial activity during decomposition, which also enhances the rate of mineralization[29]. Rautela *et al.*[42] found that agricultural waste such as sugarcane straw is rich in K, which can reduce the absorption of basic nutritional elements Mg, Ca, N and others. Because this may lead to a reduction in soil nutrients and visibly impact the plants' physiology, the amount of K used in agriculture is usually low.

Magnesium (Mg): Demonstrated results in Table 2 showed significant decrease in the Mg content in the vermicompost (1.764% or 17.64 mg g^{-1} or 17640 ppm) than in soil sample (13.007%). The results obtained in the present study was higher than in the studies by Maheswari and Priya[21] (0.093-0.568%), Singh[25] (4.900 mg g^{-1}), Oluseyi *et al.*[26] (0.35%), Punjab State council for science and technology[27] (0.2%), Manyuchi *et al.*[23] (543.7-546.8 ppm) and Ramnarain *et al.*[22] (544 ppm) (Table 3).

Table 3: Comparison of chemical properties between vermicomposts reported in other studies and the vermicompost harvested in the present study

							Percentage	
Chemical parameters	Singh[25]	Punjab state council for science and technology[27]	Oluseyi *et al.*[26]	Jaybhaye and Bhalerao[24]	Manyuchi *et al.*[23]	Ramnarain *et al.*[22]	Maheswari and Priya[21]	Current study
Nitrogen	9.500 mg g^{-1}	1.6%	1.29±0.31%	0.75±0.05%	4454.8-5331.7 ppm	1.36%	0.51-1.61	0.600
Total organic carbon	ND	ND	ND	17.38±0.68%	5.21-5.25%	18.53%	9.8-13.4	4.408
Phosphorous	0.137 mg g^{-1}	ND	1.78±0.15%	0.30±0.11%	796.3-838.1 ppm	0.58%	0.19-1.02	2.008
Potassium	0.176 mg g^{-1}	ND	6.27±0.71%	0.56±0.03%	1915.8-2384.7 ppm	0.56%	0.15-0.73	1.448
Magnesium	4.900 mg g^{-1}	0.2%	0.35±0.03%	ND	543.7-546.8 ppm	544 ppm	0.093-0.568	1.764
Copper	ND	5.0 ppm	59.83±7.27 ppm	ND	ND	26.9 ppm	0.0026-0.0048	0.042
Zinc	ND	24.5 ppm	138.33±30.73 ppm	ND	ND	611 ppm	0.0042-0.110	0.076
Iron	19.730 mg g^{-1}	175.0 ppm	633.40±150.80 ppm	ND	ND	1.56%	0.2050-1.3313	2.35
Calcium	0.276 mg g^{-1}	0.5%	3.65±0.66%	ND	1897.9-1904.6 ppm	ND	1.18-7.61	9.26
Manganese	0.016 mg g^{-1}	96.5 ppm	800.00±33.167 ppm	ND	ND	ND	0.0105-0.2038	0.022

Copper (Cu): Cu content (0.042% or 0.42 mg g^{-1} or 420 ppm) in the vermicompost was lower compared with that in the garden soil (0.074% or 740 ppm) (Table 2), but higher than it was recorded by Oluseyi *et al.*[26] (59.83 ppm), Maheswari and Priya[21] (0.0026-0.0048%), Ramnarain *et al.*[22] (26.9 ppm) and Punjab State council for science and technology[27] (5.0 ppm) (Table 3).

Zinc (Zn): The percentage of Zn (0.076% or 0.76 mg g^{-1} or 760 ppm) in the vermicompost was relatively similar to that reported by Maheswari and Priya[21] (0.0042-0.110%), Ramnarain *et al.*[22] (611 ppm) and higher in comparison with Punjab State council for science and technology[27] (24.5 ppm) and Oluseyi *et al.*[26] (138.33 ppm) (Table 3). The percentage of Zn in the garden soil was noticeably higher (0.275% or 2750 ppm) than it was in the vermicompost (Table 2).

Iron (Fe): The Fe content in the vermicompost (2.35% or 23.5 mg g^{-1} or 23500 ppm) was slightly higher than the content reported by Singh[25], Ramnarain *et al.*[22], Maheswari and Priya[21], Oluseyi *et al.*[26] and Punjab State council for science and technology[27] (19.730 mg g^{-1}, 1.56%, 0.2050-1.3313%, 633.40 and 175.0 ppm, respectively) in their vermicomposting study (Table 3). The content of Iron in the garden soil (28.9% or 289000 ppm) was considerably higher than that of vermicompost in the current study (Table 2).

Calcium (Ca): During vermicomposting, the vermiworms transform the nutrients in vermicompost into forms suitable for plant absorption, such as phosphates, exchangeable Ca and soluble K[43]. The Ca content (9.26% or 92.6 mg g^{-1} or 92600 ppm) in vermicompost was higher compared with the concentrations reported in the study by Maheswari and Priya[21], Oluseyi *et al.*[26], Punjab State council for science and technology[27], Manyuchi *et al.* [23] and Singh[25] (1.18-7.61, 3.65 and 0.5%, 1897.9 ppm and 0.276 mg g^{-1}, respectively) (Table 3) and significantly lower than that in the garden soil (28.90%) (Table 2).

Manganese (Mn): The Mn content in the vermicompost (0.022% or 0.22 mg g^{-1} or 220 ppm) and garden soil (0.018%) showed no significant difference (Table 2), these values were relatively similar to those reported by Maheswari and Priya[21], which were in the range of 0.0105-0.2038%, Punjab State council for science and technology[27] (96.5 ppm) and Singh[25] (0.016 mg g^{-1}) and significantly lower than that in Oluseyi *et al.*[26] (800.00 ppm) (Table 3).

According to Edwards *et al.*[14], vermicompost produced using the correct technique usually contains adequate amounts of micronutrients and macronutrients (owing to the high levels of total and available N, P and K in vermicompost), microbial and enzyme activities and growth regulators[44,45]. Globally, different organic wastes have been successfully used to produce vermicompost such as leaf litter[46], rice straw[47], municipal solid waste[48], paper waste[49] and silkworm litter[50].

In this study, higher concentrations of C, N and P were found in the vermicompost than in the garden soil, whereas the concentrations of K, Mg, Cu, Zn, Fe, Ca and Mn were lower in the vermicompost than in the garden soil. Earthworms consume organic matter in the soil and transform it into compost over a short period, thereby increasing the fertility of the soil. An important feature of vermicompost is that it changes many of the nutrients into forms that are more readily available to the plants[51]. Vermiworms can also change the structure of the soil and improve the degradation rate[52,53]. They are a beneficial soil additive that uses minimal space. The advantage of the vermicomposting process is that it can be maintained at various scales (small and large) and almost anywhere[9]. There is no doubt that vermicomposting is an effective technique in managing organic wastes. Therefore, the big challenge today is entering it as a product into the international markets and it requires the setting of environmental and agricultural policies seriously and attentively.

CONCLUSION

Composting with vermicompost is considered a promising method for disposing of organic waste products. The resulting vermicompost contains more exchangeable plant nutrients than other types of compost. Vermicomposting helps in the management of food, agricultural and animal wastes, which are transformed into agricultural compost that is then applied to enhance the production of nontoxic and nutritional crops. Thus, this technique is an excellent approach to reduce environmental burden of these wastes. It is also important to increase the awareness of farmers about the significance of vermicomposting and encourage more research on the vermicompost methodology as an alternative approach for using renewable and organic resources in sustainable agriculture that will improve plant growth and provide long-term food safety.

SIGNIFICANCE STATEMENT

Disposing waste is one of the most concerning modern issues in most countries. Vermicomposting production is an alternative and a promising method to eliminate the environmental threats that impact human's health and the environment. The vermicompost is a safe source of organic compost through decreasing wastes by recycling. This study revealed a developed technique that helped enhance the quality of producing a nutrient rich vermicompost from different organic wastes.

REFERENCES

1. Ansari, A.A. and A. Hanief, 2013. Microbial succession during vermicomposting. Proceedings of the 49th Annual Caribbean Food Crops Society Meeting, July 1-5, 2013, Port of Spain, Trinidad and Tobago, pp: 441-451.
2. Kaplan, M., 2016. The national master plan for agricultural development in Suriname. Final report. Kaplan Planners Ltd. Regional and Environmental Planning. https://www.share4dev.info/kb/documents/5426.pdf
3. Varghese, S.M. and M.L. Prabha, 2014. Biochemical characterization of vermiwash and its effect on growth of *Capsicum frutescens*. Malaya J. Biosci., 1: 86-91.
4. Ansari, A.A. and S. Jaikishun, 2011. Vermicomposting of sugarcane bagasse and rice straw and its impact on the cultivation of *Phaseolus vulgaris* L. in Guyana, South America. J. Agric. Technol., 7: 225-234.
5. Chauhan, H.K. and K. Singh, 2013. Effect of tertiary combinations of animal dung with agrowastes on the growth and development of earthworm *Eisenia fetida* during organic waste management. Int. J. Recycl. Org. Waste Agric., Vol. 2. 10.1186/2251-7715-2-11.
6. Lléo, T., E. Albacete, R. Barrena, X. Font, A. Artola and A. Sánchez, 2013. Home and vermicomposting as sustainable options for biowaste management. J. Clean. Prod., 47: 70-76.
7. Anjum, M., R. Miandad, M. Waqas, I.A. Tarar and Z. Alafif *et al.*, 2016. Solid waste management in Saudi Arabia: A review. J. Applied Agric. Biotechnol., 1: 13-26.
8. Waqas, M., A.S. Nizami, A.S. Aburiazaiza, M.A. Barakat, M.I. Rashid and I.M.I. Ismail, 2018. Optimizing the process of food waste compost and valorizing its applications: A case study of Saudi Arabia. J. Cleaner Prod., 176: 426-438.
9. Kumar, A., C.H.B. Prakash, N.S. Brar and B. Kumar, 2018. Potential of vermicompost for sustainable crop production and soil health improvement in different cropping systems. Int. J. Curr. Microbiol. Applied Sci., 7: 1042-1055.
10. Ismail, S.A., 2005. The Earthworm Book. Other India Press, Apusa, Goa, Pages: 101.

11. Devi, J. and M. Prakash, 2015. Microbial population dynamics during vermicomposting of three different substrates amended with cowdung. Int. J. Curr. Microbiol. Applied Sci., 4: 1086-1092.
12. Bhat, S., J. Singh and A. Vig, 2017. Instrumental characterization of organic wastes for evaluation of vermicompost maturity. J. Anal. Sci. Technol., Vol. 8, No. 1. 10.1186/s40543-017-0112-2.
13. Tahiri, A., F. Delporte, Y. Muhovski, M. Ongena, P. Thonart and P. Druart, 2016. Change in ATP-binding cassette B1/19, glutamine synthetase and alcohol dehydrogenase gene expression during root elongation in *Betula pendula* Roth and *Alnus glutinosa* L. Gaertn in response to leachate and leonardite humic substances. Plant. Physiol. Biochem., 98: 25-38.
14. Edwards, C.A., S. Subler and N. Arancon, 2011. Quality Criteria for Vermicomposts. In: Vermiculture Technology: Earthworms, Organic Waste and Environmental Management, Edwards, C.A., N.Q. Arancon and R.L. Sherman (Eds.)., CRC Press, Boca Raton, USA., ISBN: 9781439809877, pp: 287-301.
15. Sinha, K., D. Valani, B. Soni and V. Chandran, 2011. Earthworm Vermicompost: A Sustainable Alternative to Chemical Fertilizers for Organic Farming (Agriculture Issues and Policies). Nova Science Publishers Inc., New York, USA., ISBN-10: 1611225809.
16. Tandon, H.Z., 1993. Methods of Analysis of Soils, Plant, Water and Fertilisers. Fertiliser Development and Consultation Organization, New Delhi, India.
17. Hand, P., W.A. Hayes, J.C. Frankland and J.E. Satchell, 1988. The vermicomposting of cow slurry. Pedobiologia, 31: 199-209.
18. Harris, G.D., W.L. Platt and B.C. Price, 1990. Vermicomposting in a rural community. BioCycle, 31: 48-51.
19. Domínguez, J.J. and C.A. Edwards, 2011. Biology and Ecology of Earthworms Species Used for Vermicomposting. In: Vermiculture Technology: Earthworms, Organic Waste and Environmental Management, Edwards, C.A., N.Q. Arancon and R.L. Sherman (Eds.)., CRC Press, Boca Raton, USA., ISBN: 9781439809877, pp: 27-40.
20. Adhikary, S., 2012. Vermicompost, the story of organic gold: A review. Agric. Sci., 3: 905-917.
21. Maheswari, U.N. and M. Priya, 2018. Vermicompost., a backbone for sustainable agriculture-review article. Eur. J. Biomed. Pharm. Sci., 5: 835-846.
22. Ramnarain, Y.I., A.A. Ansari and L. Ori, 2019. Vermicomposting of different organic materials using the epigeic earthworm *Eisenia foetida*. Int. J. Recycl. Org. Waste. Agric., 8: 23-36.
23. Manyuchi, M.M., C. Mbohwa and E. Muzenda, 2017. Vermicomposting of soybean and maize straw residues as an agro waste management initiative. Proceedings of the 6th International Conference on Sustainability, Technology and Education, December 11-13, 2017, Sydney, Australia, pp: 11-18.
24. Jaybhaye, M. and A.B. Satish, 2016. Vermicomposting: A new trend towards management of agricultural waste (Paddy straw). Int. J. Curr. Res. Aca. Rev., 4: 61-67.
25. Singh, K., 2009. Microbial and nutritional analysis of vermicompost, aerobic and anaerobic compost. 40 CP Honours Project for Master in Environmental Engineering; Griffith University, Brisbane, Australia, (Supervisors: Dr. Rajiv K. Sinha & Dr. Sunil Heart).
26. Oluseyi, E.E., T.A. Ewemoje and A.A. Adedeji, 2016. Comparative analysis of pit composting and vermicomposting in a tropical environment. Int. J. Agric. Biol. Eng., 10: 184-187.
27. Punjab State Council for Science and Technology, 2010. Vermiculture/vermicompost. http://agri.and.nic.in/vermi_culture.htm
28. Broz, A.P., P. Verma and C. Appel, 2016. Nitrogen dynamics of vermicompost use in sustainable agriculture. J. Soil. Sci. Environ. Manage., 7: 173-183.
29. Suthar, S., 2007. Production of vermifertilizer from guar gum industrial wastes by using composting earthworm *Perionyx sansibaricus* (Perrier). Environmentalist, 27: 329-335.
30. Suthar, S., 2009. Bioremediation of agricultural wastes through vermicomposting. Bioremediat. J., 13: 21-28.
31. Garg, V.K. and P. Kaushik, 2005. Vermistabilization of tetile mill sludge spiked with poultry droppings by an epigeic earthworm *Eisenia foetida*. Bioresour. Technol., 96: 1063-1071.
32. Ansari, A.A. and J. Rajpersaud, 2012. Physicochemical changes during vermicomposting of water hyacinth (*Eichhornia crassipes*) and Grass clippings. ISRN Soil Sci., 10.5402/2012/984783
33. Marlin, C.J. and K.T. Rajeshkumar, 2012. A study on sustainable utility of sugar mill effluent to vermicompost. Adv. Applied Sci. Res., 3: 1092-1097.
34. Goswami, L., A.K. Patel, G. Dutta, P. Bhattacharyya, N. Gogoi and S.S. Bhattacharya, 2013. Hazard remediation and recycling of tea industry and paper mill bottom ash through vermiconversion. Chemosphere, 92: 708-713.
35. Kale, R.D., 1998. Earthworm: Cinderella of Organic Farming. Prism Books Pvt. Ltd., Bangalore, India, ISBN-10: 8172861001.
36. Chaudhuri, P.S., T.K. Pal, G. Bhattacharjee and S.K. Dey, 2000. Chemical changes during vermicomposting (*Perionyx excavates*) of kitchen waste. Trop. Ecol., 41: 107-110.
37. Kitturmath, M.S., R.S. Giraddi and B. Basavaraj, 2007. Nutrient changes during earthworm, *Eudrilus eugeniae* (Kinberg) mediated vermicomposting of agro-industrial wastes. Karnataka J. Agric. Sci., 20: 653-654.
38. Giraddi, R.S., 2007. Vermitechnologies. University of Agricultural Sciences, Dharwad, India, (In Kannada).

39. Giraddi, R.S., 2011. Research priorities in vermitechnologies. Final Report Submitted to NABARD., Mumbai, India.
40. Meenatchi, R., 2008. Molecular characterization of earthworms, nutrient assessment and use of vermitechnologies in pest management. Ph.D. Thesis, Dharwad (Karnataka), India.
41. Waseem, M.A., R.S. Giraddi and K.K. Math, 2013. Assessment of nutrients and micro flora in vermicompost enriched with various organics. J. Exp. Zool. India, 16: 697-703.
42. Rautela, I., S. Rathore, P. Chauhan, P. Tapliyal and D.M. Sharma, 2019. Vermicompost is boon to enrichment of micronutrient content in soil. World J. Pharm. Res., 8: 2309-2318.
43. Orozco, F.H., J. Cegarra, L.M. Trujillo and A. Roig, 1996. Vermicomposting of coffee pulp using the earthworm *Eisenia fetida*: Effects on C and N contents and the availability of nutrients. Biol. Fertil. Soils, 22: 162-166.
44. Karmegam, N. and T. Daniel, 2009. Investigating efficiency of *Lampito mauritii* (Kinberg) and *Perionyx ceylanensis* Michaelsen for vermicomposting of different types of organic substrates. The Environ., 29: 287-300.
45. Prakash, M. and N. Karmegam, 2010. Vermistabilization of pressmud using *Perionyx ceylanensis* Mich. Bioresour. Technol., 101: 8464-8468.
46. Nagar, R., A. Titov and P. Bhati, 2017. Vermicomposting of leaf litters: way to convert waste in to best. Int. J. Curr. Sci., 20: 25-30.
47. Sharma, K. and V.K. Garg, 2018. Comparative analysis of vermicompost quality produced from rice straw and paper waste employing earthworm *Eisenia fetida* (Sav.). Bioresour. Technol., 250: 708-715.
48. Singh, K., S. Sharma, J.A.D.S. Teixeira, S. Satya and K. Arora, 2012. Vermicomposting of municipal solid waste employing *Eisenia fetida* together with *Penicillium* spp. and *Azotobacter* bioinoculants. Dynamic Soil Dynamic Plant, 6: 89-95.
49. Basheer, M. and O.P. Agrawal, 2013. Management of paper waste by Vermicomposting using epigeic earthworm, *Eudrilus eugeniae* in Gwalior, India. Int. J. Curr. Microbiol. Applied Res., 2: 42-47.
50. Kalaiyarasan, V., D.U. Nandhini and K. Udhayakumar, 2015. Seriwaste vermicompost-a trend of new sustainable generation-A review. Agric. Rev., 36: 159-163.
51. Saranraj, P. and D. Stella, 2012. Vermicomposting and its importance in improvement of soil nutrients and agricultural crops. Novus Nat. Sci. Res., 1: 14-23.
52. Lemtiri, A., G. Colinet, T. Alabi, D. Cluzeau, L. Zirbes, É. Haubruge and F. Francis, 2014. Impacts of earthworms on soil components and dynamics. A review. Biotechnol. Agron. Soc. Environ., 18: 121-133.
53. Fahey, T.J., J.B. Yavitt, R.E. Sherman, J.C. Maerz, P.M. Groffman, M.C. Fisk and P.J. Bohlen, 2013. Earthworm effects on the incorporation of litter C and N into soil organic matter in a sugar maple forest. Ecol. Applied, 23: 1185-1201.