Journal of Cleaner Production 241 (2019) 118413

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Review

Insight into the recovery of nutrients from organic solid waste through biochemical conversion processes for fertilizer production: A review

Nuhaa Soobhany

Department of Chemical & Environmental Engineering, Faculty of Engineering, University of Mauritius, Reduit 80837, Mauritius

ARTICLE INFO

Article history:
Received 25 May 2019
Received in revised form
25 August 2019
Accepted 12 September 2019
Available online 13 September 2019

Handling Editor: Prof. Jiri Jaromir Klemeš

Keywords:
Nutrient recovery
Organic solid waste
Composting
Micro-nutrient
Vermitechnology
Earthworm mechanism

ABSTRACT

The safe disposal of organic solid waste (OSW) has been regarded as utmost concern in this period of green economy and the concept of producing high quality fertilizers with an enriched nutrient content is at present identified prospectively in many countries. When OSW are improperly disposed, considerable amounts of nutrients which are locked in the OSW are reduced or lost. These valuable nutrients which are lost might be recuperated through suitable biochemical technologies and employed as nutrient-rich fertilizers in agricultural fields for maintaining soil fertility. This work aimed to review macro-nutrients (N, P, K) and micro-nutrients (Ca, Mg, Na, Fe, Cu, Mn, Zn, B, Mo, S) recycling during biochemical conversion technologies e.g. composting and vermicomposting of OSW for the production of fertilizer. This work also elucidates the possible ways of enriching the nutrient content in vermicompost, the effects of possible mechanisms on earthworms linking to nutrients enrichment and the quality assessment of composts and vermicomposts in terms of nutrient content. Generally, it would appear that vermicomposts can have "added-value" characteristics since vermicomposting of OSW could efficiently amplify the nutrients content and vermicomposts could be inferred as a superior organic fertilizer with high nutritional content of agronomic importance in contrast to composts. The high nutrient content in vermicompost could be explicated by earthworm gut-borne microorganisms which mixed with organic matter (OM) during their passage in the intestine and those microorganisms consecutively have a vital role in the biochemical alterations of nutritive elements. This review recommends the importance of obtaining a comprehensive insight on the earthworm activity entailed in vermitechnology, especially the mechanisms they accomplish for the nutrients enrichment. Conclusively, the need for further scientific research aimed at outlining Mg and Na metabolisms by earthworm mechanism and also other trace elements (Fe, Cu, Mn, Zn, B, Mo, S) in vermicomposting processes is greatly recommended which will thus provide a meaningful direction for future study.

© 2019 Elsevier Ltd. All rights reserved.

Contents

1. Introduction 2
2. Biochemical conversion processes 3
   2.1. Composting process 3
   2.2. Vermicomposting/vermiremediation process 3
   2.3. Integrated composting-vermicomposting process 4
3. Nutrients concentration and availability during composting 4
   3.1. Macro-nutrients (TN or TKN, TP or available P, TK) 4
   3.2. Micro-nutrients (Ca, Mg, Na, Fe, Cu, Mn, Zn, B, Mo) 5
   3.3. Nutrient loss during composting 5
      3.3.1. Nutrient conservation approaches during composting 5
      3.3.2. Control and reduction of N-losses during composting 6

E-mail addresses: soobhanynuhaa@gmail.com, nuhaasoobhany1@umail.uom.ac.mu.

https://doi.org/10.1016/j.jclepro.2019.118413
0959-6526/© 2019 Elsevier Ltd. All rights reserved.

4. Relative efficiency of nutrient recovery 6
5. Nutrients concentration and availability during vermicomposting 6
5.1. Macro-nutrients 7
5.1.1. TN or TKN 7
5.1.2. TP 9
5.1.3. TK 9
5.2. Micro-nutrients or trace elements (Ca, Mg, Na, Fe, Cu, Mn, Zn, B, Mo, S) 9
5.3. Possible ways of enriching the nutrient content in vermicompost 10
6. Possible earthworm's mechanism in response to nutrients enrichment 10
6.1. Earthworm's mechanism on TKN 10
6.2. Earthworm's mechanism on TP 11
6.3. Earthworm's mechanism on TK 11
6.4. Earthworm's mechanism on micro-nutrients (Ca, Mg and Na) 11
7. Beneficial effect of nutrient-enriched vermicompost 11
8. Quality assessment of composts/vermicomposts linking to nutrient content 11
9. Conclusions 12
Acknowledgements 12
Supplementary data 12
References 12

1. Introduction

In present time, the enhancement of living standards as a consequence of its rapid economic development, world population growth, large scale urbanization and changing lifestyle of communities implied that the generation of solid waste has escalated tremendously. In 2016, The World Bank (2019) stated that the world's cities generated 2.01 billion tonnes of solid waste via domestic, industrial and agricultural undertakings, which consequently cause pollution, global climate change through methane generation and eventually disturb the environmental system. Disposal or environmental friendly management of growing quantities of solid waste is becoming a serious problem worldwide and is of prime concern with utmost priority. Usually, majority of solid waste consists of organic solid waste (OSW) e.g. biodegradable Municipal Solid Waste (MSW), animal dung, and crop residues are disposed in ecologically unsustainable and conventional ways for example open dumping, open burning, aerobic and anaerobic digestion, incineration and sanitary landfilling techniques. These disposal methods are not just costly but impractical due to unlimited open space (Slater and Frederickson, 2001; Soobhany, 2018a), more stringent waste disposal regulations (Ndegwa and Thompson, 2001), leaching and production of particulate matter and release of toxic substances/gases from the wastes. The production of certain toxic substances thereby cause public health and environmental hazards by contamination of surface and ground waters, soil and air pollution (Ilgen et al., 2008; Suthar and Singh, 2008a; Lou and Nair, 2009). Moreover, direct application of fresh organic solid materials to soil is not recommendable since addition of immature OSW to soil might influence plant development owing to nitrogen deprivation, generation of toxic metabolites, too much input of heavy metals, pathogenic bacteria and inorganic salts (Wang et al., 2016a; Malinska et al., 2017). As a result of these improper environmentally unhealthy waste disposal methods, considerable amounts of organic and inorganic nutrients which are locked in the OSW are reduced or lost (Ghosh et al., 2004; Zhang and Sun, 2016; Meng et al., 2017). These valuable nutrients present in OSW which are systematically lost, might be recuperated through proper biochemical technologies and employed as nutrient-rich fertilizers in agricultural fields for maintaining soil fertility (Garg et al., 2006a) and land restoration practices at low-input basis. Thus, considerable emplasis is being focussed on adopting ecologically sound on top of economically sustainable and socially acceptable tools which strenghthen potential recovery of nutrients, with minimum pollution load. Notwithstanding, composting is regarded as one of the prime techniques for the recovery of valuable nutrient resources from OSW. Composting is a controlled biological disintegration process wherein microbes change the organic matter (OM) into a stabilized and sanitized product and through which nutrients are biologically stabilized. Very valuable and interesting reviews were done with regards to composting topic (Füleky and Benedek, 2010), compost natural science (Insam and de Bertoldi, 2007) or composting technologies (Shammas and Wang, 2009; Li et al., 2013) or encompassing several basic associated problems e.g. the type of feed materials employed (Shilev et al., 2007). Nonetheless, experimental analysis of nutrients concentration and availability during composting or the relative efficiency of nutrient recovery was not the focal goal of those previous literature evaluations. Also, the microorganisms which are involved for nutrient's assemblage during the period of composting are insufficiently emphasized, including the influence of the addition of nutritive materials and nutrients conservation for the generation of compost biofertilizers with higher quality. Scientific use of compost generated from OSW can supply beneficial nutrients for plant growth and improve soil fertility (Soobhany and Mohee, 2014; Soobhany et al., 2015a). However, the presence of insufficient or unbalanced nutrients can trim down the utility and consequently, the quality of compost since the value of compost generally relies on the content of nutrients. Besides, scientific and technological questions arise which eventually necessitate an enhancement in the composting practice and quality of the finish material.

In recent years, the use of earthworms in OSW stabilization is extensively urged as a better option than composting practices in recycling the nutrients. Vermicomposting is a biological waste management technology involving the combined action of earthworms and associated microflora (Dominguez, 2004; Suthar, 2010a) which proficiently transform different type of OSW and complex organic substances into stabilized nutrient rich manure (Benitez et al., 2000; Sinha et al., 2010; Pigatin et al., 2016) in controlled environmental conditions (Aira et al., 2002). Even if the biochemical process of degrading OM are mostly achieved by microbes, earthworms are the vital “eco-system engineers” of the process as they hasten the transformation of OSW by maintaining

aeration, ingesting solids, and expelling partially stabilized matter as discrete particles/excreta. But still, it has earlier reported that earthworms cannot survive in certain type of OSW, mostly industrial wastes only (Garg et al., 2005) and thus require the addition of organic wastes which are rich in nutrients for example cow dung and biogas slurry (Suthar, 2006). It is noteworthy that the nutritional value of vermicomposts is determined by some features such as encompassing the earthworm species employed and the characteristics of the OSW initially i.e., pH, moisture content (MC) and C:N ratio. In comparison with thermophilic composting systems, vermicomposting is increasingly seen as a better viable eco-friendly technique with regards to process time, nutrients recovery (Soobhany et al., 2015a) and phytotoxicity (Dominguez and Edwards, 2011; Lim et al., 2012). A few attempts have been made on nutrient recovery during vermicomposting of OSW such as distillery industry sludge (Suthar and Singh, 2008a), agricultural wastes (Suthar, 2009a, b), bagasse (Pramanik, 2010a) and water hyacinth (Varma et al., 2016). Soobhany et al. (2015a) studied the recuperation of nutrients from organic MSW through both composting and vermicomposting technologies on a lab-scale basis. Interestingly, Ansari and Rajpersaud (2012) accounted that the nutrient content fluctuated throughout the vermicomposting of water hyacinth till end of process. As at present day, to the best of available information gathered, no attempt has been embarked for an intensive review on nutrient recycling during vermicomposting of diverse OSW.

There is also dearth of review investigation to examine the content of beneficial plant macro-nutrients and micro-nutrients throughout vermicomposting as compared to composting process. Owing to the inherent limitations of the individual processes, the simultaneous application of both technologies is increasingly getting attention in favor of the stabilization of various types of OSW for reduced time of treatment process, minimized pathogenic compounds (Ndegwa and Thompson, 2001; Nair et al., 2006; Lazcano et al., 2008; Hait and Tare, 2011a, b; Soobhany, 2018b), diminished level of heavy metals and better product quality (Soobhany et al., 2015b). In addition, it is usually hypothesized that the combined process has the potential of augmenting the level of nutrients in the final product. Albeit some research works have appraised the efficacy of the integrated method for biosolids stabilization (Hait and Tare, 2011a, b; Ndegwa and Thompson, 2001), no review article is available to scrutinize the nutrients content via integrated composting-vermicomposting of various OSW in order to have a comprehensive picture of the combined processes. Under these contexts and to fill the gaps or critical issues, the present review study is set to give a comprehensive account on the recovery of a series of important macro and micro nutrients from various OSW through composting and vermicomposting processes. A flow diagram explanation of this work that has been reviewed is as shown in Figure A.1 (Supplementary material). The present review also sought to elucidate on the effects of possible mechanisms on earthworms linking to nutrients enrichment and beneficial effect of nutrient-enriched vermicompost. It is expected that this review will be helpful in understanding the insight into the recovery of essential nutrients in composting, vermicomposting and integrated composting-vermicomposting technologies as well as providing a solution for enhancing further the presence of certain nutrients in the end products.

2. Biochemical conversion processes

2.1. Composting process

Composting of organic materials is an aerobic, microorganism-mediated, spontaneous biological decomposition route comprising the mineralization and fractional humification of OM, resulting in a product which is stable and contamination-free for crop cultivation (Bernal et al., 2009; Sánchez et al., 2017). Nowadays, composting cannot be regarded as a novel technique, but among the waste management strategies, it is getting attention as a proper choice for OSW treatment method with ecological and economic profits as it destroys or lessens possibility of pathogen propagation (Larney and Hao, 2007). Composting is generally deemed efficient for decreasing the mass of OSW and transforming it into a nutritious soil amendment which is the compost, valuable for plants and soil fertility (Awasthi et al., 2016a). Nonetheless, compost of excellent quality must be generated to surmount the expenditure of composting. The accomplishment of the composting practice, on the other hand, is dependent on the achievement of the operating factors for product value and environmental safety (Soobhany et al., 2014; Zhang and Sun, 2018; Akdeniz, 2019; Shan et al., 2019). During the progression of composting, N compounds which are stable are produced that are less vulnerable to volatilization, leaching and denitrification. Thus, from an agricultural viewpoint, composts being a stabilized material appear to represent a good supply of OM and elemental N for soil. Composting of OSW rich in N content (e.g. kitchen waste, animal manure) concurrently with OSW low in N content (e.g. sawdust, dry leaves, straw, rice husk, newsprint) generates high-quality fertilizer by regulating its MC and C:N ratio. Researchers inferred that a mix of animal droppings and straw, relatively than any of these constituents only, is hence suitable for composting (Zhu, 2007; Das et al., 2011). To operate successfully, composting necessitates balanced conditions of C/N ratio, MC and exposure to air. For ensuring the applicable conditions for the microbes to decay and convert the OM (Gil et al., 2008; Shilev et al., 2007; Shammas and Wang, 2009), the C/N ratio of the initial mix of feed materials should be between 25 and 30. Similarly, for sufficient development of microbes, moisture level of the input materials must vary between 55 and 65% as well as presence of oxygen should be guaranteed in the compost piles to avoid anoxic areas all through the progression (Shammas and Wang, 2009; Shilev et al., 2007). Niwagaba et al. (2009) found that pathogenic bacteria are also eliminated in composting owing to the high temperatures of the matrix and antagonism by the thermophilic microorganisms. The main disadvantages associated with conventional thermophilic composting are the extensive time of the method, turning frequency necessity of the composting matrix, and heterogeneous nature of the product and loss of nutrients throughout the process which restricted its use in agriculture (Ndegwa and Thompson, 2001). Thus, supplementaion with other nutrient additives and addition of microorganisms have been suggested for increasing nutrients content in the compost.

2.2. Vermicomposting/vermiremediation process

Vermicomposting of OSW does not consist of a thermophilic phase, but is mostly linked to the joint earthworm's metabolic activity and mesophiles (Suthar, 2008a–c; Pramanik and Chung, 2011). In the recent years, vermitechnology is becoming prominently as a most suitable substitute to traditional composting, as a quick technique, easily controllable, energy saving, cost-effective, zero waste process, and ecologically-green technique of generating natural fertilizer from OSW (Eastman et al., 2001; Lazcano et al., 2008; Mupambwa and Mnkeni, 2018). Among various biochemical conversion treatments, vermitechnology is established as one of the greatest efficient way for the stabilization of complex OSW (Ravindran et al., 2008; Goswami et al., 2014; Sahariah et al., 2014; Bhattacharya and Kim, 2016). It is an acceptable method for ingestion and digestion of OSW by earthworms, subsequently the excretion of casts which involved the biological systems of earthworms for augmenting the intensity of nutrients in vermicompost

(Venkatesh and Eevera, 2008), which is a nutrient-enriched soil amendment (Pramanik, 2012; Soobhany et al., 2015a; Ghosh et al., 2018; Bhat et al., 2018). Vermicompost is regarded as a good quality fertilizer because of its homogeinity, low amount of contaminants (Ndegwa and Thompson, 2001), more soluble state of minerals like N, P, K and Ca by the worm's gut (Ali et al., 2012; Soobhany et al., 2015c) which is more accessible to crops compared to those in raw materials (Ndegwa and Thompson, 2000, 2001; Atiyeh et al., 2002; Hait and Tare, 2012). In addition to having plant growth hormones as well as soil enzymes, vermicompost holds nutrients for an extensive period without poorly affecting the atmosphere in contrast to ordinary compost (Soobhany et al., 2015a). Many researches have demonstrated the capability of epigeic (surface dwelling) species of earthworm such as *Eisenia fetida* (Savigny), *Perionyx excavatus* (Perrier), and *Eudrilus eugeniae* (Kinberg) to process an extensive variety of OSW. Previous works have confirmed that these earthworm species may well mix substrates, hasten mineralization and stabilization of OSW all through the bio-oxidation phase (Ndegwa and Thompson, 2001; Khwairakpam and Bhargava, 2009), concentrate nutrients in their casts and speedily break down OSW into humic biofertilizers (Bhattacharya and Chattopadhyay, 2002; Suthar, 2006; Gupta and Garg, 2008; Soobhany et al., 2015b; Sharma and Garg, 2018). Earthworms are also found to maintain aerobic conditions, fragment the substrate therefore augmenting the surface area for microbial organisms (Lavelle et al., 2006; Suthar, 2008a), release coelomic fluids for eliminating bacteria existent in the waste, resulting in a pathogen and odor free vermicompost (Soobhany et al., 2017a; Soobhany, 2018b). Thus, the biological, chemical and physical characteristics of OSW are altered via the joint accomplishment of earthworms and microorganisms during vermiremediation process. Recent research demonstrate that earthworms has the ability in enhancing mineralization of non-organic substances like fly ash and rock phosphate in composts resulting in higher nutrient availability (Bhattacharya and Chattopadhyay, 2002; Unuofin and Mnkeni, 2014).

In contrast to conventional composting, vermicomposting often results in a better quality homogenous product with reduced mass, shorter processing time, high humus content, reduced phytotoxicity and greater fertilizer value in the microbiologically active manure, i.e., vermicompost (Soobhany et al., 2015b). Biochemical conversion of the waste materials through vermitechnology produces two beneficial outcomes: the earthworm biomass and the vermicompost as compared to traditional waste processing. Generally, it would appear that vermicomposts can have "added-value" characteristics, mostly related to its high nutritional content of agronomic importance as compared to composts (Gomez-Brandon et al., 2011). However, it has been examined that the biochemical processes are affected by microbial decomposition of substrate in the intestines of the earthworms (Ndegwa and Thompson, 2000). The main disadvantages associated with vermicomposting are temperature limits due to earthworm low heat tolerance, care/high maintenance, pathogen problems and cost. Vermicomposting is more expensive to set up than regular compost piles or batch composters as vermicompostig needs special materials to start, such as plastic or metal containers and earthworms.

2.3. Integrated composting-vermicomposting process

Owing to intrinsic drawbacks of the sole system, the integration of both composting and vermitechnology is gradually getting importance in achieving stabilized final outcome (Tognetti et al., 2007) as well as a proficient means in generating a sanitized product (Soobhany, 2018). Some research workers have studied stabilization of some OSW by integrated composting-vermicompostimg process (Hait and Tare, 2011a,b; Lazcano et al., 2008; Soobhany et al., 2015a–c). Decontamination of some OSW (Ndegwa and Thompson, 2001) as well as a decrease in heavy metals are allowed by a combined composting-vermicomposting process (Fornes et al., 2012; Wang et al., 2013; Song et al., 2014; Soobhany et al., 2015b,c; Bakar et al., 2015; He et al., 2016). The chronological arrangement of composting followed by vermi-technology moreover produces a much finer final outcome (vermicompost) with a homogeneous distribution in materials size (Ndegwa and Thompson, 2001) in addition to an increment in nutrients concentrations (Soobhany et al., 2015a; Swarnam et al., 2016). Furthermore, addition of earthworms to the composting matrix subsequent to the thermophilic stage makes the waste management strategy more cost-efficient. Vermicompost market managed to increase sales by 24.89%–38.09 M USD worldwide in 2015 (Vermicompost Market, 2019) in contrast to composts (Edwards et al., 2011).

3. Nutrients concentration and availability during composting

The crucial nutritive elements are classified into two groups: macro-nutrients (nitrogen (N), phosphorus (P), potassium (K)) (De Bertoldi et al., 2007; Sindhu et al., 2017), and micro-nutrients (calcium (Ca), magnesium (Mg), sodium (Na), iron (Fe), copper (Cu), manganese (Mn), zinc (Zn), boron (B), and molybdenum (Mo)). According to De Bertoldi et al. (2007), Ca falls somewhere between macro and the micro-nutrients. The presence of Ca is essential to counteract the effects of alkali salts and organic acids (Montejo et al., 2015). Some authors reported N as Total Nitrogen (TN) while others reported N as Total Kjeldahl Nitrogen (TKN). It is notable to illuminate that TN is the sum of nitrate-nitrogen (NO_3–N), nitrite-nitrogen (NO_2–N), ammonia-nitrogen (NH_3–N) and organically bonded nitrogen whereas TKN is the sum of ammonia-nitrogen plus organically bound nitrogen but does not include nitrate-nitrogen or nitrite-nitrogen (Hill Laboratories, 2018). At the present time, supplementation of these vital plant nutritive elements is mostly achieved by the use of chemically synthetic fertilizers. However, these inorganic chemicals simply supplement minerals to plants but do not offer stabilized OM in enhancing equilibrity of soil. Besides, unselective use of agro-chemicals has incited detriments in soil fertility and loss in its OM content. The concentration of nutrients in composts is most of the time adequate but varies among sources attributable to diversity in OSW and progressing technologies. Table 1 summarized published works which revealed how the nutrients content of feedstocks is altered by composting technology.

3.1. Macro-nutrients (TN or TKN, TP or available P, TK)

In general, the TN concentration rises during composting which is caused by the concentration effect, the total reduction in dry mass with regard to CO_2, and water lost by evaporation owing to high temperature liberation throughout oxidation of macrobiotic materials. The typical range of TN in compost is 1.0–3.0% dry weight (DW) (Lakhdar et al., 2009). Reporting compost with effective fertilizing capabilities and for proficient use in cultivation of the soil for the growing of crops, the TN content should be above 1% DW (Barker, 1997). However, if compost holds less than 1% TKN, extra N fertilizer or addition of bentonite (Li et al., 2012) will be needed if the compost is to be used as a soil conditioner. Compost containing TN content above 3% is typically designated as immature and ammoniacal such as ammonical nitrogen (NH_4^+-N) (Varma et al., 2016). According to Costa et al. (2015), a decrease in TKN content in composting is related to the characteristics of the

Table 1
Research indicating how the concentration of nutrients is affected by composting.

Source Materials (C)	Parameter	Change in nutrient conc.	Authors
Cattle deep litter	TKN,TP,TK	**R**	Sommer (2001)
Pig manure + cornstalks	TN,TP, TK, Na	**R**	Tiquia et al. (2002)
Pig manure + bentonite	TKN,TP, Av. P, TK	**A**	Li et al. (2012)
Organic wastes from different sources	Av. P	**A**	Wei et al. (2015)
Sheepbedding + cattle manure	TKN, P, K	**R**	Costa et al. (2015)
Broiler litter	TN,TP, TK, Ca, Mg, Na, Cu, Fe, Mn, Zn	**A**	McLaughlin et al. (2015)
Pig manure + medical stone	TKN	**A**	Wang et al. (2016a)
Green waste with addition of seaweed + bentonite	TKN,TP, TK, Ca, Mg, S, Fe, Cu, Mn, B, Mo	**A**	Zhang and Sun (2017)
Sewage sludge + wheat straw biochar	TKN, TP, Av. P, TK, TNa	**A**	Awasthi et al. (2017)
Household organic waste	N, Av. P, K, Ca, Mg	**A**	Vazquez and Soto (2017)
Weed + cow dung + saw dust + biochar	TN, TP, TK, Na, Ca	**A**	Jain et al. (2018)
Sewage sludge + *Arundo donax* biomass	TN, P, K	**A**	Pelegrin et al. (2018)

TN = total nitrogen; TKN: total kjeldahl nitrogen; TP = total phosphorus; TK = total potassium; Av. = Available.
Note: C = Composting; A = signifies an augmentation in nutrients content; R = signifies a reduction in nutrients content.

residues used (Chen et al., 2010), frequency of turning, and environmental conditions. Storino et al. (2016) found that the presence of meat waste as raw feedstock for composting can improve the activity of the process and maturity of the compost obtained, increasing N, K and Mg content. Total P (TP) and available P content demonstrated a growing trend with composting time which could be attributable toward the enrichment effect of the OM decomposition (Li et al., 2012; Vazquez and Soto, 2017; Jain et al., 2018). Mature composts contained different concentrations of available P (Wei et al., 2015) which is attributed to the characteristics of the P fractions from assorted OSW. As earlier reported by Hargreaves et al. (2008), TP in MSW was found to be between 5 and 35 g kg^{-1} DW and in theory, TP content in soil shall be over 0.2 mg/L for crop requirement. Vazquez and Soto (2017) reported high increase of available P (1.4%) and higher in K (3.0%) when compared to the recommended values in the Spanish rule RD 506/2013 (BOE, 2013). This rule recommends >1% content for each nutrient, expressed as N, P_2O_5 and K_2O, and that the sum for the set of three nutrients exceeds 4%. Regarding total K (TK), typical array of this element in compost is from 0.6 to 1.7% DW (Paul et al., 2018). Bioavailability of K was examined to diminish in composting feedstocks over time (2.38–7.21 folds) which might be owing to the readily leached solubilized K fractions (Paul et al., 2018).

3.2. Micro-nutrients (Ca, Mg, Na, Fe, Cu, Mn, Zn, B, Mo)

Composts contain Ca and Mg which usually react as bases when they are found as carbonates, hydroxides and oxides. Once these oxides of Ca and Mg are added to soil, they hamper soil acidification thereby causing soil nutrients further accessible to crops (Qadir and Oster, 2004). The Ca content in various OSW compost was found to be in the range of 1.0–4.0% DW and the distinctive range of Mg content is 0.2–0.4% DW (Lakhdar et al., 2009). A decrease in Na content during composting of pig manure and cornstalks was noted by Tiquia et al. (2002). From this review study, it is shown that there has been little information available on Na content in the past few years. Seaweed (*Ulva ohnoi*) and bentonite have been analysed to contain ample amounts of micro-nutrients, which has the potential to boost up the nutrient concentration in compost (Li et al., 2012; Kuwada et al., 2006). Recent study by Zhang and Sun (2017) confirmed that micro-nutrients (Fe, Zn, Mo, Cu, B, Mn) in the composting product were augmented through the addition of 35% seaweed and 4.5% bentonite to green waste. The increase in cation exchange capacity values with the supplementation of seaweed and bentonite could also enlighten the high content in micro-nutrients content (Zhang and Sun, 2014, 2016). However, in the past few years, there has been very little scientific research which has been carried out with regard to the presence of micro-nutrients (Fe, Cu, Mn, Zn, B, Mo) during composting of various OSW. Thus, in this line, there is a prospective demand in research in terms of availability of these micro-nutrients during composting.

3.3. Nutrient loss during composting

Quantification of the amount of nutrient loss is imperative in comprehending the composting route, and in support of developing lucrative methods for nutrients conservation so as to minimize probable adverse environmental impacts. When the temperature rises throughout the thermophilic stage of the composting route, NH_3 loss rises too and while the C/N ratio decreases below 18, the microbes convert the N into a higher level, supporting its volatization (Sánchez et al., 2017). The variation of N loss volatilization depends on the balance of existing carbon and oxygenation level. Several factors (C/N ratio, exposure to air, pH, temperature, and mixing) contribute to N loss through NH_3-volatilization (Parkinson et al., 2004; Shilev et al., 2007; Li et al., 2012; Jeong and Kim, 2001; Jiang et al., 2014; Yang et al., 2015; Awasthi et al., 2016a). Consequently, insufficient decomposition of OM produces low compost quality with low nutrient concentration (Chen et al., 2010; Chan et al., 2016), generates health and environmental problems. N loss was found to be 20–77% (Tiquia and Tam, 2000), and 37–60% with no significant effect from turning (Tiquia et al., 2002). Leaching is also a principal factor in N loss from compost and reported to be around one fifth of the total N losses relying on rainy circumstances (Sommer, 2001; Sun et al., 2018). N losses through composting can also happen by denitrification which results from the development of anaerobic microsites in the composting matrix. Sommer (2001) reported that less than 0.3% of the total-N was released as N_2O. Besides N, other nutrients like P, K, and Na were found to be lost all through composting, which might be owing to leaching and runoff. P and K losses were 23–39% and 20–52% of its respective initial value, whilst Na loss was in the range of 32–53% of the initial Na (Tiquia et al., 2002). K loss was 11–16%, and P loss was about 2% from composting (Sommer, 2001). These factors would lessen the efficacy of compost as a highly nutritive source for plants and could cause environmental threats. Still, an eventual demand in research is needed to confirm P, K, and Na losses during composting processes.

3.3.1. Nutrient conservation approaches during composting

Quite a few approaches are being researched for conserving the amount of nutrients during the composting process, consequently promoting to augment the end level of this nutrient in the compost before its application to plants. These approaches consisted; (1)

addition with nutrients-rich substances, (2) bioaugmentation with nutrients converting bacteria, (3) addition of bacteria in the composting matrix (Sánchez et al., 2017), (4) reducing excessive feeding levels of the nutrients, (5) using feed materials which are more palatable and accessible, preparing methodically toward the ultimate protein amount for the mixing, (6) utilizing crystalline amino acid addition to decrease largely nutritional protein amount, (7) supplementing phytase to the composting matrix for enhancing the accessibility of the nutrients e.g. P, (8) adding bulking agents for example rice hull, peat moss, or sawdust to composting substrates conserved nutrients (particularly N) in the compost (Bernal et al., 2009) since bulking agents regularly hold high water and cation absorption abilities, and (9) adding biochar as a supplementary waste material or bulking agent to compost piles reduces NH_3 and N_2O emissions (Knowles et al., 2011; Wang et al., 2013) and enhanced nutrient use efficiency (Dias et al., 2010; Awasthi et al., 2016b). When compost is complemented by nutrients or by means of nutrient-converting microbes, the improved bio-input achieved provides extra lasting advantages at the moment of its addition to soil. However, addition of wood N biochar during the composting of OM did not provide sufficient quantities of macro-nutrients and micro-nutrients in the final product (Glaser and Birk, 2012; Sánchez-García et al., 2015). In this sequence, it is required to add mineral and organic compost to smooth the progress of plant development (Schulz and Glaser, 2012; Soobhany et al., 2017c). Inoculating straw biochar to pig dung considerably raised the content of P, K, Ca, and Mg (Zhang et al., 2016a). Limited data are available to support compost enrichment by the inoculation of biochar not exclusively with P, K, Ca, and Mg but also with other trace elements such as Na, Fe, Cu, Mn, Zn, B, Mo, S (Sánchez et al., 2017). Thus, studies on compost with regard to nutrient conservation, supplementation, and addition with nutrient converting microbes could be carried out as a future challenge to make the final product of the composting system valuable in nutritional properties.

3.3.2. Control and reduction of N-losses during composting

The generation of compost having an elevated level of nutrient demands the direction and diminution of nutrient losses throughout the composting process. Rutgers static pile composting system has proved to be an excellent technique designed for lessening N-losses all the way during NH_3-volatilization as well as generating an N-enriched organic fertilizer with an elevated content in TN and NO_3—N (Bernal et al., 2009). Losses via leaching could be receded effortlessly by managing the MC of the composting matrix and by a satisfactory composting technique with a designed wrap for restraining rain penetration and an arrangement for leachate recuperation and recirculation inside the composting substrates (Bernal et al., 2009). Special consideration was drawn to the importance of employing an ample bulky material with decomposable organic-C to augment original N concentration thereby reducing N-losses (Liang et al., 2006; Bernal et al., 2009). pH is pertinent for regulating N-losses through NH_3 volatilization, which might be predominantly elevated at $pH > 7.5$. In this case, elemental sulphur (S^o) was requested like an effective alteration for preventing extremely greater pH values in the composting system (Mari et al., 2005). Sommer (2001) reported that wrapping the compost heap by means of a permeable tarpaulin diminished emanation losses near 12–18% of TN throughout composting of deep debris. The formation of struvite crystals through the adding up of Mg and P salts is a practical strategy that has been developed to reduce N-losses in the final compost (Jeong and Hwang, 2005; Jeong and Kim, 2001; Lee et al., 2009; Wang et al., 2016b) or relatively recent strategy like the addition of ammonia bacteria for reducing N volatilization during composting (Xie et al., 2012; Zhang et al., 2016b) as presented in Table 2. However, the optimal salt contents to circumvent the N volatilization exclusive of influencing the composting process itself has not yet been determined till date. Thus, research targeted on discovering the most suitable method for N preservation is entailed so that compost with utmost N content at the final stage of the process could be attained. The inoculation of adsorbing substances to the compost is a new approach for dropping N volatilization such as dipotassium phosphate (Hu et al., 2007), biochar (Hua et al., 2009) and medical stone (Wang et al., 2016a). Special attention has also been drawn to the inoculation of manure from animals (Gil et al., 2008; Soobhany et al., 2015a) and other nitrogenous materials i.e. cereals husks, vegetable scraps, coffee grounds and oilseed cakes to raise N content in the compost. Still, questions on the appropriate strategy to attain high N levels at the final stage of the composting practice are still being raised. Particularly, it is difficult in ascertaining the correct content of N in the final compost since it relies on its application as a plant growth media which mostly depends on the crop nutritional needs and characteristics of soil.

4. Relative efficiency of nutrient recovery

The relative efficiency of nutrient recovery ***(CE_{NR})*** in compost and vermicompost generated by various OSW methods is a fundamental guideline of nutrient recuperation in unit time of the biochemical conversion processes in respect of P, K and N in contrast to the control. The relative efficiency of nutrient recovery is as stated by Swarnam et al. (2016):

Relative efficiency of nutrient recovery (CE_{NR}) = RRt/RRc

Where, RRt: recovery rate of 'ith' nutrient (i = P, K and N) in't' treatment.

RRc: recovery rate of nutrient in control.

The recovery rate (RRt) is computed by

$$\textit{Recovery rate (RRt)} = [(N_{ei}/N_{fi})/D] \times 100$$

Where, N_{ei}: 'ith' nutrient content of end product from composting, N_{fi}: 'ith' nutrient content in the initial feedstock materials, D: duration of composting.

Utilization of this guideline is reasonable since nutrient recuperation from certain OSW e.g. coconut husk is too little owing to large level of lignin, broad-ranging C/N ratio and slow speed of degradadtion. Hence, high correlative nutrient level will designate the effectiveness of biochemical processes in nutrient recuperation which as well reports the time demanded for composting and/or vermicomposting. The largest relative efficiency of nutrient recovery in vermicompost prepared from coconut husk mixed with animal dung by Swarnam et al. (2016) was found to be 2.03 for P, 1.39 for N and 1.20 for K. P showed the highest relative efficiency of recovery as P was dissolved via earthworms' guts and initial high P level in the animal dung.

5. Nutrients concentration and availability during vermicomposting

Generally, the overall nutrient status in vermicompost relies on the composition of the feed materials and fraction of these various feed materials are employed as food source for earthworms (Garg et al., 2006b). Swarnam et al. (2016) disclosed substantial increment in nutrients concentration of the final vermicompost than the original feedstocks which might be owing to the disintegration and mineralization of feed substrates by the joint earthworm's metabolic activity and mesophiles. Throughout the passage of materials

Table 2
N conservation strategies on composting.

Strategy	Principle	Remarks	References
Precipitation	Ammonia precipitation with struvite crystals formed by phosphorus and magnesium salts	Final concentration of N: 1.4%	Jeong and Kim (2001)
		Reduction of the loss of N from 44.3% to 27.4%; lime addition reduces salinity (<4 dS/m)	Wang et al. (2016b)
		Ammonium increases up to 1.5%	Jeong and Hwang (2005)
		Final concentration of up to 1.49% TN	Lee et al. (2009)
		Reduction of N loss from 40% to 23.3%	Wang et al. (2013)
Adsorption	Addition of sawdust mixed with KH_2PO_4 to adsorb ammonia	Reduction of the evaporation rate down to 13% compared to the control, which had a 38% rate	Hu et al. (2007)
	Adding 9% bamboo biochar (w/w) to sewage sludge	Decrease amount of N loss during the composting process by 64%	Hua et al. (2009)
	Addition of biochar to adsorb ammonia	Reduction of the loss of N from 52% to 20%	Wang et al. (2017)
	Addition of medical stone to the compost	Decrease of ammonia (from 48.8% to 27.9%) and N_2O (from 85.3% to 46.6%) emissions	Wang et al. (2016a)
Oxidation of ammonia	Addition of ammonia oxidizing enzymes from archaea to form nitrites	Decrease of the losses of N as NH_3 (from 17.95% to 3.21%) and NO_2 (from 8.73% to 4.49%)	Xie et al. (2012)
	Addition of ammonia oxidizing bacteria	Reduction of N losses from 53.83% to 47.08%	Zhang et al. (2016b)
Modification of Physicochemical variables	Control of composting conditions (temperature, particle size, pH, moisture)	Total N increased by 3.2% at the end of the process	Bueno et al. (2008)

Adapted from Sánchez et al. (2017).

in the worm gut, various nutritive elements available in the OSW are transformed by micro-organisms and enzymes into more suitable forms for plants, thus augmenting nutrient level in vermicomposts (Garg et al., 2012; Aira et al., 2007). Tables 3 and 4 showed some past and present research which indicated how the concentration of nutrients is influenced by vermicomposting and pre-composting followed by vermicomposting respectively. Most vermicomposting processes of different OSW whether past or recent research demonstrated an increase in nutrient concentrations. However, few vermicomposting treatments from past studies showed a decrease in nutrient concentrations.

5.1. Macro-nutrients

The rise of macro-nutrients during vermitechnology might be reckoned owing to a change in microbial activity and pH on the OM whilst going across the earthworm's gut (Varma et al., 2016). In an experimental research, Das et al. (2016a) observed considerable increase in macro-nutrients (exchangeable K, TN, available P) during vermicomposting of water hyacinth, wood dust and rice straw) by *Eisenia fetida* jointly with the addition of beneficial microbes. In addition, Das et al. (2016a) reported that the joint action of earthworms and microbes produce a macro nutrient-enriched product. TP and K contents were found to increase from its respective initial value and this delineated an augmention of 593% P and 38% K (Swarnam et al., 2016). The nutrient level (exclusive of N) in vermicompost was found to be 2.1–2.4 times its initial amount in the vermicomposting feedstocks (Yadav et al., 2010).

5.1.1. TN or TKN

TN or TKN concentration in vermicompost is principally reliant on the primary N content of OSW used as organic waste supply to earthworms and on the extent of waste degradation sub-system (Kaushik and Garg, 2003; Suthar, 2009a). Recent research by Sharma and Garg (2018) revealed that OSW having lower N value usually had higher N value after vermitechnology. Vermicomposting process indicates the positive role of earthworms in enhancing N mineralization of OSW whereby the ammonium N is

Table 3
Research indicating how the concentration of nutrients is affected by vermicomposting.

Source Materials (V)	Earthworm species used	Parameter	Change in nutrient conc	Authors
Distillery industry sludge + cow dung	*Perionyx excavatus*	TKN, Av. P, Exc. K, Exc. Ca, Exc. Mg	**A**	Suthar and Singh (2008a)
Industrial sludge + cow dung	*E. fetida*	TKN, TP, TK, TCa, TNa	**A**	Yadav and Garg (2009)
Agricultural wastes	*E. fetida*	TKN, Av. P, Exc. K, Exc. Ca	**A**	Suthar (2009b)
Bagasse + coir	*E. fetida*	TKN, TP, TK	**A**	Pramanik (2010a)
Bio sludge + cattle dung	*E. fetida*	TN, P, Ca	**A**	Singh et al. (2010)
		K	**R**	
Sewage sludge	*E. fetida*	TN, TP	**A**	Hait and Tare (2011a)
Different organic wastes + microbes	*E. fetida*	TN, Av. P, Exc. K	**A**	Das et al. (2016a)
Water hyacinth	*E. fetida* + *Eudrilus eugeniae* + *Perionyx excavatus*	TKN, Av. P, K, Ca, Mg, Na	**A**	Varma et al. (2016)
Pruning litters + cattle manure + leaves	*Eudrilus eugeniae*	TP, TK, TCa	**A**	Pramanik et al. (2016)
Water lettuce + cow dung	*E. fetida*	TKN, TP, TK, TCa	**A**	Suthar et al. (2017)

TN = total nitrogen; TKN: total kjeldahl nitrogen; TP = total phosphorus; TK = total potassium; TCa = total calcium; TNa = total sodium; Exc. = Exchangeable; Av. = Available.
Note: V = Vermicomposting; A = signifies an augmentation in nutrients content; R = signifies a reduction in nutrients content.

Table 4
Research indicating how the concentration of nutrients is affected by pre-composting followed by vermicomposting.

Source Materials (C + V)	Duration of pre-composting process	Earthworm species used	Parameter	Change in nutrient conc	Authors
Industrial sludge + biogas plant slurry	NA	*E. fetida*	TKN, TP TK	**A** **R**	Sangwan et al. (2008)
Paper waste + cow dung	21 days	*E. fetida*	TKN, TP, TK	**A**	Gupta and Garg (2009)
Source-separated human faeces + soil + bulking material	1 week	*E. fetida*	TN P, K, Ca, Mg, Na	**R** **A**	Yadav et al. (2010)
Urban green waste	NA	*E. fetida* + *Eudrilus eugeniae* + *Perionyx excavatus*	TKN, TP, K, Ca, Mg	**A**	Pattnaik and Reddy (2010)
Industrial sludge + bulky agents	3 weeks	*E. fetida*	TKN, Av. P, Exc. K, Exc. Ca, Mg, Fe, Zn	**A**	Suthar (2010a)
Vegetable waste + cow dung	2 days	*E. fetida*	TKN, TP, TK	**A**	Garg and Gupta (2011)
Weed + cow dung	3 weeks	*E. fetida*	TN, Av. P, TK, TCa	**A**	Yadav and Garg (2011a)
Food industry sludge + cow dung + poultry droppings	4 weeks	*E. fetida*	TKN, TP, TK, Ca, Na	**A**	Yadav and Garg (2011b)
Sewage sludge	NA	*E. fetida*	TN, TP	**A**	Hait and Tare (2012)
Wastewater sludge + plant wastes	3 weeks	*E. fetida*	TKN, Av. P, Exc. K	**A**	Suthar et al. (2012)
Food industry sludge + weeds + cow dung	3 weeks	*E. fetida*	TKN, TP, TK, TCa	**A**	Yadav and Garg (2013)
Leaf litter + cow dung	3 weeks	*E. fetida*	Exc. K TKN, TP, TCa	**R** **A**	Suthar and Gairola (2014)
Apple pomace waste + straw	14 days	*E. fetida*	TKN, TP, TK, TMg	**A**	Hanc and Chadimova (2014)
Corn stalk + cow manure + paper	30 days	*E. fetida*	TKN, TP	**A**	Kharrazi et al. (2014)
Animal manure + mushroom residues	20 days	*E. fetida*	TKN, TP, TK	**A**	Song et al. (2014)
Organic fraction of MSW + cow dung	3 weeks	*E. fetida*	TKN, TP, TK	**A**	Suthar et al. (2015)
Organic MSW	16 days	*Eudrilus eugeniae*	TKN, Av. P, TK, Ca, Mg, Na	**A**	Soobhany et al. (2015a)
Coconut husk + either pig slurry or poultry manure	3 weeks	*Eudrilus eugeniae*	TN, TP, TK	**A**	Swarnam et al. (2016)
Vinasse + cow manure + bagasse + natural zeolite	3 weeks	*E. fetida*	TP TK	**A** **R**	Alavi et al. (2017)
Tea factory waste + cattle manure	1 week	*Eudrilus eugeniae*	TKN, TP, TK	**A**	Ghosh et al. (2018)
Silk industry waste + cow dung	4–5 days	*E. fetida* + *Eudrilus eugeniae*	TKN, Av. P Av. K, Av. Ca	**A** **R**	Paul et al. (2018)
Distillery sludge waste + tea leaf residues	40 days	*E. fetida*	TKN, TP, TK, Av. P, Av. K, TCa, TMg	**A**	Mahaly et al. (2018)
Rice straw + paper waste	3 weeks	*E. fetida*	TKN, TP, TK, TNa	**A**	Sharma and Garg (2018)
Paper mill wastewater sludge + cow dung + brown-rot fungi *Oligoporus placenta*	1 week	*E. fetida*	TKN, TP, TK	**A**	Negi and Suthar (2018)
Bakery industry sludge + cow dung	3 weeks	*E. fetida*	TKN, TK, TCa	**A**	Yadav et al., 2019

TN = total nitrogen; TKN: total kjeldahl nitrogen; TP = total phosphorus; TK = total potassium; TNa = total sodium; TCa = total calcium; TMg = total magnesium; Exc. = Exchangeable; Av. = Available; NA: Not available.
Note: C + V = pre-composting followed by vermicomposting; A = signifies an augmentation in nutrients content; R = signifies a reduction in nutrients content.

maintained in the nitrate form (Yadav and Garg, 2011b; Atiyeh et al., 2000). Vermicomposting technology has been reported to cause sharp increase in TN or TKN contents of feed materials after worm process (Aira et al., 2007; Khwairakpam and Bhargava, 2009; Suthar et al., 2015; Negi and Suthar, 2018). This relative enriched N concentration is directly connected to the physico-chemical nature of OSW (Suthar et al., 2012) and reduction in dry mass of OSW owing to higher degree of decomposition (Gupta and Garg, 2008). Few studies reported that the addition of microorganisms during vermicomposting into OSW increases TKN of the vermicompost, but their outcome differs extensively relying on the nature of the materials (Pramanik, 2010a; Kharrazi et al., 2014). The difference for N level in vermicompost might be connected to the presence of metals in substrates which straightly influences the N mineralization rate as advocated by Suthar and Singh (2008a). As reported by Das et al. (2016a), the TN increase rate in vermicompost from its equivalent OSW correlated with the C/N ratio of the parent substrate. The correlative rise in TN concentration all through vermitechnology was found to be due to the reduction in organic carbon in respect of CO_2 through microbial respiration (Huang et al., 2004; Plaza et al., 2008; Varma et al., 2016), and evaporative humidity loss owing to environmental circumstance (Hait and Tare, 2011a). A concentration outcome originated from the mass loss of heaps during mineralization of C-rich materials containing proteins also contributed to N increment during vermicomposting (Fornes et al., 2012). Activities of N-fixing microscopic organism by the earthworm's enteric microflora contributed to an increase in TKN (Paul et al., 2018). Earthworm's metabolic activities during mineralization of OM (Suthar, 2007) and simultaneous supply of N by worms as growth stimulating hormones, mucus, nitrogenous excreta, and enzymes in OSW mixtures increased TN content in vermicompost (Tripathi and Bhardwaj, 2004b; Karmegam and Daniel, 2009).

Decrease in pH might be one more imperative indicator in N preservation by vermicompost and if not; N could be lost as NH_3 at elevated pH values (Yadav and Garg, 2011b). Most of the previous studies reported an increase in TN after vermicomposting process of various OSW but however, a research conducted by Yadav et al. (2010) reported that N was lost during the biodegradation phase. A quite similar study by Benitez et al. (1999) noted that 36% N content was discharged in sewage sludge vermicomposting. In general, TN content in vermicompt was found to be ranged from 1.5 to 2.7% (Padmavathiamma et al., 2008). Vermicomposting increased TKN content (30.5–51.29%) in treated hard stem leftover wastes from pruning of tea plantation (Pramanik et al., 2016). Also, vermicomposting increased TN content (19.5–152%) in agricultural residues (Pigatin et al., 2016) and (300%) in coconut husk (Swarnam et al., 2016). Sharma and Garg (2018) accounted 1.2–2.9-folds increase in TKN content during vermicomposting and quite similar increase in TKN was observed by other authors on various OSW (Kaushik and Garg, 2004; Garg et al., 2006a; Sudkolai and Nourbakhsh, 2017; Suthar et al., 2017). Hait and Tare (2011a) noted that during composting of sewage sludge, TN increased in the range of 15.2–49.5% whereas TN showed a greater increase during vermicomposting (31.3–90.0%). Similarly, Sangwan et al. (2008) reported that the rise in TKN concentration was higher in earthworm-inoculated vermicomposters than in the controls without earthworms.

5.1.2. TP

TP is a vital nutrient that is needed for energy movement inside crops, photosynthesis as well as for plant development (Garg and Gupta, 2011). TP is captured by crops in the state of inorganic ions namely $H_2PO_4^-$ and HPO_4^{2-}. Generally, the presence of P is very much linked to the pH value of the feed materials which should not be extremely alkaline or acidic as reported by Sahariah et al. (2014). Research by Ghosh et al. (1999) documented that vermitechnology might be a valuable technique in transforming unavailable forms of P to suitable state for crops. TP content is usually higher in vermicomposts (with an increasing effect) generated from sewage sludge and various OSW than parent material (Suthar, 2009c; Khwairakpam and Bhargava, 2009; Kaur et al., 2010; Singh et al., 2010; Hait and Tare, 2011a, b; Varma et al., 2016) or than composted material (Suthar and Singh, 2008a). Increase in TP all through vermitechnology might be owing to mineralization rate of OM which is straightly influenced by the characteristics of feed materials and P-mineralizing microflora in OSW decomposition (Suthar et al., 2012; Negi and Suthar, 2018) due to P-solubilizing bacterial and fecal phosphatase movement of earthworms (Pramanik et al., 2007; Hanc and Pliva, 2013) and additional discharge of P is aided by microbial communities linked with accumulated vermicasts (Vinotha et al., 2000). Few earlier studies indicated that production of labile OM during the release of CO_2 (Patel et al., 2011; Das et al., 2016a; Malinska et al., 2016), phosphatase and phytase enzymes play an important role in P-mineralization during vermicomposting (Gaume et al., 2001; Pramanik et al., 2009; Ghosh et al., 2018). Increase in TP could also be attributed to the enzymatic activities of earthworm gut (Suthar, 2010a) and indirectly by precipitation of micro flora (Varma et al., 2016). An augmentation in TP was also observed from vermicomposting of several OSW which could be attributed to microorganism movement following addition of bacteria (Kumar and Singh, 2001; Pramanik et al., 2007; Singh and Sharma, 2002; Pramanik, 2010a). Sangwan et al. (2010) reported 1.3–1.5-folds increment in TP value of press mud following worm activity and quite similarly, Suthar et al. (2017) accounted 1.38–1.69-folds, suggesting the positive role of earthworms in P-mineralization process during vermicomposting process. Similar finding (1.4–1.8-folds increase in TP content) was noted by Gupta and Garg (2009) during the paper waste vermicomposting. Hait and Tare (2011a) recorded that TP concentration was in the range of 30.1–86.1% all throughout vermitechnology while a much lower increase in TP content (8.1–29.7%) was obtained for the control.

5.1.3. TK

An increase in concentration of TK in OSW vermicompost was detected in various vermicomposting experiments (Khwairakpam and Bhargava, 2009; Manna et al., 2003; Kaushik and Garg, 2004; Gupta and Garg, 2008). Similar K increment in vermicomposts has been reported by other workers as compared to initial values of feedstocks (Subramanian et al., 2010; Sangwan et al., 2010; Hait and Tare, 2012; Negi and Suthar, 2018). The increase in TK contents in vermicomposts could be due to acid release through OSW degradation by microbes which is the key procedure for solubilization of insoluble K as justified by Pramanik et al. (2007). Vermicomposting increased TK content by 22% in apple pomace waste compared to the control compost (Hanc and Chadimova, 2014), 39.5–50% in organic wastes (Yadav and Garg, 2011b), 104–160% in distillery sludge (Suthar, 2008d), 78–230% increase in agro-industrial sludge (Suthar, 2010a), and by 30.1–51.9% for vermicompost as compared to the initial compost material (Hait and Tare, 2011a). Tripathi and Bhardwaj (2004a) observed that TK content was 2.14-folds the initial level after vermitechnology while Yadav et al., 2019 found that TK content was 1.28–1.41 times higher in the vermicomposts in comparison to initial values. Another study by Garg et al. (2006a) demonstrated that TK content after the vermicomposting was 1.2–1.7-folds the initial value.

There are contradictory reports as regards to K content in vermicomposts obtained from different OSW. A decrease in K has been reported in the vermicomposting process than the initial feed mixtures (Orozco et al., 1996; Sangwan et al., 2008; Garg and Gupta, 2011). These authors claimed that this decrease could be attributed to leakage of soluble K by surplus water that drew off through the feedstocks or could also be linked to the different physico-chemical characteristics of original substrates. In addition, Benitez et al. (1999) analysed that leachate gathered during vermitechnology had high presence of K. Singh et al. (2010) described that a rise in pH of the product may be accountable for a decline in K as it makes K ions more liable to fixation by colloids. Other authors explained this decline in K by the production of organic acids during the OM decomposition in the process of solubilizing insoluble K species of mixtures (Pramanik, 2010b; Suthar and Gairola, 2014; Das et al., 2016a).

5.2. Micro-nutrients or trace elements (Ca, Mg, Na, Fe, Cu, Mn, Zn, B, Mo, S)

Earlier studies recorded a considerable increment in Ca level during vermicomposting process of different OSW i.e. industrial wastes, forest leaf litter, rice straw etc. as compared to feedstocks (Garg and Kaushik, 2005; Suthar and Gairola, 2014; Lim and Wu, 2016; Mahaly et al., 2018). The increase in Ca content might be related to the chemical quality of various OSW employed in vermitechnology operation (Suthar and Gairola, 2014) and to the improved Ca mineralization by the presence of earthworms (Yadav and Garg, 2013). Consequently, earthworms manage the mineralization route and transform a fraction of Ca from binding state to a more suitable state, ensuring its enhancement in the vermicasts. Varma et al. (2016) noted a Ca increment in the range of 1.1–1.9-folds, 1–1.5-folds, and 1–1.3-folds with earthworm species *Eudrilus eugeniae, Eisenia fetida* and *Perionyx excavatus* respectively during vermicomposting of water hyacinth. Quite comparable increase in Ca was detected by Pattnaik and Reddy (2010) and Suthar

et al. (2017). A much higher increase of 1.15–3.57-folds in Ca was observed in different vermicomposts (Yadav and Garg, 2011b). However, Ca content decreased by 1.05–1.35-folds in industry waste during vermicomposting as reported by Paul et al. (2018). Yet, a large fraction of Ca remains in decomposed substances as soluble species which depends upon the rate of loss through leaching mechanism (Benitez et al., 1999; Orozco et al., 1996). Mg increased with time during vermicomposting as perceived by Mahaly et al. (2018) which related to mass loss and OM (Wani and Mamta Rao, 2013). Moreover, it has also been found that micro-algal hyphae and fungal, which effortlessly settle on newly accumulated vermicasts in vermicomposts contribute to the increment of Mg concentration (Suthar, 2010a). In an experiment performed by Pattnaik and Reddy (2010), Mg content in green waste vermicompost was found to be 0.8% following worm activity. Nonetheless, on the basis of an in-depth literature review, few scientific studies have been carried out with regard to Mg analysis during vermicomposting of various OSW. Consequently, there is an eventual demand in research in terms of availability of Mg during vermicomposting.

Vermicomposting caused substantial increase in Na content comparative to the composting product (Hait and Tare, 2012) as compared to initial values of feedstocks (Yadav and Garg, 2011b; Lim and Wu, 2016). An increase in Na content of materials after vermitechnology of industrial sludge was researched by workers (Khwairakpam and Bhargava, 2009; Yadav and Garg, 2009; Suthar, 2009c; Singh et al., 2010). Yadav and Garg (2011b) investigated that the increase in Na content might be related to the availability of Na in initial feed substrate. Na increased in the range of 1.1–1.7-folds and 1.1–1.5-folds during vermi-processing of water hyacinth with the earthworm species *Eisenia fetida* and *Eudrilus eugeniae*, respectively (Varma et al., 2016). A higher augmentation in Na concentration in the range of 1.06–2.05-folds was observed in the mature vermicomposts as compared with the initial Na content of OSW (Yadav and Garg, 2011b). Anantavalli et al., 2019 reported that Mg, Mn and Ca contents showed maximum of 35.28 and 52.15% increase in the vermicomposts of *Gracilaria corticata* + CD and *Halimeda gracilis* + CD combinations respectively. Other trace elements or micro-nutrients such as Fe, Cu, Mn, Zn, B, Mo, and S are crucial elements of soil chemistry that are fundamentally needed for typical crop development. In recent times, many micro-nutrients are becoming scarce owing to an increasing requirement in suitable forms of nutrients by the speedily developing plants. The substantial availability of such components in mature vermicompost designates its agronomical prospective for land applications. Higher content of some micro-nutrients in vermicompost was reported by earlier scientists (Plaza et al., 2008; Selladurai et al., 2010). Availability of Zn, Fe, Mn and S in feed materials notably augmented after vermicomposting in contrast to composting (Paul et al., 2018) which might be attributed to mineralization of partly assimilated worm excrement by bacteria and fungi during the passage of materials through earthworm's gut (Kizilkaya, 2004). Similarly, an increase in Fe, Mn, Cu and Zn concentrations was reported by Patil et al. (2018) during the vermicomposting of coconut coir waste employing *Eudrilus eugeniae*. Daman et al. (2016) reported an increase in the concentrations of Zn, Cu, Mn, and Fe after 90 days vermicomposting of waste rose flower by *Eudrilus eugeniae*. Increase in S was justified by the decomposition of S organic dyes in the silk industry waste which might have assisted in the discharge of soluble S (Chequer et al., 2013).

5.3. Possible ways of enriching the nutrient content in vermicompost

With regard to an improvement in sustainable agriculture, OSW improvement with nutrients is of great concern that could effectually be performed by preliminary treating the OSW with some productive microflora. Addition of appropriate supplements has been found to accelerate the vermicomposting period together with the enhancement of nutritive elements in the ready vermicompost (Singh and Sharma, 2002). One of the promising means of enriching N level in vermicompost is through the supplementation of N_2 fixing bacteria (Kaushik and Garg, 2004; Busato et al., 2012). The strategies which are presently exploited for enhancing the soluble P content in vermicompost are addition of phosphate-solubilizing bacteria and phosphate rock (Kumar and Singh, 2001; Kumar et al., 2010). Other authors also revealed that inoculation of microorganisms in OSW produced a stabilized vermicompost which is rich in TP and TKN (Pramanik et al., 2007). Similarly, with regard to the concentration of K, the vermicompost could be generated from OSW loaded in K and supplementing microbes to solubilize it. The addition of straw to apple pomace (Hanc and Chadimova, 2014), activated sludge to a corn stalk (Kharrazi et al., 2014) and cow dung in waste mixture (Suthar et al., 2017), in a certain proportion increased the nutrients content during vermicomposting. Mupambwa et al. (2016) assessed the possibility of supplementing cow dung–paper waste mixture with an efficient micro-organism upon vermitechnology for enhancing nutrients content. Along with the implementation of the strategies mentioned for enriching nutrient content in vermicompost, an original bioinput helping in the availability of nutritive elements for crops and to protect the physico-chemical stability of soil may possibly be studied.

6. Possible earthworm's mechanism in response to nutrients enrichment

Microorganisms generate enzymes which resulted in the biochemical degradation of OM, but earthworms are known to be the essential engineers of the system since they are engaged in the indirect stimulation of microbial communities during disintegration and consumption of OM (Aira et al., 2002). Earthworm gut-borne microorganisms get mixed up with OM during their passage in the intestine and those microorganisms consecutively have a vital role in the biochemical alterations of nutritive elements (Atkins and de Paula, 2006). Thus, the nutrients are transformed into more soluble and available forms, which consequently enrich the vermicomposts with higher plant nutrients (Suthar and Singh, 2008a; Suthar, 2008b; Gupta and Garg, 2009).

6.1. Earthworm's mechanism on TKN

The N mineralization rate during vermicomposting was found to be directly related to the earthworm mediated N enrichment (Suthar et al., 2012). Additionally, some microbes together with earthworms improve the generation of some important enzymes (e.g., invertase, protease, xylanase, amylase, urease, cellulose, and phosphatase), which are directly entailed in N-mineralization process (Pramanik, 2010b; Fu et al., 2015). Previous experiments sustain the responsibility of earthworm in N enhancement of vermicomposting product (Taylor et al., 2003; Suthar, 2010b; Oyedele et al., 2006; Suthar and Singh, 2008b). The microclimatic condition is altered by earthworms in the vermibeds which as a result encouraged microbial populations responsible for N improvement (Suthar, 2010a). Earthworm's mechanism enhances the TKN profile for various OSW vermitechnology upon the secretion of metabolic nitrogenous products by earthworms as excretory substances, urine, body fluid, enzymes and growth stimulating hormones (Tripathi and Bhardwaj, 2004b; Hobson et al., 2005; Suthar and Gairola, 2014; Varma et al., 2016) during the fragmentation and

digestion of OM in the vermicomposting process (Vig et al., 2011). Besides, polysaccharide fluid called mucus is produced by earthworms under favorable condition of earthworm gut to moisten its exterior body and to enhance OSW by means of N fixers (Padmavathiamma et al., 2008; Hussain et al., 2016). Still, these additional N loaded materials were not initially detected in feedstocks (Garg and Gupta, 2011). Tripathi and Bhardwaj (2004b) and Suthar (2006), however, implied that the decomposing tissues of lifeless earthworms contribute to a considerable level of N in vermicompost.

6.2. Earthworm's mechanism on TP

The earthworm intestine generates a substantial quantity of acid and alkaline phosphatases (Swarnam et al., 2016) especially phosphate-solubilizing bacteria which is a crucial enzyme engrossed in bio-chemical succession of P (Le Bayon and Binet, 2006) that is, converting organic-P into mineralized states and maintaining the degree of fixation of liberated P into impenetrable inert forms at low stages (Ghosh et al., 1999; Bhattacharya and Chattopadhyay, 2002). In the research studies of several authors, the discharge of existing P content from OSW is achieved to a certain extent by stimulation of the micro-flora present in earthworm's gut phosphatases during vermicomposting (Kaviraj and Sharma, 2003; Suthar, 2009c; Garg and Gupta, 2011; Bhat et al., 2013), and by the P-solubilizing microbes available in vermicasts (Vinotha et al., 2000; Suthar and Singh, 2008a; Prakash and Karmegam, 2010). Earthworm leads its synergetic enteric microflora through enhancing OM decomposition by releasing water, metabolites, enzymes (phosphatase) and mucus (Khwairakpam and Bhargava, 2009). Singh et al. (2010) also found that earthworm gut enzymes showed stimulating influence on P-solubilizing bacteria as P increased in the vermicasts, eventually increasing TP in vermicompost. Thus, directly or indirectly earthworm enhanced OSW vermicompost with P contents.

6.3. Earthworm's mechanism on TK

Earthworms play a vital role in K mineralization during vermitechnology. Usually, when OSW passes through the earthworm gut, a portion of organic TK is transformed into more accessible exchangeable K owing to enzymes activity (Suthar, 2010a). The increase in the quantity of micro-flora present in the earthworm's gut upon vermicomposting may also have contributed an essential part in this system and boosted K over the control (Kaviraj and Sharma, 2003). Increase in TK concentration subsequent to vermicomposting could be attributed to the enzymatic activities of earthworm's gut and settlement of K in the earthworm casts (Pramanik et al., 2007). The role of earthworms in K enrichment is also advocated by few researchers (Singh et al., 2010; Negi and Suthar, 2013; Khwairakpam and Bhargava, 2009).

6.4. Earthworm's mechanism on micro-nutrients (Ca, Mg and Na)

The Ca-mineralization during vermitechnology process reflects the outcome of earthworm's mechanism in OSW mixtures (Suthar et al., 2015). Many earthworm species secretes calcium carbonate through their calciferous glands (Lakshmi et al., 2015) for pH buffering of ingested foods which then is egested in cast material (Briones et al., 2008). The Ca metabolism is mostly linked by the gut-exuded enzymes generated from earthworm's activity and by the accelerated assimilation in the vermicast's deposition by fugal hyphae or other microbial communities (Pramanik and Chung, 2011). Vermitechnology indicates the earthworm-mediated conversion of organic-bound complexes of Ca into suitable state for crops (Suthar and Gairola, 2014) which makes vermicomposting techniques superior than conventional composting method. Up to date, no straight involvement of earthworm's mechanism within Mg and Na metabolisms are known during the process of vermicomposting. Yet, it is theorized from a research made by Suthar (2010a), that mycelium or micro-algal filamentous structure of fungi which straightforwardly settles on freshly sedimented vermicasts, helps to bring about a small quantity of Mg in vermicompost. Yet, an apparent demand for further scientific investigation and development intended at outlining Mg and Na metabolisms during vermicomposting processes is required.

7. Beneficial effect of nutrient-enriched vermicompost

Vermicompost which resembles native soil humic substances (Benitez et al., 2005) is one of the nutrient-rich organic manure in the world and has shown to be first-rate manure for land improvement. Nutrient-enriched vermicompost was shown to have a positive role in plant development (Soobhany et al., 2015a; Singh and Kalamdhad, 2016) because of its homogeneity and have a tendency in retaining extra nutrients for a prolonged time (Ndegwa and Thompson, 2000). Vermicomposts which are rich in nutrients also hold enzymes and plant growth hormones (humic substances, cytokinins, auxins) that increase plant growth and reduce plant diseases (Hussain et al., 2017; Atiyeh et al., 2002). Nutrient-enriched vermicompost are potentially used by growers for sustainable crop production and thus, has shown to have a valuable and marketable value. Vermicompost is thus dissuading the utilization of chemical fertilizers and is highly preferred in sustainable agriculture over chemical fertilizers (Bhat et al., 2015, 2017; Yadav et al., 2015; Das et al., 2016b; Fu et al., 2016). The nutrient-rich vermicompost has also a beneficial effect on crop yield which comprises strawberry (Singh et al., 2008), tomato (Atiyeh et al., 2002; Joshi and Vig, 2010), lady finger (Hussain et al., 2017) and green bean (Soobhany et al., 2017c).

8. Quality assessment of composts/vermicomposts linking to nutrient content

The usefulness of compost pertaining to valuable influences on soil physico-chemical and biological characteristics, in addition to comprising a nutrient supply, relies on its quality. According to Bernal et al. (2009), the quality criteria for compost are set up with respect to nutrient content, stabilized OM, maturity grade, sanitization degree and the occurrence of certain lethal complexes like heavy metals, xenobiotics and soluble salts. The significance of maturity and stability factors in evaluating compost quality is extensively conceded by investigators (Soobhany et al., 2017b; Soobhany, 2018c). Nevertheless, incorporation of the most unswerving indices designates the only choice for assessing the maturity/stability extent of degraded OSW as affirmed by Eggen and Vethe (2001). A clear paradigm of this is the CCQC maturity evaluation procedure (TMECC, 2002; CCQC, 2001), which foremost implied that a compost is considered undeveloped when the C/N ratio >25. Conversely, additional quality criteria besides maturity index must also be considered to classify the compost utilization, such as nutrient content. Hence, the expansion of a market for organic fertilizer which sustains an OSW composting/vermicomposting approach significantly relies on the description and implementation of quality standards including nutrient content. It is thought that conventional composts are usually of poor quality since they do not contain high levels of nutritive elements like N, P, and K in contrast to synthetic fertilizers. Still, such evaluation is incorrect as these two products differed chemically, microbiologically and structurally and behave differently when applied to soil.

There are quite a few compost quality standards suggested by official organisations (TMECC, 2002; BSI, 2005; European Commission, 2001; Ge et al., 2006) which consider compost parameters such as nutrient content. Presently, there is an urge for harmonisation of such nutrient content criteria universally.

9. Conclusions

Conclusively, addition of various additives on composting process might be a resonance technique in recuperating valuable nutritive elements from OSW for rendering fertility of soil. This work has clarified that the inoculation of nutrient-rich materials, integration of nutrients from natural sources and the supplementation of microbes, signifies a propitious continuing approach to achieve a ready outcome with improved nutrient quality. The use of nutrient-rich composts could eventually contribute to diminish production costs over and above decreasing the ecological effect triggered by discarding OSW. For the most part, the development of bio-inputs which are rich in nutritive elements demands further investigation and not only in the enhancement of the end product, but also in the separation and detection of microbes permitting the transfer of nitrogenous materials and substances containing K and P available in OSW. The search for more effective additives to improve the composting technology whilst regarding the economic advantages, lessen the N loss and improving the quality of the end product in terms of nutrient content is entailed. This review demands additional research efforts to discover the most suitable method for N preservation so that compost with utmost N content at the final stage of the composting process could be attained. Moreover, an eventual demand in research is needed to confirm P, K, and Na losses during composting processes. Studies on compost with regard to nutrient conservation, supplementation, and addition with nutrient converting microbes could also be carried out as a future challenge to make the final product of the composting system valuable in nutritional properties.

On the other hand, OSW can be converted into a richer environmentally-friendly nutrient biofertilizer (vermicompost) through vermitechnology operation for sustainable land restoration practices and urban forestry programme. In contrast to compost, vermicompost holds elevated quantity of major nutritive elements (TKN, TP, TK) and some minor nutrients (Ca, Mg, Na) with enhanced nutritional features for specifically improving crop quality. These increased levels of major nutrients in vermicomposts can be attributed to the improved synergetic enteric microflora secreted from earthworm's gut through earthworm activity. The secretion of metabolic nitrogenous products by earthworms as excretory substances, body fluid, enzymes and growth stimulating hormones increase the TKN profile during vermicomposting. The rise in TP concentration upon vermitechnology is performed partly by stimulation of the micro-flora present in earthworm's gut phosphatases and by the P-solubilizing microbes available in vermicasts. Increase in TK concentration subsequent to vermicomposting could be attributed to the enzymatic activities of earthworm's gut and settlement of K in the earthworm casts. The Ca metabolism is mostly linked by the gut-exuded enzymes generated from earthworm's activity and by the accelerated assimilation in the vermicast's deposition by fugal hyphae or other microbial communities. But still, earthworm's mechanism on micro-nutrients i.e. Mg and Na is not lucidly known. In this sequence, an apparent demand for further scientific investigation and development intended at outlining Mg and Na metabolisms and also other trace elements (Fe, Cu, Mn, Zn, B, Mo, S) during vermicomposting processes is needed. Composting of OSW can be a practice of a highest standard and vermicomposting of OSW can be beneficial in the supplement of superior plant nutrients. In summary, vermicomposting can be recommended as one of the technologies by developing countries or small island developing states for the management of OSW since the utilization of vermicompost in agriculture might be useful in lowering the use of inorganic fertilizer, attain sustainable development and land degradation issues.

Acknowledgements

The author appreciatively expresses infinite thanks to each individual whose involvement, through scientific data, fundamental findings with broad array of critical principles and suppositions, was of colossal help in adding consistency to this review. Special thanks to the anonymous reviewers for their instructive comments and suggestions.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2019.118413.

References

Aira, M., Monroy, F., Dominguez, J., 2007. Earthworms strongly modify microbial biomass and activity triggering enzymatic activities during vermicomposting independently of the application rates of pig slurry. Sci. Total Environ. 385, 252–261.

Aira, M., Moroy, F., Dominguez, J., Mato, S., 2002. How earthworm density affects microbial biomass and activity in pig manure. Eur. J. Soil Biol. 38, 7–10.

Akdeniz, N., 2019. A systematic review of biochar use in animal waste composting. Waste Manag. 88, 291–300.

Alavi, N., Daneshpajou, M., Shirmardi, M., Goudarzi, G., Neisi, A., Babaei, A.A., 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.

Ali, M., Bhatia, A., Kazmi, A.A., Ahmed, N., 2012. Characterization of high rate composting of vegetable market waste using Fourier transform-infrared (FTIR) and thermal studies in three different seasons. Biodegradation 23, 231–242.

Anantavalli, R., Ramadas, V., Paul, J.A.J., Selvi, B.K., Karmegam, N., 2019. Seaweeds as bioresources for vermicompost production using the earthworm, *Perionyx excavatus* (Perrier). Bioresour. Technol. 275, 394–401.

Ansari, A.A., Rajpersaud, J., 2012. Physicochemical changes during vermicomposting of water hyacinth (*Eichhornia crassipes*) and grass clippings. ISRN Soil Sci. 2012. Article ID 984783,6 pages). https://doi.org/10.5402/2012/984783.

Atiyeh, R.M., Arancon, N.Q., Edwards, C.A., Metzger, J.D., 2002. The influence of earthworm-processed pig manure on the growth and productivity of marigolds. Bioresour. Technol. 81, 103–108.

Atiyeh, R.M., Dominguez, J., Subler, V., Edwards, C.A., 2000. Changes in biochemical properties of cow manure during processing by earthworms (*Eisenia andrei* Bouche) and the effects on seedling growth. Pedobiologia 44, 709–724.

Atkins, P., de Paula, J., 2006. Physical Chemistry for the Life Sciences. W.H. Freeman and Company, New York, pp. 363–371.

Awasthi, M.K., Wang, M., Chen, H., Wang, Q., Zhao, J., Ren, X., Li, D., Awasthi, S.K., Shen, F., Li, R., Zhang, Z., 2016b. Heterogeneity of biochar amendment to improve the carbon and nitrogen sequestration through reduce the greenhouse gases emissions during sewage sludge composting. Bioresour. Technol. 224, 428–438.

Awasthi, M.K., Wang, Q., Chen, H., Wang, M., Ren, X., Zhao, J., Li, J., Guo, D., Li, D., Awasthi, S.K., Sun, X., Zhang, Z., 2017. Evaluation of biochar amended biosolids co-composting to improve the nutrient transformation and its correlation as a function for the production of nutrient-rich compost. Bioresour. Technol. 237, 156–166.

Awasthi, M.K., Wang, Q., Huang, H., Ren, X.N., Lahori, A.H., Mahar, A., Ali, A., Shen, F., Li, R.H., Zhang, Z.Q., 2016a. Influence of zeolite and lime as additives on greenhouse gas emissions and maturity evolution during sewage sludge composting. Bioresour. Technol. 216, 172–181.

Bakar, A.A., Yee, C.M., Mahmood, N.Z., Abdullah, N., 2015. Effect on heavy metals concentration from vermiconversion of agro-waste mixed with landfill leachate. Waste Manag. 38, 431–435.

Barker, A.V., 1997. Composition and uses of compost, agricultural uses of by-products and wastes ASC Symposium Series. Am. Chem. Soc. 668, 140–162.

Benitez, E., Nogales, R., Elvira, C., Masciandaro, G., Ceccanti, B., 1999. Enzyme activities as indicators of the stabilization of sewage sludges composting with *Eisenia foetida*. Bioresour. Technol. 67, 297–303.

Benitez, E., Nogales, R., Masciandaro, G., Ceccanti, B., 2000. Isolation by isoelectric focusing of humic urease complexes from earthworm (*Eisenia foetida*) processed sewage sludges. Biol. Fertil. Soils 31, 489–493.

Benitez, E., Sainz, H., Nogales, R., 2005. Hydrolytic enzyme activities of extracted

humic substances during the vermicomposting of a lignocellulosic olive waste. Bioresour. Technol. 96, 785–790.
Bernal, M.P., Alburquerque, J.A., Moral, R., 2009. Composting of animal manures and chemical criteria for compost quality assessment: a review. Bioresour. Technol. 100, 5444–5453.
Bhat, S.A., Singh, J., Vig, A.P., 2013. Vermiremediation of dyeing sludge from textile mill with the help of exotic earthworm *Eisenia fetida* Savigny. Environ. Sci. Pollut. Res. 20, 5975–5982.
Bhat, S.A., Singh, J., Vig, A.P., 2015. Potential utilization of bagasse as feed material for earthworm Eisenia fetida and production of vermicompost. SpringerPlus 4, 11.
Bhat, S.A., Singh, J., Vig, A.P., 2017. Earthworms as organic waste managers and biofertilizer producers. Waste Biomass Valorization 7, 1073–1086.
Bhat, S.A., Singh, S., Singh, J., Kumar, S., Bhawana, Vig, A.P., 2018. Bioremediation and detoxification of industrial wastes by earthworms: vermicompost as powerful crop nutrient in sustainable agriculture. Bioresour. Technol. 252, 172–179.
Bhattacharya, S.S., Chattopadhyay, G.N., 2002. Increasing bioavailability of phosphorous from fly ash through vermicomposting. J. Environ. Qual. 31, 2116–2119.
Bhattacharya, S.S., Kim, K.H., 2016. Utilization of coal ash: is vermitechnology a sustainable avenue? Renew. Sustain. Energy Rev. 58, 1376–1386.
BOE, 2013. Real Decreto 506/2013, del 10 de julio, sobre productos fertilizantes [Online]. http://www.boe.es/diario_boe/txt.php?id=BOE-A-2013-7540. (Accessed 29 April 2019).
Briones, M.J.I., Ostle, N.J., Piearce, T.G., 2008. Stable isotopes reveal that the calciferous gland of earthworms is a CO_2-fixing organ. Soil Biol. Biochem. 40, 554–557.
BSI, 2005. PAS 100:2005, Specification for Composted Materials. British Standard Institution, London.
Bueno, P., Tapias, R., López, F., Díaz, M.J., 2008. Optimizing composting parameters for nitrogen conservation in composting. Bioresour. Technol. 99, 5069–5077.
Busato, J.G., Lima, L.S., Aguiar, N.O., Canellas, L.P., Olivares, F.B., 2012. Changes in labile phosphorous forms during maturation of vermicompost enriched with phosphorus solubilizing and diazotrophic bacteria. Bioresour. Technol. 110, 390–395.
Compost Quality Council (CCQC), California, 2001. Compost maturity index, technical report.
Chan, M.T., Selvam, A., Wong, J.W.C., 2016. Reducing nitrogen loss and salinity during 'struvite' food waste composting by zeolite amendment. Bioresour. Technol. 200, 838–844.
Chen, Y.X., Huang, X.D., Han, Z.Y., Huang, X., Hu, B., Shi, D.Z., Wu, W.X., 2010. Effects of bamboo charcoal and bamboo vinegar on nitrogen conservation and heavy metals immobility during pig manure composting. Chemosphere 78, 1177–1181.
Chequer, F.M.D., De Olivera, G.A.R., Raquel Anastacio Ferraz, E., Cardoso, J., Zanoni, M., De Olivera, D.P., 2013. Textile dyes: dyeing process and environmental impact. Eco Friendly Textile Dyeing and Finishing. https://doi.org/10.5772/53659.
Costa, M.S.S., Cestonaro, T., Costa, L.A.M., Rozatti, M.A.T., Carneiro, L.J., Pereira, D.C., Lorin, H.E.F., 2015. Improving the nutrient content of sheep bedding compost by adding cattle manure. J. Clean. Prod. 86, 9–14.
Daman, R., Singh, K.K., Singh, B., 2016. Determination of micronutrients in vermicompost prepared with waste rose flower (*Rosa berberia*) collected from religious places of Patna. Res. J. Chem. Environ. Sci. 4, 37–43.
Das, D., Bhattacharyya, P., Ghosh, B.C., Banik, P., 2016a. Bioconversion and biodynamics of *Eisenia foetida* in different organic wastes through microbially enriched vermiconversion technologies. Ecol. Eng. 86, 154–161.
Das, M., Uppal, H.S., Singh, R., Beri, S., Mohan, K.S., Gupta, V.C., Adholeya, A., 2011. Co-composting of physic nut (*Jatropha curcas*) deoiled cake with rice straw and different animal dung. Bioresour. Technol. 102, 6541–6546.
Das, S., Deka, P., Goswami, L., Sahariah, B., Hussain, N., Bhattacharya, S.S., 2016b. Vermiremediation of toxic jute mill waste employing *Metaphire posthuma*. Environ. Sci. Pollut. Res. 23, 15418–15431.
De Bertoldi, M., Bidlingmaier, W., Diaz, L.F., Stentiford, E., 2007. Compost Science and Technology. Elsevier, Amsterdam, The Netherlands.
Dias, B.O., Silva, C.A., Higashikawa, F.S., Roig, A., Sanchez-Monedero, M.A., 2010. Use of biochar as bulking agent for the composting of poultry manure: effect on organic matter degradation and humification. Bioresour. Technol. 101, 1239–1246.
Dominguez, J., 2004. State-of-the-art and new perspectives on vermicomposting research. In: Edwards, C.A. (Ed.), Earthworm Ecology. CRC Press, Boca Raton, pp. 401–424.
Dominguez, J., Edwards, C.A., 2011. Relationship between composting and vermicomposting. In: Edwards, C.A., Arancon, N.Q., Sherman, R. (Eds.), Vermiculture Technology—Earthworms, Organic Wastes, and Environmental Management. CRC Press, Boca Raton, FL, pp. 11–26.
Eastman, B.R., Kane, P.N., Edwards, C.A., Trytek, L., Gunadi, B., Stermer, A.L., Mobley, J.R., 2001. The effectiveness of vermiculture in human pathogen reduction for USEPA biosolids stabilization. Compost Sci. Util. 9, 38–49.
Edwards, C.A., Arancon, N.Q., Sherman, R.L., 2011. Vermiculture Technology: Earthworms, Organic Wastes and Environmental Management. CRC Press, Boca Raton, USA.
Eggen, T., Vethe, O., 2001. Stability indices for different composts. Compost Sci. Util. 9, 19–26.
European Commission, 2001. Working Document: Biological Treatment of Biowaste, 2nd draft, p. 22.
Fornes, F., Mendoza-Hernández, D., García-de-la-Fuente, R., Abad, M., Belda, R.M., 2012. Composting versus vermicomposting: a comparative study of organic matter evolution through straight and combined processes. Bioresour. Technol. 218, 296–305.
Fu, X., Cui, G., Huang, K., Chen, X., Li, F., Zhang, X., Li, F., 2016. Earthworms facilitate the stabilization of pelletized dewatered sludge through shaping microbial biomass and activity and community. Environ. Sci. Pollut. Res. 23, 4522–4530.
Fu, X., Huang, K., Cui, G., Chen, X., Li, F., Zhang, X., Li, F., 2015. Dynamics of bacterial and eukaryotic community associated with stability during vermicomposting of pelletized dewatered sludge. Int. Biodeterior. Biodegrad. 104, 452–459.
Füleky, G., Benedek, S., 2010. Composting to recycle biowaste. In: Lichtfouse, E. (Ed.), Sociology, Organic Farming, Climate Change and Soil Science. Springer, Netherlands, pp. 319–346.
Garg, P., Gupta, A., Satya, S., 2006b. Vermicomposting of different types of waste using *Eisenia foetida*: a comparative study. Bioresour. Technol. 97, 391–395.
Garg, V.K., Gupta, R., 2011. Optimization of cow dung spiked pre-consumer processing vegetable waste for vermicomposting using *Eisenia fetida*. Ecotoxicol. Environ. Saf. 74, 19–24.
Garg, V.K., Chand, S., Chhillar, A., Yadav, A., 2005. Growth and reproduction of *Eisenia foetida* in various animal wastes during vermicomposting. Appl. Ecol. Environ. Res. 3, 51–59.
Garg, V.K., Kaushik, P., 2005. Vermistabilization of textile mill sludge spiked with poultry droppings by an epigeic earthworm *Eisenia foetida*. Bioresour. Technol. 96, 1189–1193.
Garg, V.K., Kaushik, P., Dilbaghi, N., 2006a. Vermiconversion of wastewater sludge from textile mill spiked with anaerobically digested biogas plant slurry employing *Eisenia foetida*. Ecotoxicol. Environ. Saf. 65, 412–419.
Garg, V.K., Suthar, S., Yadav, A., 2012. Management of food industry waste employing vermicomposting technology. Bioresour. Technol. 126, 437–443.
Gaume, A., Mächler, F., Frossard, E., 2001. Aluminum resistance in two cultivars of Zea mays L.: root exudation of organic acids and influence of phosphorus nutrition. Plant Soil 73–81.
Ge, B., McCartney, D., Zeb, J., 2006. Compost environmental protection standards in Canada. J. Environ. Eng. Sci. 5, 221–234.
Ghosh, M., Chattopadhyay, G.N., Baral, K., 1999. Transformation of phosphorus during vermicomposting. Bioresour. Technol. 69, 149–154.
Ghosh, P.K., Ramesh, P., Bandyopadhyay, K.K., Tripathi, A.K., Hati, K.M., Mishra, A.K., Acharya, C.L., 2004. Comparative effectiveness of cattle manure, poultry manure, phospho-compost and fertilizer-NPK on the cropping systems in vertisols of semi-arid tropics; crop yield and system performance. Bioresour. Technol. 95, 77–83.
Ghosh, S., Goswami, A.J., Ghosh, G.K., Pramanik, P., 2018. Quantifying the relative role of phytase and phosphatase enzymes in phosphorus mineralizationduring vermicomposting of fibrous tea factory waste. Ecol. Eng. 116, 97–103.
Gil, M.V., Carballo, M.T., Calvo, L.F., 2008. Fertilization of maize with compost from cattle manure supplemented with additional mineral nutrients. Waste Manag. 28, 1432–14440.
Glaser, B., Birk, J.J., 2012. State of the scientific knowledge on properties and genesis of Anthropogenic Dark Earths in Central Amazonia (terra preta de Índio). Geochem. Cosmochim. Acta 82, 39–51.
Gomez-Brandon, M., Lazcano, C., Lores, M., Dominguez, J., 2011. Short-term stabilization of grape marc through earthworms. J. Hazard Mater. 187, 291–295.
Goswami, L., Sarkar, S., Mukherjee, S., Das, S., Barman, S., Raul, P., Bhattacharyya, P., Mandal, N.C., Bhattacharya, S., Bhattacharya, S.S., 2014. Vermicomposting of tea factory coal ash: metal accumulation and metallothionein response in *Eisenia fetida* (Savigny) and *Lampito mauritii* (Kinberg). Bioresour. Technol. 166, 96–102.
Gupta, R., Garg, V., 2008. Stabilization of primary sewage sludge during vermicomposting. J. Hazard Mater. 153, 1023–1030.
Gupta, R., Garg, V.K., 2009. Vermiremediation and nutrient recovery of non-recyclable paper waste employing *Eisenia fetida*. J. Hazard Mater. 162, 430–439.
Hait, S., Tare, V., 2011a. Vermistabilization of primary sewage sludge. Bioresour. Technol. 102, 2812–2820.
Hait, S., Tare, V., 2011b. Optimizing vermistabilization of waste activated sludge using vermicompost as bulking material. Waste Manag. 31, 502–511.
Hait, S., Tare, V., 2012. Transformation and availability of nutrients and heavy metals during integrated composting–vermicomposting of sewage sludges. Ecotoxicol. Environ. Saf. 79, 214–224.
Hanc, A., Chadimova, Z., 2014. Nutrient recovery from apple pomace waste by vermicomposting technology. Bioresour. Technol. 168, 240–244.
Hanc, A., Pliva, P., 2013. Vermicomposting technology as a tool for nutrient recovery from kitchen bio-waste. J. Mater. Cycles Waste Manag. 15, 431–439.
Hargreaves, J.C., Adl, M.S., Warman, P.R., 2008. A review of the use of composted municipal solid waste in agriculture. Agric. Ecosyst. Environ. 123, 1–14.
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.
Hill Laboratories, 2018. Technical Note on Nitrogen Species [Online]. <Nitrogen Species Tech Note KB34247 v1.Pdf (accessed 15.01.19).
Hobson, A.M., Frederickson, J., Dise, N.B., 2005. CH_4 and N_2O from mechanically turned windrow and vermicomposting systems following in-vessel pre-treatment. Waste Manag. 25, 345–352.
Hu, T.J., Zeng, G.M., Huang, D.L., Yu, H.Y., Jiang, X.Y., Dai, F., Huang, G.H., 2007. Use of potassium dihydrogen phosphate and sawdust as adsorbents of ammoniacal nitrogen in aerobic composting process. J. Hazard Mater. 141, 736–744.
Hua, L., Wu, W.X., Liu, Y.X., McBride, M.B., Chen, Y.X., 2009. Reduction of nitrogen

loss and Cu and Zn mobility during sludge composting with bamboo charcoal amendment. Environ. Sci. Pollut. Res. 16, 1–9.
Huang, G.F., Wong, J.W., Wu, Q.T., Nagar, B.B., 2004. Effect of C/N on composting of pig manure with sawdust. Waste Manag. 24, 805–813.
Hussain, N., Abbasi, T., Abbasi, S.A., 2017. Enhancement in the productivity of ladies finger (*Abelmoschus esculentus*) with concomitant pest control by the vermicompost of the weed salvinia (*Salvinia molesta*, Mitchell). Int. J. Recycl. Org. Waste Agric. 6, 335–343.
Hussain, N., Singh, A., Saha, S., Kumar, M.V.S., Bhattacharyya, P., Bhattacharya, S.S., 2016. Excellent N-fixing and P-solubilizing traits in earthworm gut-isolated bacteria: a vermicompost based assessment with vegetable market waste and rice straw feed mixtures. Bioresour. Technol. 165–174.
Ilgen, G., Glindemann, D., Herrmann, R., Hertel, F., Huang, J.H., 2008. Organo metals of tin, lead and mercury compounds in landfill gases and leaches from Bavaria, Germany. Waste Manag. 28, 1518–1527.
Insam, H., de Bertoldi, M., 2007. Microbiology of the composting process. In: Diaz, L.F., de Bertoldi, M., Bidlingmaier, W., Golueke, C. (Eds.), Compost Science and Technology. Elsevier, pp. 25–48.
Jain, M.S., Jambhulkar, R., Kalamdhad, A.S., 2018. Biochar amendment for batch composting of nitrogen rich organic waste: effect on degradation kinetics, composting physics and nutritional properties. Bioresour. Technol. 253, 204–213.
Jeong, Y.K., Hwang, S.J., 2005. Optimum doses of Mg and P salts for precipitating ammonia into struvite crystals in aerobic composting. Bioresour. Technol. 96, 1–6.
Jeong, Y.K., Kim, J.S., 2001. A new method for conservation of nitrogen in aerobic composting processes. Bioresour. Technol. 79, 129–133.
Jiang, J., Huang, Y., Liu, X., Huang, H., 2014. The effects of apple pomace, bentonite and calcium superphosphate on swine manure aerobic composting. Waste Manag. 34, 1595–1602.
Joshi, R., Vig, A.P., 2010. Effect of vermicompost on growth, yield and quality of tomato (*Solanum lycopersicum* L.). Afr. J. Basic Appl. Sci. 2, 117–123.
Karmegam, N., Daniel, T., 2009. Investigating efficiency of *Lampito mauritii* (Kinberg) and *Perionyx ceylanensis michaelsen* for vermicomposting of different types of organic substrates. Environmentalist 29, 287–300.
Kaur, A., Singh, J., Vig, A.P., Dhaliwal, S.S., Rup, P.J., 2010. Co-composting with and without *Eisenia fetida* for conversion of toxic paper mill sludge to a soil conditioner. Bioresour. Technol. 101, 8192–8198.
Kaushik, P., Garg, V.K., 2003. Vermicomposting of mixed solid textile mill sludge and cow dung with the epigeic earthworm *Eisenia fetida*. Bioresour. Technol. 90, 311–316.
Kaushik, P., Garg, V.K., 2004. Dynamics of biological and chemical parameters during vermicomposting of solid textile mill sludge mixed with cow dung and agricultural residues. Bioresour. Technol. 94, 203–209.
Kaviraj, Sharma, S., 2003. Municipal Solid waste management through vermicomposting employing exotic and local species of earthworms. Bioresour. Technol. 90, 169–173.
Kharrazi, S.M., Younesi, H., Abedini-Torghabeh, J., 2014. Microbial biodegradation of waste materials for nutrients enrichment and heavy metals removal: an integrated composting-vermicomposting process. Int. Biodeterior. Biodegrad. 92, 41–48.
Khwairakpam, M., Bhargava, R., 2009. Vermitechnology for sewage sledge recycling. J. Hazard Mater. 161, 948–954.
Kizilkaya, R., 2004. Cu and Zn accumulation in earthworm *Lumbricus terrestris* L. in sewage sludge amended soil and fractions of Cu and Zn in casts and surrounding soil. Ecol. Eng. 22, 141–151.
Knowles, O.A., Robinson, B.H., Contangelo, A., Clucas, L., 2011. Biochar for the mitigation of nitrate leaching from soil amended with biosolids. Sci. Total Environ. 409, 3206–3210.
Kumar, R., Verma, D., Singh, B.L., Kumar, U., Shweta, 2010. Composting of sugarcane waste byproducts through treatment with microrganisms and subsequent vermicomposting. Bioresour. Technol. 101, 6707–6711.
Kumar, V., Singh, K.P., 2001. Enriching vermicompost by nitrogen fixing and phosphate solubilizing bacteria. Bioresour. Technol. 76, 173–175.
Kuwada, K., Kuramoto, M., Utamura, M., Matsushita, I., Ishii, T., 2006. Isolation and structural elucidation of a growth stimulant for arbuscular mycorrhizal fungus from *Laminaria japonica* Areschoug. J. Appl. Phycol. 18, 795–800.
Lakhdar, A., Rabhia, M., Ghnayaa, T., Montemurroc, F., Jedidi, N., Abdellya, C., 2009. Effectiveness of compost use in salt-affected soil. J. Hazard Mater. 171, 29–37.
Lakshmi, P.M., Nagalakshmi, N., Shanmuga, P.M., 2015. Analysis of nutrient contents in vermicompost. Eur. J. Mol. Biol. Biochem. 2, 42–48.
Larney, F.J., Hao, X., 2007. A review of composting as a management alternative for beef cattle feedlot manure in southern Alberta, Canada. Bioresour. Technol. 98, 3221–3227.
Lavelle, P., Decaens, T., Aubert, M., Barot, S., Blouin, M., Bureau, F., 2006. Soil invertebrates and ecosystem services. Eur. J. Soil Biol. 42, 3–15.
Lazcano, C., Gomez-Brandon, M., Dominguez, J., 2008. Comparison of the effectiveness of composting and vermicomposting for the biological stabilization of cattle manure. Chemosphere 72, 1013–1019.
Le Bayon, R.C., Binet, F., 2006. Earthworms change the distribution and availability of phosphorous in organic substrates. Soil Biol. Biochem. 38, 235–246.
Lee, J., Rahman, M., Ra, C., 2009. Dose effects of Mg and PO4 sources on the composting of swine manure. J. Hazard Mater. 169, 801–807.
Li, R., Wang, J.J., Zhang, Z., Shen, F., Zhang, G., Qin, R., Li, X., Xiao, R., 2012. Nutrient transformations during composting of pig manure with bentonite. Bioresour. Technol. 121, 362–368.
Li, Z., Lu, H., Ren, L., He, L., 2013. Experimental and modeling approaches for food waste composting: a review. Chemosphere 93, 1247–1257.
Liang, Y., Leonard, J.J., Feddes, J.J.R., McGill, W.B., 2006. Influence of carbon and buffer amendment on ammonia volatilization in composting. Bioresour. Technol. 97, 748–761.
Lim, S.L., Wu, T.Y., 2016. Characterization of matured vermicompost derived from valorization of palm oil mill by product. J. Agric. Food Chem. 64, 1761–1769.
Lim, S.L., Wu, T.Y., Sim, E.Y.S., Lim, P.N., Clarke, C., 2012. Biotransformation of rice husk into organic fertilizer through vermicomposting. Ecol. Eng. 41, 60–64.
Lou, X.F., Nair, J., 2009. The impact of landfilling and composting on greenhouse gas emissions – a review. Bioresour. Technol. 100, 3792–3798.
Mahaly, M., Senthilkumar, A.K., Arumugam, S., Kaliyaperumal, C., Karupannan, N., 2018. Vermicomposting of distillery sludge waste with tea leaf residues. Sustain. Environ. Res. 28, 223–227.
Malinska, K., Golanska, M., Caceres, R., Rorat, A., Weisser, P., Slezak, E., 2017. Biochar amendment for integrated composting and vermicomposting of sewage sludge – the effect of biochar on the activity of *Eisenia fetida* and the obtained vermicompost. Bioresour. Technol. 225, 206–214.
Malinska, K., Zabochnicka Swiateka, M., Caceresb, R., Marfa, O., 2016. The effect of precomposted sewage sludge mixture amended with biochar on the growth and reproduction of *Eisenia fetida* during laboratory vermicomposting. Ecol. Eng. 90, 35–41.
Manna, M.C., Jha, S., Ghosh, P.K., Acharya, C.L., 2003. Comparative efficacy of three epigeic earthworms under different deciduous forest litters decomposition. Bioresour. Technol. 88, 197–206.
Mari, I., Ehaliotis, C., Kotsou, M., Chatzipavlidis, I., Georgakakis, D., 2005. Use of sulfur to control pH in composts derived from olive processing by-products. Compost Sci. Util. 13, 281–287.
McLaughlin, M.R., Brooks, J.P., Adeli, A., Miles, D.M., 2015. Using broiler litter and swine manure lagoon effluent in sawdust-based swine mortality composts: effects on nutrients, bacteria, and gaseous emissions. Sci. Total Environ. 532, 265–280.
Meng, L.Q., Li, W.G., Zhang, S.M., Wu, C.D., Lv, L.Y., 2017. Feasibility of cocomposting of sewage sludge, spent mushroom substrate and wheat straw. Bioresour. Technol. 226, 39–45.
Montejo, C., Costa, C., Marquez, M.C., 2015. Influence of input material and operational performance on the physical and chemical properties of MSW compost. J. Environ. Manag. 162, 240–249.
Mupambwa, H.A., Mnkeni, P.N.S., 2018. Optimizing the vermicomposting of organic waste materials for production of nutrient rich organic fertilizers: a review. Environ. Sci. Pollut. Res. 25, 10577–10595.
Mupambwa, H.A., Ravindran, B., Mnkeni, P.N.S., 2016. Potential of effective microorganisms and *Eisenia fetida* in enhancing vermi-degradation and nutrient release of fly ash incorporated into cow dung-paper waste mixture. Waste Manag. 48, 165–173.
Nair, J., Sekiozoic, V., Anda, M., 2006. Effect of pre-composting on vermicomposting of kitchen waste. Bioresour. Technol. 97, 2091–2095.
Ndegwa, P.M., Thompson, S.A., 2000. Effect of C-to-N ratio on vermicomposting of Biosolids. Bioresour. Technol. 75, 7–12.
Ndegwa, P.M., Thompson, S.A., 2001. Integrating composting and vermicomposting in the treatment and bioconversion of biosolids. Bioresour. Technol. 76, 107–112.
Negi, R., Suthar, S., 2013. Vermistabilization of paper mill wastewater sludge using *Eisenia fetida*. Bioresour. Technol. 128, 193–198.
Negi, R., Suthar, S., 2018. Degradation of paper mill wastewater sludge and cow dung by brown-rot fungi *Oligoporus placenta* and earthworm (*Eisenia fetida*) during vermicomposting. J. Clean. Prod. 201, 842–852.
Niwagaba, C., Nalubega, M., Vinneråas, B., Sundberg, C., Jonsson, H., 2009. Benchscale composting of source-separated human faeces for sanitation. Waste Manag. 29, 585–589.
Orozco, F.H., Cegarra, J., Trujillo, L.M., Roig, A., 1996. Vermicomposting of coffee pulp using the earthworm *Eisenia foetida*: effects on C and N contents and the availability of nutrients. Biol. Fertil. Soils 22, 162–166.
Oyedele, D.J., Schjonning, P., Amusan, A.A., 2006. Physicochemical properties of earthworm casts and uningested parental soil from selected sites in southwestern Nigeria. Ecol. Eng. 28, 106–113.
Padmavathiamma, P.K., Li, L.Y., Kumari, U.R., 2008. An experimental study of vermibiowaste composting for agricultural soil improvement. Bioresour. Technol. 99, 1672–1681.
Parkinson, R., Gibbs, P., Burchett, S., Misselbrook, T., 2004. Effect of turning regime and seasonal weather conditions on nitrogen and phosphorus losses during aerobic composting of cattle manure. Bioresour. Technol. 91, 171–178.
Patel, D.K., Murawala, P., Archana, G., Kumar, G.N., 2011. Repression of mineral phosphate solubilizing phenotype in the presence of weak organic acids in plant growth promoting fluorescent pseudomonads. Bioresour. Technol. 102, 3055–3061.
Patil, S.S., Kasture, M.C., Dhopavkar, R.V., 2018. Micro-nutrient enriched vermicompost by coconut coir waste. Int. J. Curr. Microbiol. Appl. Sci. 7, 2352–2361.
Pattnaik, S., Reddy, M.V., 2010. Nutrient status of vermicompost of urban green waste processed by three earthworm species – *Eisenia fetida*, *Eudrilus eugeniae*, and *Perionyx excavatus*. Appl. Environ. Soil Sci. 2010, 1–13.
Paul, S., Das, S., Raul, P., Bhattacharya, S.S., 2018. Vermi-sanitization of toxic silk industry waste employing *Eisenia fetida* and *Eudrilus eugeniae*: substrate compatibility, nutrient enrichment and metal accumulation dynamics.

Bioresour. Technol. 266, 267–274.
Pelegrin, M., Saez-Tovar, J.A., Andreu-Rodriguez, J., Perez-Murcia, M.D., Martinez-Sabater, E., Marhuenda-Egea, F.C., Perez-Espinosa, A., Bustamanate, M.A., Agullo, E., Vico, A., Paredes, C., Moral, R., 2018. Composting of the invasive species *Arundo donax* with sewage and agri-food sludge: agronomic, economic and environmental aspects. Waste Manag. 78, 730–740.
Pigatin, L.B.F., Atoloye, I.O., Obikoya, O.A., Borsato, A.V., Rezende, M.O.O., 2016. Chemical study of vermicomposted agro industrial wastes. Int. J. Recycl. Org. Waste Agric. 5, 55–63.
Plaza, C., Nogales, R., Senesi, N., Benitez, E., Polo, A., 2008. Organic matter humification by vermicomposting of cattle manure alone and mixed with two-phase olive pomace. Bioresour. Technol. 99, 5085–5089.
Prakash, M., Karmegam, N., 2010. Vermistabilization of press mud using *Perionyx ceylanensis* Mich. Bioresour. Technol. 101, 8464–8468.
Pramanik, P., 2010a. Changes in microbial properties and nutrient dynamics in bagasse and coir during vermicomposting: quantification of fungal biomass through ergosterol estimation in vermicompost. Waste Manag. 30, 787–791.
Pramanik, P., 2010b. Changes in enzymatic activities and microbial properties in vermicompost of water hyacinth as affected by precomposting and fungal inoculation: a comparative study of ergosterol and chitin for estimating fungal biomass. Waste Manag. 30, 1472–1476.
Pramanik, P., 2012. Effect of composting and vermicomposting on recycling of three aquatic weeds treated with rock phosphate on P-dynamics, phosphatase activity and biomass P. In: Dynamic Soil Dynamic Plant. Global Science Books, pp. 51–56.
Pramanik, P., Chung, Y.R., 2011. Changes in fungal population of fly ash and vinasse mixture during vermicomposting by (*Eudrilus eugeniae*) and (*Eisenia fetida*): documentation of cellulase isozymes in vermicompost. Waste Manag. 31, 1169–1175.
Pramanik, P., Ghosh, G., Banik, P., 2009. Effect of microbial inoculation during vermicomposting of different organic substrates on microbial status and quantification and documentation of acid phosphatase. Waste Manag. 29, 574–578.
Pramanik, P., Ghosh, G.K., Ghosal, P.K., Banik, P., 2007. Changes in organic-C, N, P and K and enzyme activities in vermicomposts of biodegradable organic wastes under liming and microbial inoculants. Bioresour. Technol. 98, 2485–2494.
Pramanik, P., Safique, S., Jahan, A., Bahagat, R.M., 2016. Effect of vermicomposting on treated hard stem leftover wastes from pruning of tea plantation: a novel approach. Ecol. Eng. 97, 410–415.
Qadir, M., Oster, J.D., 2004. Crop and irrigation management strategies for saline-sodic soils and waters aimed at environmentally sustainable agriculture. Sci. Total Environ. 323, 1–19.
Ravindran, B., Dinesh, S.L., Kennedy, L.J., Sekaran, G., 2008. Vermicomposting of solid waste generated from leather industries using epigeic earthworm *Eisenia foetida*. Appl. Biochem. Biotechnol. 151, 480–488.
Sahariah, B., Sinha, I., Sharma, P., Goswami, L., Bhattacharyya, P., Gogoi, N., Bhattacharya, S.S., 2014. Efficacy of bioconversion of paper mill bamboo sludge and lime waste by composting and vermiconversion technologies. Chemosphere 109, 77–83.
Sánchez, O.J., Ospina, D.A., Montoya, S., 2017. Compost supplementation with nutrients and microorganisms in composting process. Waste Manag. 69, 136–153.
Sánchez-García, M., Alburquerque, J.A., Sánchez-Monedero, M.A., Roig, A., Cayuela, M.L., 2015. Biochar accelerates organic matter degradation and enhances N mineralisation during composting of poultry manure without a relevant impact on gas emissions. Bioresour. Technol. 192, 272–279.
Sangwan, P., Kaushik, C.P., Garg, V.K., 2008. Vermiconversion of industrial sludge for recycling the nutrients. Bioresour. Technol. 99, 8699–8704.
Sangwan, P., Kaushik, C.P., Garg, V.K., 2010. Vermicomposting of sugar industry waste (press mud) mixed with cow dung employing an epigeic earthworm *Eisenia fetida*. Waste Manag. Res. 28, 71–75.
Schulz, H., Glaser, B., 2012. Effects of biochar compared to organic and inorganic fertilizers on soil quality and plant growth in a greenhouse experiment. J. Plant Nutr. Soil Sci. 175, 410–422.
Selladurai, G., Anbusaravanan, N., Shyam, K.P., Palanivel, K., Kadalmani, B., 2010. Recycling of distillery sludge from sugarcane industry using bioresource technology. J. Appl. Sci. Res. 6, 218–223.
Shammas, N.K., Wang, L.K., 2009. Biosolids composting. In: Wang, L.K., Pereira, N.C., Hung, Y.T., Shammas, N.K. (Eds.), Biological Treatment Processes. Humana Press Inc, Totowa, NJ, USA, pp. 669–713.
Shan, G., Xu, J., Jiang, Z., Li, M., Li, Q., 2019. The transformation of different dissolved organic matter subfractions and distribution of heavy metals during food waste and sugarcane leaves co-composting. Waste Manag. 87, 636–644.
Sharma, K., Garg, V.K., 2018. Comparative analysis of vermicompost quality produced from rice straw and paper waste employing earthworm *Eisenia fetida* (Sav.) Bioresour. Technol. 250, 708–715.
Shilev, S., Naydenov, M., Vancheva, V., Aladjadjiyan, A., 2007. Composting of food and agricultural wastes. In: Oreopoulou, V., Russ, W. (Eds.), Utilization of By-Products and Treatment of Wastes in the Food Industry. Springer, pp. 283–301.
Sindhu, R., Binod, P., Pandey, A., Madhavan, A., Alphonsa, J.A., Vivek, N., Gnansounou, E., Castro, E., Faraco, V., 2017. Water hyacinth a potential source for value addition: an overview. Bioresour. Technol. 230, 152–162.
Singh, A., Sharma, S., 2002. Composting of a crop residue through treatment with microorganisms and subsequent vermicomposting. Bioresour. Technol. 85, 107–111.
Singh, J., Kaur, A., Vig, A.P., Rup, P.J., 2010. Role of *Eisenia fetida* in rapid recycling of nutrients from bio sludge of beverage industry. Ecotoxicol. Environ. Saf. 73, 430–435.
Singh, R., Sharma, R.R., Kumar, S., Gupta, R.K., Patil, R.T., 2008. Vermicompost substitution influences growth, physiological disorders, fruit yield and quality of strawberry (*Fragaria ananassa* Duch.). Bioresour. Technol. 99, 8507–8511.
Singh, W.R., Kalamdhad, A.S., 2016. Transformation of nutrients and heavy metals during vermicomposting of the invasive green weed *Salvinia natans* using *Eisenia fetida*. Int. J. Recycl. Org. Waste Agric. 5, 205–220.
Sinha, R.K., Agarwal, S., Chauhan, K., Chandran, V., Soni, B.K., 2010. Vermiculture technology: reviving the dreams of Sir Charles Darwin for scientific use of earthworms in sustainable development programs. Technol. Invest. 3, 155–172.
Slater, R.A., Frederickson, J., 2001. Composting municipal waste in the UK: some lesions from Europe. Resour. Conserv. Recycl. 32, 359–374.
Sommer, S.G., 2001. Effect of composting on nutrient loss and nitrogen availability of cattle deep litter. Eur. J. Agron. 14, 123–133.
Song, X., Liu, M., Wu, D., Qi, L., Ye, C., Jiao, J., Hu, F., 2014. Heavy metal and nutrient changes during vermicomposting animal manure spiked with mushroom residues. Waste Manag. 34, 1977–1983.
Soobhany, N., 2018a. Remediation potential of metalliferous soil by using extracts of composts and vermicomposts from Municipal Solid Waste. Process Saf. Environ. Prot. 118, 285–295.
Soobhany, N., 2018b. Preliminary evaluation of pathogenic bacteria loading on organic Municipal Solid Waste compost and vermicompost. J. Environ. Manag. 206, 763–767.
Soobhany, N., 2018c. Assessing the physicochemical properties and quality parameters during composting of different organic constituents of Municipal Solid Waste. J. Environ. Chem. Eng. 6, 1979–1988.
Soobhany, N., Gunasee, S., Rago, Y.P., Joyram, H., Raghoo, P., Mohee, R., Garg, V.K., 2017b. Spectroscopic, thermogravimetric and structural characterization analyses for comparing Municipal Solid Waste composts and vermicomposts stability and maturity. Bioresour. Technol. 236, 11–19.
Soobhany, N., Mohee, R., 2014. Comparison of heavy metals content in compost against vermicompost of organic solid waste: past and present. Resour. Conserv. Recycl. 92, 206–213.
Soobhany, N., Mohee, R., Garg, V.K., 2015a. Recovery of nutrient from Municipal Solid Waste by composting and vermicomposting using earthworm *Eudrilus eugeniae*. J. Environ. Chem. Eng. 3, 2931–2942.
Soobhany, N., Mohee, R., Garg, V.K., 2015b. Comparative assessment of heavy metals content during the composting and vermicomposting of Municipal Solid Waste employing *Eudrilus eugeniae*. Waste Manag. 39, 130–145.
Soobhany, N., Mohee, R., Garg, V.K., 2015c. Experimental process monitoring and potential of *Eudrilus eugeniae* in the vermicomposting of Municipal Solid Waste in Mauritius. Ecol. Eng. 84, 149–158.
Soobhany, N., Mohee, R., Garg, V.K., 2017a. Inactivation of bacterial pathogenic load in compost against vermicompost of organic solid waste aiming to achieve sanitation goals: a review. Waste Manag. 64, 51–62.
Soobhany, N., Mohee, R., Garg, V.K., 2017c. A comparative analysis of composts and vermicomposts derived from municipal solid waste for the growth and yield of green bean (*Phaseolus vulgaris*). Environ. Sci. Pollut. Res. 24, 11228–11239.
Soobhany, N., Mohee, R., Somaroo, G.D., 2014. Process parameters analysis for the vermicomposting of shredded paper using *Pheretimoid Spp*. Int. J. Environ. Waste Manag. 14, 99–116.
Storino, F., Arizmendiarrieta, J.S., Irigoyen, I., Muro, J., Aparicio-Tejo, P.M., 2016. Meat waste as feedstock for home composting: effects on the process and quality of compost. Waste Manag. 56, 53–62.
Subramanian, S., Sivarajan, M., Saravanapriya, S., 2010. Chemical changes during vermicomposting of sago industry solid wastes. J. Hazard Mater. 179, 318–322.
Sudkolai, S.T., Nourbakhsh, F., 2017. Urease activity as an index for assessing the maturity of cow manure and wheat residue vermicomposts. Waste Manag. 64, 63–66.
Sun, X., Ma, S., Han, L., Li, R., Schlick, U., Chen, P., Huang, G., 2018. The effect of a semi-permeable membrane-covered composting system on greenhouse gas and ammonia emissions in the Tibetan Plateau. J. Clean. Prod. 204, 778–787.
Suthar, S., 2006. Potential utilization of guargum industrial waste in vermicompost production. Bioresour. Technol. 97, 2474–2477.
Suthar, S., 2007. Nutrient changes and biodynamics of epigeic earthworm *Perionyx excavatus* (Perrier) during recycling of some agriculture wastes. Bioresour. Technol. 98, 1608–1614.
Suthar, S., 2008a. Bioconversion of post harvest crop residues and cattle shed manure into value-added products using earthworms *Eudrilus eugeniae* Kinberg. Ecol. Eng. 32, 206–214.
Suthar, S., 2008b. Microbial and decomposition efficiencies of monoculture and polyculture vermireactors based on epigeic and anecic earthworms. World J. Microbiol. Biotechnol. 24, 1471–1479.
Suthar, S., 2008c. Development of a novel epigeic–anecic-based polyculture vermireactor for efficient treatment of municipal sewage water sludge. Int. J. Environ. Waste Manag. 2, 84–101.
Suthar, S., 2008d. Bioremediation of aerobically treated distillery sludge mixed with cow dung by using an epigeic earthworm *Eisenia fetida*. Environmentalist 28, 76–84.
Suthar, S., 2009a. Vermicomposting of vegetable-market solid waste using *Eisenia fetida*, impact of bulking material on earthworm growth and decomposition rate. Ecol. Eng. 35, 914–920.
Suthar, S., 2009b. Bioremediation of agricultural wastes through vermicomposting. Ann. Finance 13, 21–28.
Suthar, S., 2009c. Vermistabilization of municipal sewage sludge amended with

sugarcane trash using epigeic *Eisenia fetida* (Oligochaeta). J. Hazard Mater. 163, 199–206.
Suthar, S., 2010a. Recycling of agro-industrial sludge through vermitechnology. Ecol. Eng. 36, 1028–1036.
Suthar, S., 2010b. Pilot-scale vermireactors for sewage sludge stabilization and metal remediation process: comparison with small-scale vermireactors. Ecol. Eng. 36, 703–712.
Suthar, S., Gairola, S., 2014. Nutrient recovery from urban forest leaf litter waste solids using *Eisenia fetida*. Ecol. Eng. 71, 660–666.
Suthar, S., Kumar, K., Mutiyar, P.K., 2015. Nutrient recovery from compostable fractions of municipal solid wastes using vermitechnology. J. Mater. Cycles Waste Manag. 17, 174–184.
Suthar, S., Mutiyar, P.K., Singh, S., 2012. Vermicomposting of milk processing industry sludge spiked with plant wastes. Bioresour. Technol. 116, 214–219.
Suthar, S., Pandey, B., Gusain, R., Gaur, R.Z., Kumar, K., 2017. Nutrient changes and biodynamics of *Eisenia fetida* during vermicomposting of water lettuce (*Pistia* sp.) biomass: a noxious weed of aquatic system. Environ. Sci. Pollut. Res. 24, 199–207.
Suthar, S., Singh, S., 2008a. Feasibility of vermicomposting in biostabilization of sludge from a distillery industry. Sci. Total Environ. 394, 237–243.
Suthar, S., Singh, S., 2008b. Comparison of some novel polyculture and traditional monoculture vermicomposting reactors to decompose organic wastes. Ecol. Eng. 33, 210–219.
Swarnam, T.P., Velmurugan, A., Pandey, S.K., Dam Roy, S., 2016. Enhancing nutrient recovery and compost maturity of coconut husk by vermicomposting technology. Bioresour. Technol. 207, 76–84.
Taylor, M., Clarke, W.P., Greenfield, P.F., 2003. The treatment of domestic wastewater using small-scale vermicompost filter beds. Ecol. Eng. 21, 197–203.
The World Bank, 2019. Solid waste management [Online]. https://www.worldbank.org/en/topic/urbandevelopment/brief/solid-waste-management (accessed 24.08.19).
Tiquia, S.M., Richard, T.L., Honeyman, M.S., 2002. Carbon, nutrient, and mass loss during composting. Nutrient Cycl. Agroecosyst. 62, 15–24.
Tiquia, S.M., Tam, N.F.Y., 2000. Fate of nitrogen during composting of chicken litter. Environ. Pollut. 110, 535–541.
TMECC, 2002. Test Methods for the Examination of Composting and Compost. US Composting Council, Bethesda, MD.
Tognetti, C., Mazzarino, M.J., Laos, F., 2007. Co-composting biosolids and municipal organic waste: effects of process management on stabilization and quality. Biol. Fertil. Soils 43, 387–397.
Tripathi, G., Bhardwaj, P., 2004a. Decomposition of kitchen waste amended with cow manure using epigeic species (*Eisenia fetida*) and an anecic species (*Lampito mauritii*). Bioresour. Technol. 92, 215–218.
Tripathi, G., Bhardwaj, P., 2004b. Comparative studies on biomass production, life cycles and composting efficiency of *Eisenia foetida* (Savigny) and *Lampito mauritii* (Kinberg). Bioresour. Technol. 92, 275–278.
Unuofin, F.O., Mnkeni, P.N.S., 2014. Optimization of *Eisenia fetida* stocking density for the bioconversion of rock phosphate enriched cow dung–waste paper mixtures. Waste Manag. 34, 2000–2006.
Varma, V.S., Kalamdhad, A.S., Khwairkpam, M., 2016. Feasibility of *Eudrilus eugeniae* and *Perionyx excavatus* in vermicomposting of water hyacinth. Ecol. Eng. 94, 127–135.
Vazquez, M.A., Soto, M., 2017. The efficiency of home composting programmes and compost quality. Waste Manag. 64, 39–50.
Venkatesh, R.M., Eevera, T., 2008. Mass reduction and recovery of nutrients through vermicomposting of fly ash. Appl. Ecol. Environ. Res. 6, 77–84.
Vermicompost Market, 2019. Global industry share, size, revenue, latest trends, business boosting strategies, CAGR status, growth opportunities and forecast 2024 - 360 research report [Online]. https://www.marketwatch.com/press-release/vermicompost-market-2019-global-industry-share-size-revenue-latest-trends-business-boosting-strategies-cagr-status-growth-opportunities-and-forecast-2024–360-research-report-2019-06-05 (accessed 14.08.19).
Vig, A.P., Singh, J., Wani, S.H., Dhaliwal, S.S., 2011. Vermicomposting of tannery sludge mixed with cattle dung into valuable manure using earthworm *Eisenia fetida* (Savigny). Bioresour. Technol. 102, 7941–7945.
Vinotha, S.P., Parthasarthim, K., Rangnathanm, L.S., 2000. Enhanced phosphatase activity in earthworm casts is more of microbial origin. Curr. Sci. 79, 1158–1159.
Wang, C., Lu, H., Dong, D., Deng, H., Strong, P.J., Wang, H., Wu, W., 2013. Insight into the effects of biochar on manure composting: evidence supporting the relationship between N_2O emission and denitrifying community. Environ. Sci. Technol. 47, 7341–7349.
Wang, Q., Wang, Z., Awasthi, M.K., Jiang, Y., Li, R., Ren, X., Zhao, J., Shen, F., Wang, M., Zhang, Z., 2016a. Evaluation of medical stone amendment for the reduction of nitrogen loss and bioavailability of heavy metals during pig manure composting. Bioresour. Technol. 220, 297–304.
Wang, X., Selvam, A., Chan, M., Wong, J.W.C., 2013. Nitrogen conservation and acidity control during food wastes composting through struvite formation. Bioresour. Technol. 147, 17–22.
Wang, X., Selvam, A., Wong, J.W.C., 2016b. Influence of lime on struvite formation and nitrogen conservation during food waste composting. Bioresour. Technol. 217, 227–232.
Wang, X., Zhao, Y., Wang, H., Zhao, X., Cui, H., Wei, Z., 2017. Reducing nitrogen loss and phytotoxicity during beer vinasse composting with biochar addition. Waste Manag. 61, 150–156.
Wani, K.A., Mamta Rao, R.J., 2013. Bioconversion of garden waste, kitchen waste and cow dung into value-added products using earthworm *Eisenia fetida*. Saudi J. Biol. Sci. 20, 149–154.
Wei, Y., Zhao, Y., Xi, B., Wei, Z., Li, X., Cao, Z., 2015. Changes in phosphorus fractions during organic wastes composting from different sources. Bioresour. Technol. 189, 349–356.
Xie, K., Jia, X., Xu, P., Huang, X., Gu, W., Zhang, F., Yang, S., Tang, S., 2012. Improved composting of poultry feces via supplementation with ammonia oxidizing archaea. Bioresour. Technol. 120, 70–77.
Yadav, A., Garg, V.K., 2009. Feasibility of nutrient recovery from industrial sludge by vermicomposting technology. J. Hazard Mater. 168, 262–268.
Yadav, A., Garg, V.K., 2011a. Vermicomposting - an effective tool for the management of invasive weed *Parthenium hysterophorus*. Bioresour. Technol. 102, 5891–5895.
Yadav, A., Garg, V.K., 2011b. Recycling of organic wastes by employing *Eisenia fetida*. Bioresour. Technol. 102, 2874–2880.
Yadav, A., Garg, V.K., 2013. Nutrient recycling from industrial solid wastes and weeds by vermiprocessing using earthworms. Pedosphere 23, 668–677.
Yadav, A., Suthar, S., Garg, V.K., 2015. Dynamics of microbiological parameters, enzymatic activities and worm biomass production during vermicomposting of effluent treatment plant sludge of bakery industry. Environ. Sci. Pollut. Res. 22, 14702–14709.
Yadav, A., Suthar, S., Garg, V.K., 2019. Biotransformation of bakery industry sludge into valuable product using vermicomposting. Bioresour. Technol. 274, 512–517.
Yadav, K.D., Tare, V., Ahammed, M.M., 2010. Vermicomposting of source-separated human faeces for nutrient recycling. Waste Manag. 30, 50–56.
Yang, F., Li, G., Shi, H., Wang, Y., 2015. Effects of phosphogypsum and superphosphate on compost maturity and gaseous emissions during kitchen waste composting. Waste Manag. 36, 70–76.
Zhang, J., Chen, G., Sun, H., Zhou, S., Zou, G., 2016a. Straw biochar hastens organic matter degradation and produces nutrient-rich compost. Bioresour. Technol. 200, 876–883.
Zhang, L., Sun, X., 2017. Addition of seaweed and bentonite accelerates the two-stage composting of green waste. Bioresour. Technol. 243, 154–162.
Zhang, L., Sun, X., 2018. Evaluation of maifanite and silage as amendments for green waste composting. Waste Manag. 77, 435–446.
Zhang, L., Sun, X.Y., 2014. Changes in physical, chemical, and microbiological properties during the two-stage co-composting of green waste with spent mushroom compost and biochar. Bioresour. Technol. 171, 274–284.
Zhang, L., Sun, X.Y., 2016. Improving green waste composting by addition of sugarcane bagasse and exhausted grape marc. Bioresour. Technol. 218, 335–343.
Zhang, Y., Zhao, Y., Chen, Y., Lu, Q., Li, M., Wang, X., Wei, Y., Xie, X., Wei, Z., 2016b. A regulating method for reducing nitrogen loss based on enriched ammonia oxidizing bacteria during composting. Bioresour. Technol. 221, 276–283.
Zhu, N., 2007. Effect of low initial C/N ratio on aerobic composting of swine manure with rice straw. Bioresour. Technol. 98, 9–13.