International Journal of Recycling of Organic Waste in Agriculture (2022)11: 165-175
Doi: 10.30486/IJROWA.2021.1922034.1196

ORIGINAL RESEARCH

Biotransformation of sludges from dairy and sugarcane industries through vermicomposting using the epigeic earthworm *Eisenia fetida*

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Received: 29 January 2021 / Accepted: 23 July 2021 / Published online: 09 March 2022

Abstract

Purpose In India, the global contribution of milk and sugarcane production are 21% and 12 to 15%. Dairy and sugarcane industries produce end products as sludge which is directly dumped in open land which pollute the land and groundwater of the nearby areas. The present study was aimed to utilize the vermicomposting technique to treat the sludge generated from these two industries.

Method The dairy sludge, sugarcane press mud were homogenously mixed with cattle manure to form five different proportions of waste mixture M1, M2, M3, M4, and M5. The waste mixtures were kept in reactors for 15 days for pre-composting. Once the pre-composting temperature reached to 25 °C, fifty adults *Eisenia fetida* earthworms with an average weight of 0.4 to 0.5 gram each was introduced into each reactor.

Results The highest production of earthworm cocoons was studied in the combinations of M4 and M5. The higher growth of earthworm was observed in M5 (39%) followed by M3 (34%). The germination index and carbon to nitrogen ratio were found to be 100 to 121% and 9 to 11, respectively, along with the negligible carbon dioxide evolution in every combination that revealed the maturity and stability of vermicomposting.

Conclusion The vermicompost obtained from the combination of dairy (milk processing unit) and sugarcane industries press mud sludge was rich in nutrients and suitable to utilize as nutrients (fertilizer) for the crops. Vermicomposting can solve the issue of sludge management from these two industries with the utilization of end products as vermicompost.

Keywords Nutrient, Germination index, Vermicompost, Industrial sludge, Carbon to nitrogen ratio

Introduction

In India, small and medium enterprises contribute to the US $5 billion, constituting about 80% of total industrial enterprises (Singh et al. 2015). Among that, small scale industries (around 3 million) contribute 30 to 35% of industrial production and contribute approximately 50% of industrial pollution (Singh et al. 2015; Kumar et al. 2010). Small scale industries are usually associated with various processes, namely, textile, foundries, food processing, chemical, manufacturing, dyeing, printing, distilleries, etc. In general, in India, small scale industries are usually outside the regulatory measures and use conventional/outdated technologies, thus generating excessive pollution which aggravates environmental issues.

Gujarat is the sixth largest state of India by area (195,984 square kilometer). It is situated between 20°01' to 24°07' north latitudes and 68°04' to 74°04' east longitude. Gujarat is well- known for the sugarcane and dairy industry with 40 milk processing (dairy industries) and 22 sugarcane industries with advanced technology. The waste generated from these two industries are problematic due to the lack of adequate waste treatment, and disposal facility (Singh et al. 2015).

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Sugarcane industries produce a considerable quantity of sugarcane bagasse, dry leaves, sugar cane press mud (SPM), and molasses apart from sugar (Kumar et al. 2010). The generation of press mud is approximately around 30 to 40 kg from 1 ton of crushed sugarcane. The dairy industry also produces sludge, and the generation of sludge varies according to the capacity of the milk processing industry (Ashekuzzaman et al. 2019). The traditional disposal methods such as open dumping and/ or landfilling of dairy sludge and sugarcane press mud are not only increasingly expensive, but impractical as open space becomes limited (Suthar et al. 2012). The open dumping and landfilling of these dumped waste material will generate leachate which will responsible for contamination of soils, and pollute nearby ground water (Suthar et al. 2012). The emission of greenhouse gas (GHGs) from open waste dumping/ landfilling site is a main issue of prime concern. On the other hand, the sugarcane press mud and dairy sludge contain macro nutrients (Mg, K, P, Na, Ca and N) and micro nutrients (Zn, Fe, Mn and Cu) which are wasted. However, the stabilization of such sludge prior to use of disposal should reduce the environmental problems associated with its open dumping.

The global need for the recycling of solid waste using sustainable environment-friendly techniques is increasing rapidly. Nowadays, vermicomposting emerges as a promising option in solid waste disposal as it has greater socio-economic benefits to the nation. Vermicomposting stabilizes the organic material through the combined process exerted by microorganisms and earthworms. In vermicomposting, the microbes influence the biochemical degradation process of organic matter. On the other hand, earthworms typically do the conditioning of surface on which organism lives (substrate) and change the process's biological activities (Domínguez et al. 2000; Ghasemi et al. 2019). Many researchers have processed the different industrial wastes into vermicompost to form nutrient-rich manure. In the past decade, several industrial waste/ sludge has cited namely textile mill sludge (Kaushik and Garg 2003; Yadav and Garg 2011), sugar industry sludge (Suthar et al. 2012), distillery sludge (Singh et al. 2014; Suthar and Singh 2008), paper waste (Singh et al. 2014), agro-industrial sludge (Lim et al. 2014), beverage industry sludge (Singh et al. 2010) and primary sewage sludge (Gupta and Garg 2008).

In recent literature, organic wastes, namely, animal manure, crop residues, sewage sludge, and industrial refuse are cited that are effectively consumed by earthworms (Atiyeh et al. 2000; Garg and Gupta 2011). Earthworms break the waste substrate and aggravate the decomposition rate of organic matter. As a result, the composting effect takes place, and organic matter gets stabilized. After the process, the final vermicompost contains much more nutrients (per kg weight) compared to the organic substrate from which it originates (Chauhan and Singh 2015). The transfer of nutrients for plant growth has facilitated by the biological activities of earthworm, which provides nutrient-rich compost (Ansari 2008).

As comprehended from the literature, the present study was aimed to stabilize the dairy sludge and sugarcane press mud (SPM) with cattle manure in different combinations using the epigeic earthworm *Eisenia fetida.* The different ratio of dairy sludge, SPM and cattle manure were tested under vermicomposting process in order to find out the appropriate waste combinations for optimizing the activity of earthworm.

Materials and methods

The specimens of earthworm species *Eisenia fetida* were taken from a reared stock culture. Freshly deposited sludge and sugarcane press mud were collected from the local dairy milk processing wastewater treated sludge and local sugarcane industry, respectively. The collected wet sludge usually contains 70 to 80% moisture content, which was further kept in sunlight for three days to remove the excess moisture content. Subsequently, the turns were prepared at regular interval to minimize the characteristic smell of putrescible elements and bio-toxic compounds existing in sludge,which usually come across due to the anaerobic reaction. Later, partly dried sludge lump solids were homogenized by turning and shredding before using in experimental vermibeds. Fresh cattle manure was then collected from the cattle farm, Ahmedabad, India. The volume of the vermicomposting reactor was 0.3 m^3. Appropriate quantities of industrial sludge and cattle manure are mixed in the reactor to form the combinations of mixture called pre-composting.

Different pre-composting combinations were prepared using a different proportion of feed material (sludge and cattle manure). Various trials of different waste mixture combinations were performed for the vermicomposting process, and the best results obtained were selected for the present study. Table 1 shows the initial physico-chemical properties of waste mixtures and it also gives the details of waste mixture combinations of dairy and sugarcane industries sludge with cattle manure mixture.

The set of two identical vermicomposting reactors for a particular pre-composting combination would be available for analysis. Each pre-composting (feed mixture) combination was thoroughly mixed for uniformity and kept for fifteen days in the reactor (called the pre-composting phase). After the pre-composting phase and once the pre-composting temperature was recorded 25 °C, fifty adults *Eisenia fetida* earthworms with an average weight of 0.4 to 0.5 gram each were introduced in each reactor. The top surface of each reactor exposed to the atmosphere was closed with gunny bags and was kept in a dark place with controlled maintained temperature of 25 °C. The day when earthworms were introduced into the reactor was marked as 0^{th} day and keeping 0^{th} day as the starting event of the vermicomposting process, subsequent days of analysis were planned. Each feed material combination was then analysed at fifteen days' interval on the 0^{th}, 15^{th}, 30^{th}, 45^{th}, 60^{th}, 75^{th}, and 90^{th} day. Physico-chemical parameters, namely, pH, total nitrogen, C/N ratio, electrical conductivity, total organic carbon, phosphorus, K^+, Na^+ and carbon dioxide (CO_2) evolution rate, etc. were examined in each feed material. To determine the electrical conductivity and pH, fresh sample was used in the analysis. Initially, moisture content was recorded, and then the dried sample from the oven was grinded and sieved using a 0.1 mm sieve size. Further, this sieved sample was analysed to determine the total organic carbon, total nitrogen, phosphorus, Na^+, and K^+, along with C:N ratio. Germination index test was performed after every seven days' interval. Fifty-gram sample was taken and mixed with 100 mL distilled water and shaking in rotary shaker for six hours for the complete mixing of sample and water. After shaking sample was centrifuged at 8000 rpm for 20 minutes. The centrifuged sample of 5 mL quantity was put into each Petri dish, and for controlling, 5 mL deionized water was put into the Petri dish. Ten radish seeds were sown in each petri dish with three replicates of each treatment. The petri dish was kept in dark mode in incubator at 25 °C for 72 hours. Seed germinated in each petri dish was counted after seven days and the equation (1) and (2) were used

Table 1 Characteristics of initial physico-chemical properties of waste mixtures and combinations of waste mixtures

Parameters	Unit	Sugarcane press mud	Cattle manure	Dairy sludge
Total organic carbon	g/kg	365.9 ± 1.07	381.07 ± 1.47	402.98 ± 1.82
pH		6.98 ± 0.09	7.1 ± 0.09	6.72 ± 0.8
Total nitrogen	g/kg	20.03 ± 0.08	24.09 ± 0.64	19.09 ± 0.09
Moisture content	%	80.05 ± 0.95	79.85 ± 2.9	15.84 ± 0.68
C:N ratio		19 ± 0.44	16 ± 0.90	21 ± 2.79
Electrical conductivity	mS/cm	5.40 ± 0.09	3.45 ± 0.08	5.87 ± 0.8
Calcium (Ca)	g/kg	5.08 ± 0.92	8.32 ± 0.83	5.60 ± 0.89
Copper (Cu)	mg/kg	32.98 ± 0.55	34.67 ± 0.19	36.08 ± 0.84
Potassium (K)	g/kg	4.02 ± 0.69	9.21 ± 0.71	3.07 ± 0.67
Iron (Fe)	g/kg	1.03 ± 0.57	0.98 ± 0.57	0.77 ± 0.71
Manganese (Mn)	mg/kg	98.98 ± 0.81	26.09 ± 1.75	91.09 ± 1.78
Magnesium (Mg)	g/kg	1.45 ± 0.08	4.83 ± 0.08	1.93 ± 0.09
Sodium (Na)	g/kg	0.95 ± 0.09	1.98 ± 0.09	1.84 ± 0.07
Zinc (Zn)	g/kg	115.87 ± 1.94	178.98 ± 1.70	165.09 ± 1.87
Total phosphorous	g/kg	3.73 ± 0.07	2.39 ± 0.09	3.92 ± 0.07
Combinations of waste mixtures	**Unit**	**Sugarcane press mud**	**Cattle manure**	**Dairy sludge**
M1	%	20	80	-
M2	%	30	70	-
M3	%	-	80	20
M4	%	-	70	30
M5	%	20	60	20

to calculate the relative seed germination and germination index (GI) similar to Sharma and Yadav (2018).

$$\text{Relative seed germination (\%)} = \frac{\text{Number of seeds germinated extra} \times 100}{\text{Number of seeds germinated in control}} \quad (1)$$

$$\text{GI (\%)} = \frac{\text{(Relative seed germination)} \times \text{(Relative root growth)}}{100} \times 100 \quad (2)$$

Statistical analysis

One-way ANOVA was used to evaluate significant difference ($P < 0.05$) of the physicochemical parameter among different combinations throughout the composting period utilizing SPSS 13.0 version statistical package.

Results and discussion

pH, Electrical conductivity (EC), Total organic carbon (TOC) and Total nitrogen

pH is a critical parameter and influences the vermicomposting process. The range of pH from 6 to 8 is suitable for the vermicomposting process (Chauhan and Singh 2013; Garg and Kaushik 2005; Sharma and Yadav 2017). The variations of pH for the different mix combinations have shown in Fig. 1a. The initial pH values for the composting combinations recorded 6.4 ± 0.09 (M1), 6.5 ± 0.08 (M2), 6.8 ± 0.09 (M3), 6.9 ± 0.10 (M4) and 6.9 ± 0.13 (M5) increased to 7.87 ± 0.13, 7.28 ± 0.07, 7.98 ± 0.14, 7.9 ± 0.11 and 7.9 ± 0.15, respectively. The onset of the trend depicted that the pH range is neutral, with pH value nearer to 7. The pH value in all vermireactor increased slightly and reached the pH value nearer to 8. It is observed that with minor increment, the pH tended to be alkaline across all the vermireactors. Earthworms and microorganisms have the capabilities to alter the pH of soil. The degradation of organic and nitrogen compound to ammonium (NH_4^+) ions and humic acid are also responsible due to earthworms and microorganisms (Alavi et al. 2017; Ramnarain et al. 2019). Ammonium ions are responsible for the increase in the pH. Moreover, humic acid is responsible for the reduction in the pH. The presence of both could be responsible for the reduction of pH in vermicompost makes the value of pH neutral (Sharma and Yadav 2017).

Electrical conductivity is usually used for maturity and reveals salinity in the vermicompost process (Garg and Kaushik 2005; Suthar et al. 2012). Electrical conductivity is widely used to check the plant's phytotoxicity effects when vermicompost is mixed with the soil. Fig. 1b shows the variations of electrical conductivity. The variation of electrical conductivity into vermireactor (M1 to M5) was from 5.1 to 5.9 mS/cm, which was decreased to 4.2 to 3.1 mS/cm. During the degradation of organics, the combined action of earthworms and microorganisms releases the soluble salt which further decreases the EC. Further, the increasing content of mineral salt due to continuous loss of organic matter leads to a decrease in EC. The decrease in value of EC is due to the ammonia precipitation and production of mineral salt converted from initially present salt (Domínguez et al. 2000; Reza and Singh 2010). The previous researcher observed similar, decreasing trends of electrical conductivity during the vermicomposting of sewage sludge and textile sludge (Ansari 2008; Domínguez et al. 2000; Garg and Kaushik 2005).

Total organic carbon is a parameter to determine the maturity of the parameter. During the vermicomposting process other than an earthworm, carbon is used by microbes as an energy source and nitrogen for building the cell structure. It may be noted that during the vermicomposting process, some part of carbon was lost as CO_2. Initially, the presences of total organic carbon into combinations were 382 ± 1.27, 401 ± 1.14, 365 ± 2.02, 395 ± 2.12, 432 ± 2.54 g/kg and decreased to 300 ± 2.31, 285 ± 1.87, 287 ± 1.89, 265 ± 2.76 and 267± 2.35 g/kg, respectively in M1, M2, M3, M4 and M5 (Fig. 1c). The highest reduction in TOC was observed in combination M5 (38%) followed by M4 (32%), M2 (28%), M1 (21%) and M3 (21%). It was observed that the mineralization of carbon into the vermicomposting process was directly related to the combinations of waste mixtures. The vermibeds, which contain less sludge and high cattle manure, were observed to have a higher reduction in total organic carbon.

Along with the fungal stains, a larger microbe's population, namely, bacteria, nematodes, fungi, protozoa, and actinomycetes are present in cattle manure. In vermibeds, such microbes provide additional cellular enzymes during organic decomposition. The concentration of total nitrogen into all the vermireactor was observed as increased significantly. The total nitrogen availability in vermicomposted feedstock material was in the range of 19 to 22 g/kg (Fig. 1d). The initial concentration of total nitrogen in all the combinations was 20 ± 1.98, 22 ± 0.98, 19 ± 0.09, 18 ± 1.54 and 21 ± 0.97 g/kg, which increased from 26 to 28 g/kg, respectively in M1, M2, M3, M4, and M5. The rate of increment of total nitrogen in the vermireactor was arranged in the sequence: M4 > M1 > M3 > M5 > M2. The increasing rate of nitrogen concentration slightly varied among all the vermibeds. In substrate, the nitrogen rate increases due to the excretion of the earthworm body, present in organic matter for a longer time (Muthukumaravel et al. 2008; Sharma and Yadav 2018). The mucus, a polysaccharide excretion by earthworm, changes the climatic conditions of vermibeds leading to microbial inhabitants and enhances the nitrogen fixers leading to nitrogen enrichment in the material of vermicompost. ANOVA showed that pH, EC, TOC and total nitrogen significantly varied between vermicomposting days (P < 0.0001) and different mix proportions (P = 0.0001).

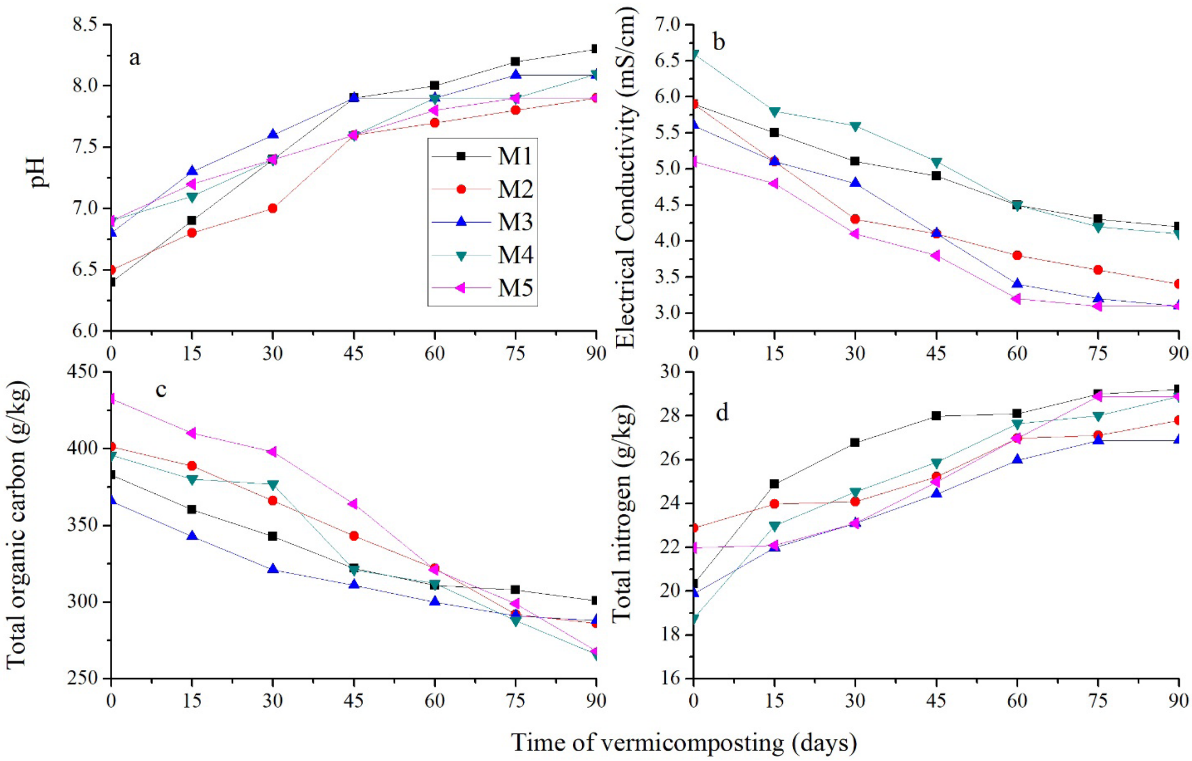

Fig. 1 Variations of time of vermicomposting vs. observation parameters (pH, electrical conductivity, total organic carbon and total nitrogen)

CO_2 evolution rate, C:N ratio, Oxygen uptake rate, and Germination index (GI)

The compost stability can be determined by a parameter named CO_2 evolution, which involves oxygen and releases carbon dioxide to produce cellular energy (aerobic respiration). CO_2 evolution rate was widely used to measure the microbial activity and respiration and shows the compost's stability (Chauhan and Singh 2015; Sharma et al. 2018). In the present analysis, the decreasing trend was observed for CO_2 evolution rate with the vermicomposting time. The presence of initial CO_2 evolution concentration into all combinations was 6.97 ± 1.34, 7.97 ± 1.23, 7.63 ± 1.45, 7.01 ± 1.67 and 6.87 ± 0.96 mg/g VS/day which decreased to 0.21 ± 0.82, 0.1 ± 0.78, 0.34 ± 0.76, 0.02 ± 0.87 and 0.001 ± 0.73 mg/g.VS/day (Fig. 2a). Also, the decreasing CO_2 evolution rate was observed due to the mineralization of present carbon. For mature and stable vermicompost, the permissible range of CO_2 evolution rate is cited approximately between 0.001 to 3 mg/g.VS/day (Sharma and Yadav 2018). In the present analysis for the dairy and sugarcane press mud sludge, the results obtained in a range of 0.001 to 0.21 mg/g.VS/day are within the cited permissible limit.

Oxygen uptake rate shows the compost maturity (Ansari 2008; Garg and Kaushik 2005). Initially, more microorganisms were present during the vermicomposting process due to the higher degradation rate of sludge, resulting in a higher concentration of oxygen uptake rate. During the vermicomposting process, the oxygen uptake rate decreased with time, as the number of microorganisms decreased due to food unavailability. The oxygen uptake rate into all combinations on the initial day was 10.98 ± 1.24, 12.09 ± 0.98, 9.87 ± 1.54, 10.98 ± 0.87, and 11.87 ± 1.43 mg/g.VS/day which reduced to 2.09 ± 0.74, 1.54 ± 0.54, 1.23 ± 0.64, 1.98 ± 0.32 and 0.98 ± 0.24 mg/g.VS/day at the end of the vermicomposting process (Fig. 2b). Similar decreasing trends of oxygen uptake rate was observed by Nayak et al. (2013) during the vermicomposting of sewage sludge waste.

C:N ratio is widely used to check the maturity of compost/ vermicompost, and it influences the microbial activity (Reza and Singh 2010; Singh et al. 2014). The active microbial degradation process is assured by maintaining an appropriate ratio of carbon to nitrogen ratio. Initial C:N ratio for the present combination was 19 ± 1.25, 18 ± 1.53, 18 ± 1.62, 21 ± 1.81 and 20 ± 0.98, which decreased from 11 to 9, respectively in M1 to M5 combinations (Fig. 2c). In the present analysis, the C:N ratio is obtained within the permissible range reported for agronomic use of compost, below 20 (acceptable maturity) to <15 (preferable) (Faisal et al. 2019; Lim et al. 2014).

Germination index is used to check the phytotoxicity effect and maturity of the vermicompost. Vermicompost having rich concentration of heavy metals harmfully affects the growth of the plant during the vermicompost process. In the present study, the initial concentration of germination index was 72 ± 0.76, 71 ± 0.87, 81 ± 0.56, 79 ± 0.63 and 83 ± 0.93% which increased to 100 ± 0.35, 110 ± 0.65, 119 ± 0.73, 112 ± 0.63 and 121 ± 0.33%, respectively in combinations M1 to M5 (Fig. 2d). A previous researcher considered the suitability of vermicompost if the germination index was more than 80% (Singh et al. 2014; Thi et al. 2018). In the present study, the germination index was more than 100% in all trial, which was applicable to use for agriculture purposes. ANOVA showed that CO_2 evolution rate, C:N ratio, oxygen uptake rate and GI significantly varied between vermicomposting days (P < 0.0001) and different mix proportions (P = 0.0001).

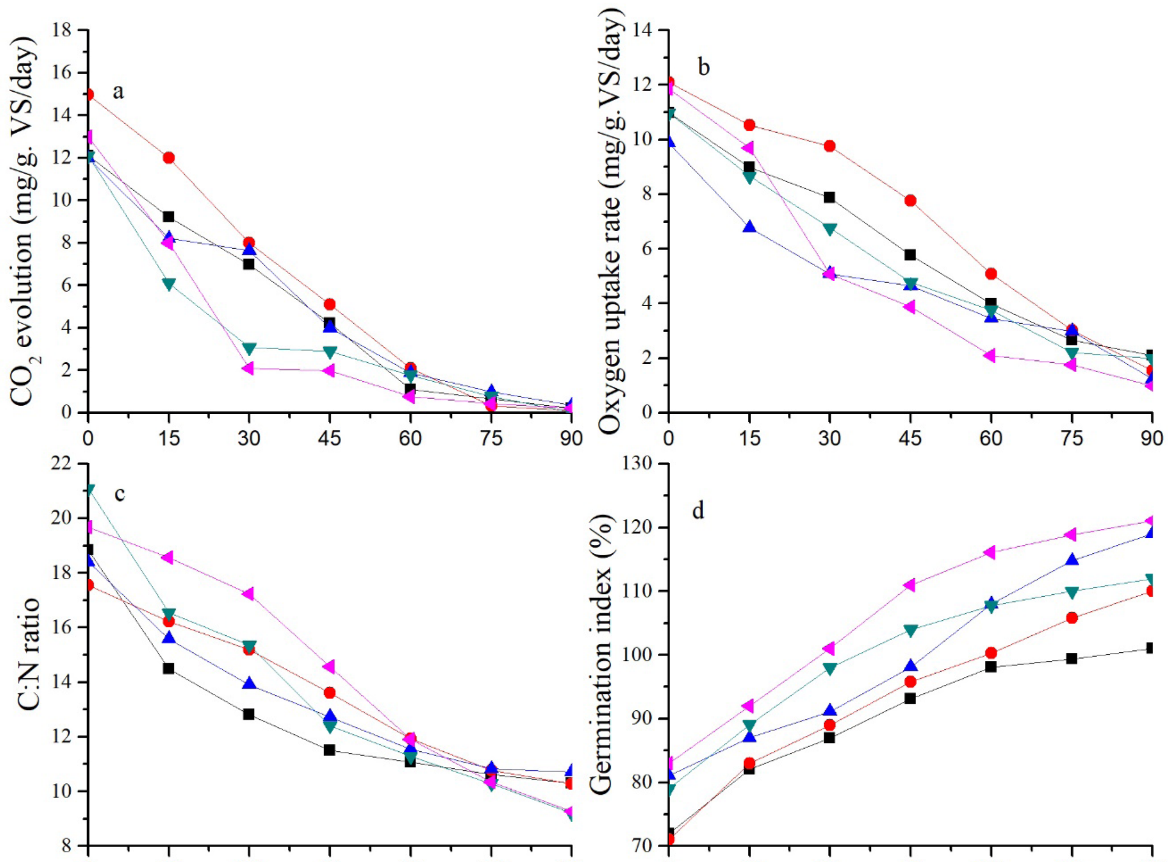

Fig. 2 Variations of carbon dioxide evolution, oxygen uptake rate, carbon to nitrogen ratio and germination index during the vermicomposting

Micro and macro nutrients

Micro and macronutrients are essential elements that help to increase the fertility of the soil. The fertility of the soil is an important factor to increase the yield of the crops. To protect the plant from drought and diseases, the availability of nutrients into the soil is essential. Micro and macro nutrients availability can be maintained within the soil with the addition of vermicompost obtained from the treated sludge of sugarcane and dairy sludge. The concentration of calcium, potassium, phosphorus, and sodium increased during the vermicomposting cycle (initial day to final day). Moreover, the concentration of Na and Ca increased gradually, which reports a net loss of dry mass. This loss was incurred due to organic matter degradation and the CO_2 release, NH_3, and H_2S during the vermicomposting process/cycle (Gupta and Garg 2008; Sharma and Yadav 2018). The initial concentration of sodium into combination M1 to M5 is shown in Table 2 as 1.09 ± 0.14, 1.03 ± 0.25, 1.63 ± 0.13, 1.16 ± 0.11 and 1.39 ± 0.13 g/kg which were improved to 4.76 ± 0.21, 2.01 ± 0.21, 3.91 ± 0.16, 2.65 ± 0.15 and 3.07 ± 0.17 g/kg, respectively at the end of the vermicomposting process. The increases in sodium concentration in the final compost are beneficial for the plants as sodium helps in the metabolism and synthesis of chlorophyll (Singh et al. 2014; Sharma et al. 2021).

Table 2 Presence of nutrients into the vermicompost

Elements	Day	M1	M2	M3	M4	M5
Total nitrogen (g/kg)	0	20.32 ± 0.34	22.88 ± 0.16	19.88 ± 0.12	18.77 ± 0.18	21.98 ± 0.17
	90	29.21 ± 0.14	27.8 ± 0.15	26.88 ± 0.11	28.9 ± 0.16	28.88 ± 0.15
Na (g/kg)	0	1.09 ± 0.14	1.03 ± 0.25	1.63 ± 0.13	1.16 ± 0.11	1.39 ± 0.13
	90	4.76 ± 0.21	2.01 ± 0.21	3.91 ± 0.16	2.65 ± 0.15	3.07 ± 0.17
K (g/kg)	0	14.80 ± 1.15	12.35 ± 1.87	14.68 ± 1.39	12.68 ± 1.44	14.75 ± 1.27
	90	16.21 ± 1.10	17.11 ± 1.49	19.21 ± 1.40	18.45 ± 132	22.22 ± 1.41
Ca (g/kg)	0	5.69 ± 1.40	6.02 ± 1.20	5.67 ± 1.32	6.40 ± 1.41	6.68 ± 1.37
	90	13.42 ± 1.23	12.05 ± 1.37	9.05 ± 1.38	11.09 ± 1.34	12.34 ± 1.42
P (g/kg)	0	4.07 ± 0.59	4.08 ± 0.59	4.14 ± 0.72	3.52 ± 0.68	4.31 ± 0.59
	90	6.93 ± 0.62	6.88 ± 0.68	6.70 ± 0.71	6.48 ± 0.57	6.48 ± 0.62
Mg (g/kg)	0	1.08 ± 0.36	1.68 ± 0.20	1.99 ± 0.29	2.56 ± 0.24	3.86 ± 0.23
	90	5.12 ± 0.32	4.19± 0.17	4.42 ± 0.30	5.32 ± 0.22	5.96 ± 0.08
Fe (g/kg)	0	0.83 ± 0.69	0.98 ± 0.62	0.89 ± 0.68	1.05 ± 0.58	1.12 ± 0.59
	90	6.15 ± 0.77	6.21 ± 0.68	5.31 ± 0.71	5.68 ± 0.55	6.22 ± 0.54
Mn (mg/kg)	0	91.37 ± 1.65	102.25 ± 1.25	99.07 ± 1.42	102.09 ± 1.58	112.11 ± 1.65
	90	112.31 ± 1.95	121.64 ± 1.43	116.75 ± 1.37	124.42 ± 1.66	136.12 ± 1.42
Zn (mg/kg)	0	115.45 ± 0.98	120.54 ± 0.79	122.85 ± 0.78	132.02 ± 0.80	134.61 ± 1.32
	90	134.12 ± 0.84	136.21 ± 0.76	144.21 ± 0.80	159.05 ± 0.71	165.87 ± 0.69
Cu (mg/kg)	0	36.52 ± 0.42	36.12 ± 0.42	39.88 ± 0.39	38.32 ± 0.29	44.31 ± 0.29
	90	46.45 ± 0.53	49..21 ± 0.43	52.35 ± 0.42	56.11 ± 0.49	59.01 ± 0.39

The initial presence of calcium was 5.69 ± 1.40, 6.02 ± 1.20, 5.67 ± 1.32, 6.40 ± 1.41 and 6.68 ± 1.37 g/kg which were improved to 13.42 ± 1.23, 12.05 ± 1.37, 9.05 ± 1.38, 11.09 ± 1.34 and 12.34 ± 1.42 g/kg, respectively in combination M1, M2, M3 M4, and M5. When calcium present in compost is mixed with soil calcium, it provides useful nutrition and helps to maintain the growth of plants as well as cell wall deposition. The presence of calcium in the compost maintains the chemical balance of the soil mixture, helps to reduce the salinity of the soil and also helps in improving the penetration of water (Al-Najar et al. 2016; Domínguez et al. 2000).

The increasing potassium rate in combinations M1 to M5 was 22, 54, 45.24, 68, and 53% after 90 days. The high, increasing rate of potassium was observed in combination with C5. Nitrogen, phosphorous and potassium, the important nutrients for plant growth, are used to evaluate the maturity of vermicompost and its quality as bio-fertilizer (Garg and Kaushik 2005; He et al. 2016). The initial concentration of phosphorous in

M1 to M5 was 4.07 ± 0.59, 4.08 ± 0.59, 4.14 ± 0.72, 3.52 ± 0.68 and 4.31 ± 0.59 g/kg, which increased to 6.93 ± 0.62, 6.88 ± 0.68, 6.70 ± 0.71, 6.48 ± 0.57 and 6.48 ± 0.62 g/kg after completion of the vermicomposting period. After the composting period, the increased content of non-volatile phosphorous and potassium was measured from the compost mass losses incurred due to organic matter biodegradation (Domínguez et al. 2000; He et al. 2016). The initial concentration of magnesium was 1.08 ± 0.36, 1.68 ± 0.20, 1.99 ± 0.29, 2.56 ± 0.24, and 3.86 ± 0.23 g/kg, which increased to 5.12 ± 0.32, 4.19 ± 0.17, 4.42 ± 0.30, 5.32 ± 0.22, and 5.96 ± 0.08 g/kg after 90 days. The presences of magnesium in the plants are significant because magnesium is the powerhouse behind the photosynthesis activity in plants. If the soil has less magnesium concentration, chlorophyll cannot capture the solar energy needed for photosynthesis (Sharma et al. 2018; Thi et al. 2018). The initial concentration of iron in combination M1 to M5 was 0.83 ± 0.69, 0.98 ± 0.62, 0.89 ± 0.68, 1.05 ± 0.58 and 1.12 ± 0.59 g/kg, which increased to 6.15 ± 0.77, 6.21 ± 0.68, 5.31 ± 0.71, 5.68 ± 0.55 and 6.22 ± 0.54 g/kg after vermicomposting. The role of iron concentration in the plant is that without iron, a plant cannot produce chlorophyll (Ghasemi et al. 2019; Lim et al. 2014). Hence, the presence of iron concentration in the compost protects from chlorosis disease in the plant. In each combination, the presence of manganese was 91.37 ± 1.65, 102.25 ± 1.25, 99.07 ± 1.42, 102.09 ± 1.58 and 112.11 ± 1.65 mg/kg, which increased to 112.31 ± 1.95, 121.64 ± 1.43, 116.75 ± 1.37 ± 1.65, 124.42 ± 1.66, and 136.12 ± 1.42 mg/kg at the end of vermicomposting periods. It is noted that manganese helps the plant for photosynthesis and protects the leaves from the disease called chlorosis (Reza and Singh 2010; Singh et al. 2010). The increase percentage of zinc in combination M1 to M5 was 13, 11, 14, 16, and 18%, respectively at the end of the vermicomposting period. Similarly increasing the rate of copper in combination M1 to M5 was 21, 26, 23, 31, and 24% at the end of vermicomposting period. Singh et al. (2010) reported that the presence of a concentration of zinc and copper in compost is used for the plants for the formation of auxins, which help with growth regulation and stem elongation.

Growth of earthworm

During the experiment, the cocoons were produced by *Eisenia fetida* in all the vermibeds. The maximum production of cocoons was observed in M5 (100 ± 3.0) followed by M3 (74.0 ± 4.0), M4 (69 ± 2), M2 (65 ± 3.0), M1 (61 ± 2.2) (Fig. 3a). It may be noted that in the waste mixture, the cocoon production was responsible for the quality of the feedstock. Fig. 3b shows the growth of hatchlings during the vermicomposting process. The earthworm growth in vermibeds is directly affected by the waste proportion of feedstock. On the other hand, microbes greatly influenced the diet of the earthworm and were directly responsible for the proportion of substance which slowed down the growth rate in earthworm feed (Muthukumaravel et al. 2008; Nayak AK et al. 2013; Sharma and Yadav 2017). In the present analysis, earthworms' regeneration is better in bedding having an acceptable ratio of bulking agents. It is cited in the literature that the rate of cocoon production in composting earthworms is enriched due to the higher nitrogen fraction of decomposing waste (Domínguez et al. 2000; Singh et al. 2014). In earthworms, the cocoon production patterns have been reliant on waste quality during the vermicomposting (Al-Najar et al. 2016; Gupta and Garg 2008; Thi et al. 2018).

Significant growth of earthworm was observed during the vermicomposting cycle or process, which results in a high growth rate of earthworm biomass. The mortality of earthworm was substantial in the last two weeks of the vermicomposting cycle. The suitability of waste to earthworm is an analysing factor that is usually observed through cocoon production and continuous growth in vermibeds. As shown in Fig. 3c, the maximum increase/growth of individual earthworm recorded was about 83 ± 2 in M5 followed by 76 ± 3 (M2), 70 ± 4 (M1), 67 ± 3 (M4), 62 ± 3 (M4). The reported improvement in results was observed due to the different chemical composition in the earthworm feeding rate. Moreover, the gain of earthworm biomass was different in each vermibeds due to feeding composition difference and palatability (Suthar et al. 2012). It is worth noting that the earthworm diet is significantly dependent on the richness of the substrate microbial activities. Further, microbial activities, along with the feedstock quality and nutrient pools, availability in vermibeds, affect the earthworm feeding rate. The earthworm biomass after the vermicomposting process was observed less than the maximum separate biomass reported during 60 to 75 days. It shows the loss in inoculated earthworms biomass due to the conversion of used substrate into vermicompost known as substrate material ageing (Atiyeh et al. 2000; Gupta and Garg

2008; Sharma and Yadav 2017). The ageing of substrate material usually restricts the earthworms growth during the vermicomposting (Domínguez et al. 2000; Singh et al. 2014).

Conclusion

Vermicomposting is emerged as an effective methodology for producing quality crop nutrients from organic matters/residues. In the present analysis, cattle manure along with the sugarcane press mud and dairy sludge have been considered, and the various mixture combinations were formed and used as feed during the vermicomposting process. The best combination for the dairy sludge was M2 and for the SPM was M4. The waste mixture of SPM, dairy sludge with cattle manure (M5) was the best combinations among all proportions of waste mixtures. C:N ratio and germination index were found to be 11 to 13, 105 to 129%, respectively, along with the appropriate concentration of oxygen uptake rate. The vermicompost obtained from the dairy and sugarcane press mud was rich in nutrient content and suitable for agricultural use. The determination of greenhouse gas (GHGs) generation during pre-composting and microbial activity during vermicomposting of dairy sludge and SPM is the recommendation for the further research.

Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest associated with this study.

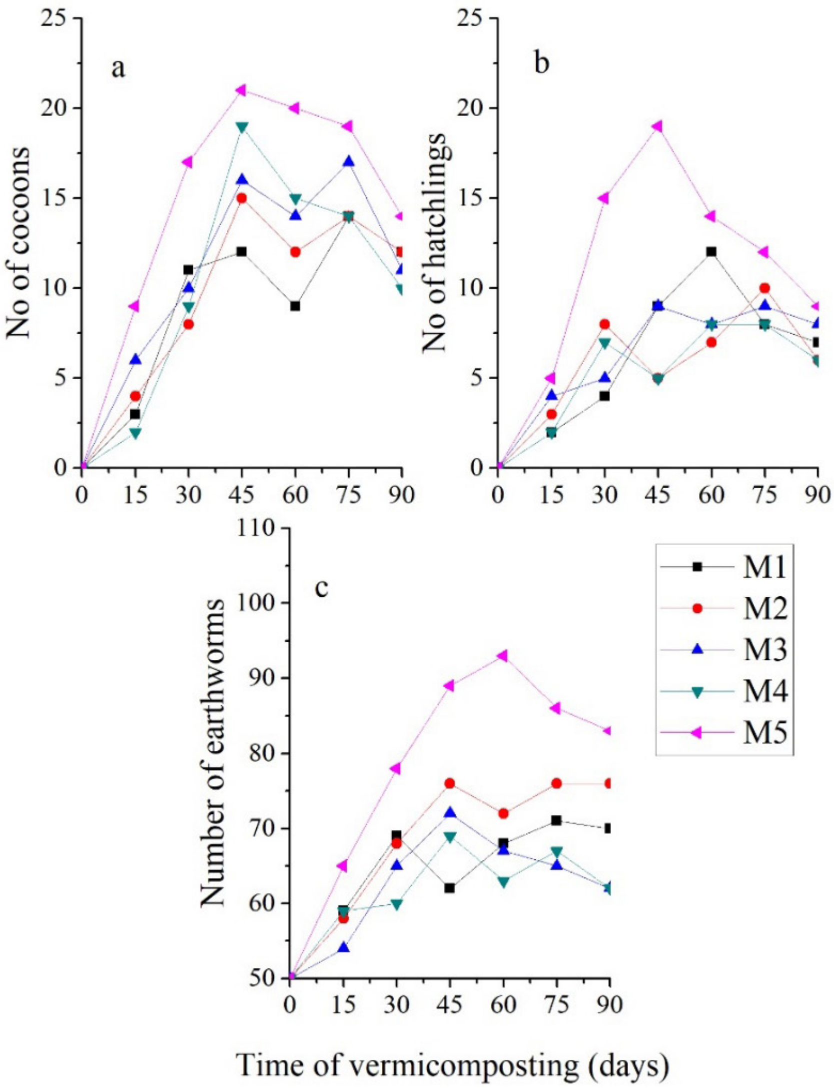

Fig. 3 Variations of number of cocoons, hatchlings, and earthworm during the vermicomposting process

References

Al-Najar H, Dohle D, Kurz H, Breuer J, Müller T, Schulz R (2016) Sequential extraction of Cu and Zn from soil amended with bio-compost for 12 years: Risk of leaching. Int J Environ Waste Manag 18:317–334. https://doi.org/10.1504/IJEWM.2016.081834

Alavi N, Daneshpajou M, Shirmardi M, Goudarzi G, Neisi A, Babaei AA (2017) Investigating the efficiency of co-composting and vermicomposting of vinasse with the mixture of cow manure wastes, bagasse, and natural zeolite. Waste Manag 69:117–126. https://doi.org/10.1016/j.wasman.2017.07.039

Ansari AA (2008) Effect of vermicompost and vermiwash on the productivity of spinach (*Spinacia oleracea*), Onion (*Allium cepa*) and Potato (*Solanum tuberosum*). World J Agric Sci 4:554–557

Ashekuzzaman SM, Forrestal P, Richards K, Fenton O (2019) Dairy industry derived wastewater treatment sludge: Generation, type and characterization of nutrients and metals for agricultural reuse. J Clean Prod 230:1266–1275. https://doi.org/10.1016/j.jclepro.2019.05.025

Atiyeh RM, Arancon NQ, Edwards CA, Metzger JD (2000) The influence of earthworm-processed pig manure on the growth and productivity of marigolds. Bioresour Technol 81:103–108. https://doi.org/10.1016/S0960-8524(01)00122-5

Chauhan HK, Singh K (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 2:1–7. https://doi.org/10.1186/2251-7715-2-11

Chauhan HK, Singh K (2015) Potancy of vermiwash with neem plant parts on the infestation of *Earias vittella* (Fabricius) and productivity of okra (*Abelmoschus esculentus*) (L.) Moench. Asian J Res Pharm Sci 5:36-40. https://doi.org/10.5958/2231-5659.2015.00006.5

Domínguez J, Edwards CA, Webster M (2000) Vermicomposting of sewage sludge: Effect of bulking materials on the growth and reproduction of the earthworm *Eisenia andrei*. Pedobiologia (Jena) 44:24–32. https://doi.org/10.1078/S0031-4056(04)70025-6

Faisal NM, Talib F, Bhutta MK (2019) Enablers of sustainable municipal solid waste management system in India. Int J Environ and Waste Manag 23(3):213–237. https://doi.org/10.1504/IJEWM.2019.10019829

Garg VK, Kaushik P (2005) Vermistabilization of textile mill sludge spiked with poultry droppings by an epigeic earthworm *Eisenia foetida*. Bioresour Technol 96:1063–1071. https://doi.org/10.1016/j.biortech.2004.09.003

Garg VK, Gupta R (2011) Optimization of cow dung spiked pre-consumer processing vegetable waste for vermicomposting using *Eisenia fetida*. Ecotoxicol Environ Saf 74:19–24. https://doi.org/10.1016/j.ecoenv.2010.09.015

Ghasemi O, Mehrdadi N, Baghdadi M, Aminzadeh B (2019) An investigation on absorption properties of exfoliated graphite for oil spill from Caspian Sea water. Iran Chem Commun 7:352–367. https://doi.org/10.30473/icc.2019.43537.1503

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

He X, Zhang Y, Shen M, Zeng G, Zhou M, Li M (2016) Effect of vermicomposting on concentration and speciation of heavy metals in sewage sludge with additive materials. Bioresour Technol 218:867–873. https://doi.org/10.1016/j.biortech.2016.07.045

Kaushik P, Garg VK (2003) Vermicomposting of mixed solid textile mill sludge and cow dung with the epigeic earthworm *Eisenia foetida*. Bioresour Technol 90:311–316. https://doi.org/10.1016/S0960-8524(03)00146-9

Kumar R, Verma D, Singh BL, Kumar U (2010) Composting of sugar-cane waste by-products through treatment with microorganisms and subsequent vermicomposting. Bioresour Technol 101:6707–6711. https://doi.org/10.1016/j.biortech.2010.03.111

Lim SL, Wu TY, Clarke C (2014) Treatment and biotransformation of highly polluted agro-industrial wastewater from a palm oil mill into vermicompost using earthworms. J Agric Food Chem 62:691–698. https://doi.org/10.1021/jf404265f

Muthukumaravel K, Amsath A, Sukumaran M (2008) Vermicomposting of vegetable wastes using cow dung. E-Journal Chem 5:810–813. https://doi.org/10.1155/2008/572431

Nayak AK, Varma VS, Kalamdadh AS (2013) Effects of various C/N ratios during vermicomposting of sewage sludge using *Eisenia fetida*. J Environ Sci Technol 6:63–78. https://doi.org/10.3923/jest.2013.63.78

Ramnarain YI, Ansari AA, Ori L (2019) Vermicomposting of different organic materials using the epigeic earthworm *Eisenia foetida*. Int J Recycl Org Waste Agric 8:23–36. https://doi.org/10.1007/s40093-018-0225-7

Reza R, Singh G (2010) Heavy metal contamination and its indexing approach for river water. Int J Environ Sci Technol 7:785–792. https://doi.org/10.1007/BF03326187

Sharma D, Yadav KD (2017) Bioconversion of flowers waste: Composing using dry leaves as bulking agent. Environ Eng Res 22:237–244. https://doi.org/10.4491/eer.2016.126

Sharma D, Yadav KD (2018) Application of rotary in-vessel composting and analytical hierarchy process for the selection of a suitable combination of flower waste. Geol Ecol Landscapes 2:137–147. https://doi.org/10.1080/24749508.2018.1456851

Sharma D, Yadav KD, Kumar S (2018) Biotransformation of flower waste composting: Optimization of waste combinations using response surface methodology. Bioresour Technol 270:198–207. https://doi.org/10.1016/j.biortech.2018.09.036

Sharma D, Pandey AK, Yadav KD, Kumar S (2021) Response surface methodology and artificial neural network modelling for enhancing maturity parameters during vermicomposting of floral waste. Bioresour Technol 324:124672. https://doi.org/10.1016/j.biortech.2021.124672

Singh J, Kaur A, Vig AP, Rup PJ (2010) Role of *Eisenia fetida* in rapid recycling of nutrients from bio sludge of beverage industry. Ecotoxicol Environ Saf 73:430–435. https://doi.org/10.1016/j.ecoenv.2009.08.019

Singh J, Kaur A, Vig AP (2014) Bioremediation of distillery sludge into soil-enriching material through vermicomposting with the help of *Eisenia fetida*. Appl Biochem Biotechnol 174:1403–1419. https://doi.org/10.1007/s12010-014-1116-7

Singh M, Brueckner M, Padhy PK (2015) Environmental management system ISO 14001: Effective waste minimisation in small and medium enterprises in India. J Clean Prod 102:285–301

Suthar S, Singh S (2008) Feasibility of vermicomposting in biostabilization of sludge from a distillery industry. Sci Total Environ 394:237–243. https://doi.org/10.1016/j.scitotenv.2008.02.005

Suthar S, Mutiyar PK, Singh S (2012) Vermicomposting of milk processing industry sludge spiked with plant wastes. Bioresour Technol 116:214–219. https://doi.org/10.1016/j.biortech.2012.03.101

Thi NBD, Tuan NT, Thi NHH (2018) Assessment of food waste management in Ho Chi Minh City, Vietnam: Current status and perspective. Int J Environ Waste Manag 22:111–123. https://doi.org/10.1504/IJEWM.2018.094100

Yadav A, Garg VK (2011) Industrial wastes and sludges management by vermicomposting. Reviews in Environmental Science and Biotechnology 10:243–276. https://doi.org/10.1007/s11157-011-9242-y