Pakistan J. Zool., vol. 51(3), pp 1027-1034, 2019. DOI: http://dx.doi.org/10.17582/journal.pjz/2019.51.3.1027.1034

Vermicomposting by *Eisenia fetida* is a Sustainable and Eco-Friendly Technology for Better Nutrient Recovery and Organic Waste Management in Upland Areas of China

Syed Turab Raza[1,*], Zhu Bo[1,*], Zulfiqar Ali[2] and Tang Jia Liang[3]

[1]*Lab of Soil and Environmental Science, Yanting Agro-Ecological Experiment Station, Chinese Ecosystem Research Center, China*

[2]*Laboratory of Environmental Health and Wildlife, Department of Zoology, University of the Punjab, Lahore, 54590, Pakistan*

[3]*Institute of Mountain Hazards and Environment, Chinese Academy of Sciences, China*

Article Information
Received 19 November 2018
Revised 22 February 2019
Accepted 21 March 2019
Available online 05 April 2019

Authors' Contribution
STR and ZB conducted the experiment. ZA and STR prepared the manuscript. TJ helped in preparation of manuscript.

Key words
Vermicomposting, *Eisenia fetida*, Wheat straw, Biochar, Rapeseed residues.

ABSTRACT

Management and recycling of organic waste materials such as agricultural crops (wheat straw, rapeseed) and animal manure (pig manure, cow dung) is becoming an important issue in rapidly growing population. Vermicomposting by earthworms (*Eisenia fetida*) is useful technique to recover nutrients of plants such as NPK (nitrogen, phosphorus, calcium). A vermicomposting system using the earthworm species (*Eisenia fetida*) and treating it with cattle dung, pig manure and biochar with crop (wheat straw and rapeseed) waste was established in upland areas of China. It was monitored for two months. Four treatments (T1 to T4) were prepared using crop residues *i.e.* wheat straw, rapeseed and cow manure in different concentrations. Vermicomposting through biochar (Biochar 50%, rapeseed residues 20% and Biochar with earthworms) gave maximum increase in soil fertility with maximum decrease (39.63%) in C:N ratio. Significant increase of N content in nutrients and reduction in C: N ratios during this process shows conversion of harmful wastes into useful fertilizer.

INTRODUCTION

Different anthropogenic activities have contaminated the soil with heavy metals in different areas, which resulted in potential risk to environment and human health (Zheng *et al*., 2013). Wide variety of organic wastes comprising animal manure, industrial refuse, sewage sludge and crop residues are extensively used to form vermicompost through earthworms (Roberts *et al*., 2007; Pascal *et al*., 2010). Globally, organic waste materials like crop residues and cattle manure are used as cheap organic fertilizers, as they are rich in micro and macro nutrients, for improvement in plant growth, soil fertility and crop production. Because of hazardous gas emissions, their direct disposal is a problem, as it is causing health risks and environmental conditions (Lazcano *et al*., 2008). Different treatments (vermicompost, composting through pig manure, cow manure and biochar) have been proposed to increase soil nutrients through recycling of such materials. Earthworms (*Easenia fetida*) increase the decay of waste materials because of their enzymatic activity that helps in plant growth and increase in soil fertility (Bhattacharya *et al*., 2012). In this process, earthworms convert organic waste into humus like substance that is also produced as byproduct of biomass of worm (Lalander *et al*., 2015). In recent times, the trend of using vermicompost is increasing in Northern Vietnam and other areas to regain the fertility and increase plant growth in the soil which is degraded due to erosion (Jouquet *et al*., 2011; Ngo *et al*., 2011; Doan *et al*., 2013a, b) and to minimize negative impact of organic manure amendment on transfer of microbes and mineral N to water (Jouquet *et al*., 2011; Amossé *et al*., 2013). Rapeseed is one of the important protein crops (Eskandari and Kazemi, 2012) and its agricultural waste is used as a substrate in vermicomposting.

Application of pig manure can be helpful in recycling plant nutrients when used in crop land (Chaudhary *et al*., 1996). Biochar is also used as soil amendment that plays role in better crop production, activation of composting material having environmental and horticultural uses as a mixture with dung to recycle nutrients (Sanchez-Monedero *et al*., 2018). Little information is available

* Corresponding author: bzhu@imde.ac.cn; zali.zool@pu.edu.pk
0030-9923/2019/0003-1027 $ 9.00/0

on production of vermicompost from crop residues. Crop residues are deprived in nitrogen; therefore, organic waste is added to provide nutrients for microorganisms (Elvira *et al*., 1996). Composting with earthworms reduces C:N ratio and causes an increase in nitrogen content for better growth of plants (Gandhi *et al*., 1997; Crescent, 2003; Nagavallemma *et al*., 2004).

The aim of study was to determine the impact of earthworms and their interaction with manure and biochar to increase soil nutrients, hence increasing soil fertility.

MATERIALS AND METHODS

Site description

The study was conducted at Agro-ecological Experimental Station of Purple Soil, Yanting, Chinese Academy of Sciences (CAS) located at 31°16'N, 105°28'E, at altitude of 600m, in Sichuan Basin, China. Climatic condition of the area is subtropical monsoon with an annual temperature of 17.3°C and 826mm precipitation.

Collection of materials for vermicomposting

Agricultural crop residues (wheat straw and rapeseed) were collected from the field of Yanting agro ecological station of CAS, Sichuan Basin. China. Biochar was obtained from Henan Company. Clittelated and un-clitelatted earthworms (*Eisenia fetida*) were bought from the market as employing agent in transforming the organic waste products into useful nutrient rich fertilizer.

Experimental design

For current research four treatments were used to assess the difference in nutrient level after vermicomposting. Four treatments (T1 to T4) were prepared using crop residues *i.e.* wheat straw, rapeseed and cow manure in different concentrations (T1, wheat straw 50%: rapeseed residues 20%: cow manure 30% with no earthworms as control; T2, wheat straw 50%: rapeseed residues 20%: cow manure 30% with earthworms; T3, wheat straw 50%: rapeseed residues 20%: pig manure 30% with earthworms; T4, Biochar 50%: Rapeseed residues 20%: Biochar (biochar) 30% with earthworms). All the treatments were used in triplicates *i.e.* compost with cow manure (COM), vermicompost with cow manure (VCM), vermicompost with pig manure (VPM), vermicompost with biochar (VBC).

The mixture of 7:3 ratio of crop residues and manure (cow and pig) was used in plastic circular drums (60cm diameter and 50cm height) placed under shade to avoid direct sunlight and rain to keep the environment favorable. Biochar was also used instead of manure in one treatment. The total 10kg of organic waste consisting of wheat straw, rapeseed and manure were mixed in drums covered by net for well aeration. After 15 days, 100 earthworms (*Eisenia foetida*) were added in the 4 treatments while one treatment was kept as control. The experiment was carried for two months (twenty days interval), adding water to maintain 60-70% moisture for earthworms as their favorable conditions. For detection of phosphorous (Lu, 1999) wet digestion method was used by spectophotometer For further analysis samples were prepared using 2g of dried material (from each plot), and digested with 10ml diacid (HNO_3:$HClO_4$ with 5:1 ratio). Volume of the digest was made up to 100 ml and filtered through Whatmann No.1 filter paper. Total Carbon and Nitrogen Nutrient concentration was obtained by running samples in Elementar Analysensysteme Gmbh (Germany). Other nutrients (potassium (K), calcium (Ca), magnesium (Mg), manganese (Mn), copper (Cu), iron (Fe), zinc (Zn)) concentration was obtained by using Flame Atomic Spectrophotometer.

Physicochemical properties like pH, EC and total dissolved solids were analyzed with 1:10 aqueous suspension (Mahaly *et al*., 2018).

Statistical analysis

One way analysis of variance (ANOVA) was applied to analyze the difference in nutrient concentration between treatments using SPSS 16.0 software with significance level $p<0.05$. Post-hoc Dunnett test was applied to determine differences among group means.

Table I.- Composition of various treatments used for vermicomposting.

S. No	Treatments (T)	Wheat straw (%)	Rapeseed residues (%)	Cow manure (%)	Biochar (%)	Pig manure (%)	Earthworms
1	T1 (COM)	50	20	30	-	-	-
2	T2 (VCM)	50	20	30	-	-	Present
3	T3 (VPM)	50	20	-	-	30	Present
4	T4 (VBC)	50	20	-	30	-	Present

COM, compost with cow manure; VCM, vermicompost with cow manure; VPM, vermicompost with pig manure; VBC, vermicompost with biochar.

Table II.- Physicochemical properties of treatments various treatments in different time intervals.

Time interval	Treat-ments	pH	EC (micro s/cm)	TDS (mg/l)	Temp. (°C)
First interval	COM	7.22	3.95	2.56	22.5
	VCM	7.2	2.74	1.9	22.3
	VPM	7.04	4.27	2.78	22.3
	VBC	7.03	5.66	3.68	22.4
Second interval	COM	7.19	3.89	2.63	22.3
	VCM	7.15	4.49	2.92	22.4
	VPM	6.87	5.17	3.36	22.4
	VBC	6.92	4.1	2.66	22.3
Third interval	COM	6.94	4.23	2.25	22.4
	VCM	7.1	2.01	2.11	22.4
	VPM	6.8	4.53	2.44	22.4
	VBC	6.77	2.92	2.20	22.4

EC, electrical conductivity; TDS, total dissolved solids. For other abbreviations, see Table I.

RESULTS AND DISCUSSION

The study was conducted to estimate the variance in nutrient content due to the application of different treatments to increase the fertility of soil using crop residues and manure (cow and pig). Difference in nutrient concentration was statistically analyzed. Significant variation was observed in different treatments. Mean, standard deviation and percentage increase or decrease in concentration is given in Tables III and IV, respectively. No significant difference was observed in physicochemical properties of treatments in various intervals (Table II).

The amount of nitrogen increased in all treatments except VPM from its initial concentration (Table III). Nitrogen is an essential building block and its increase is attributed to the mineralization of plant residues that contains aminoacids and conversion of ammonium nitrogen (Pattnaik and Reddy, 2009; Cabrera *et al*., 2005). Joy (2017) and Singh and Wasnik (2013) also reported increase in nitrogen due to vermicomposting. Pig slurry composting was proved as an efficient source for nitrogen by Silva *et al*. (2016). The percentage of organic carbon decreased in all treatments from its initial value (Table IV). Similar results for vermicompost were recorded by Manyuchi *et al*. (2017). Decrease in carbon content can be attributed to the loss of carbon dioxide due to microbial respiration of earthworms (Cabrera *et al*., 2005). Maximum decrease in concentration was observed in VBC. The addition of biochar in soil increased the retention of different nutrients *i.e.* nitrogen and carbon in soil (Barrow, 2012; Borchard *et al*., 2012; Clough and Condron, 2010; Clough *et al*., 2013; Farrell *et al*., 2014).

Overall carbon to nitrogen ratio decreased in all treatments as compared to their initial value (Table III). Therefore, treating agro wastes for achieving high quality product and reduced nitrogen loss, decreased C:N ratio is recommended (Zhou, 2014). Decrease in C:N ratio is beneficial for soil fertility and plant growth. C/N ratio is a precarious factor that limits the earthworm population. It became difficult to extract sufficient nitrogen for tissue production if C/N ratio of feedstock increased (Ashiya, 2017). Wheat straw composts with different concentration revealed that it was only partly degraded after composting for first interval to decrease carbon to nitrogen ratio (Zhang *et al*., 2016). Concentration of potassium increased in COM and VCM (Figs. 1, 2) while decreased in VPM and VBC (Figs. 3, 4) with respect to their initial values (Table IV). Increase in potassium level can be attributed to physical decomposition of organic matter by earthworms that convert insoluble potassium to soluble potassium (Kaviraj and Sharma, 2003). It is suggested that as compared to

Table III.- Concentrations (Mean±SD) of various nutrients in different treatments.

S. No	Treatment / Nutrients	COM Initial	COM Final	VCM Initial	VCM Final	VPM Initial	VPM Final	VBC Initial	VBC Final
1	N (%)	1.51±1.54	2.28±0.17	1.82±0.21	2.32±0.25	2.48±0.10	2.83±0.15[a]	1.21±0.67	1.80±0.07
2	C (%)	37.03±0.11	36.79±0.15	38.17±2.11	35.01±2.35	35.17±2.15	35.01±2.60	46.74±1.06	41.35±1.07
3	C/N	24.51±0.16	16.27±1.18[a]	21.01±1.32	15.18±1.75	14.18±2.21	12.42±2.29[a,b]	38.66±1.02	23.34±1.20[b]
4	TK (ppm)	12.62±0.71	13.16±2.42	10.22±0.41	12.45±1.53	14.89±0.95	13.89±1.84	34.32±1.27	17.17±3.99
5	TP (ppm)	4.13±2.91	3.72±0.49	2.22±0.42	4.00±0.30	2.27±0.25	6.55±0.47	3.03±0.61	2.34±0.50
6	Ca (ppm)	32.02±2.88	22.68±1.91	11.01±0.68	22.24±1.25	42.63±5.33	29.32±3.70	26.87±0.60	23.99±1.24
7	Mg (ppm)	2.56±0.17	3.24±0.27	4.10±0.36	3.40±0.30	9.89±1.09	4.80±0.60	7.41±0.14	4.57±0.49
8	Mn (ppm)	0.20±0.05	0.25±0.02	0.14±0.04	0.31±0.02	0.14±0.07	0.31±0.07	0.05±0.08	0.28±0.07
9	Cu (ppm)	0.02±0.00	0.02±0.00	0.04±0.00	0.02±0.00	0.80±0.05	0.23±0.00	0.03±0.00	0.02±0.00
10	Fe (ppm)	1.91±0.77	1.26±0.38	0.95±0.21	1.52±1.02	3.32±0.25	1.44±0.50	3.64±0.17	2.11±0.33
11	Zn (ppm)	0.01±0.00	0.03±0.00	0.06±0.00	0.03±0.00	0.80±0.03	0.19±0.02	0.04±0.00	0.02±0.00

[a]P <0.05 different from COM group by ANOVA with post-hoc Dunnett test. [b]P <0.05 different from VPM group by ANOVA with post-hoc Dunnett test. For other abbreviations, see Table I.

Table IV.- Percentage increase or decrease in concentration of nutrients in different treatments.

S. No.	Treatment / Nutrients	COM		VCM		VPM		VBC	
		Increase (%)	Decrease (%)	Increase (%)	Decrease (%)	Increase (%)	Decrease (%)	Increase (%)	Decrease (%)
1	N (%)	50.99		27.47		14.11		48.76	
2	C (%)		0.65		8.28		0.45		11.53
3	C/N		33.62		27.75		12.41		39.63
4	TK (ppm)	4.28		21.82			6.72		49.97
5	TP (ppm)		9.93	80.18		188.55			22.77
6	Ca (ppm)		29.17	102.00			31.22		10.72
7	Mg (ppm)	26.56			17.07		51.47		38.33
8	Mn (ppm)	25.00		121.43		121.43		460.00	
9	Cu (ppm)	0.00			50.00		71.25		33.33
10	Fe (ppm)		34.03	60.00			56.63		42.03
11	Zn (ppm)	200.00			50.00		76.25		50.00

For abbreviations, see Table I.

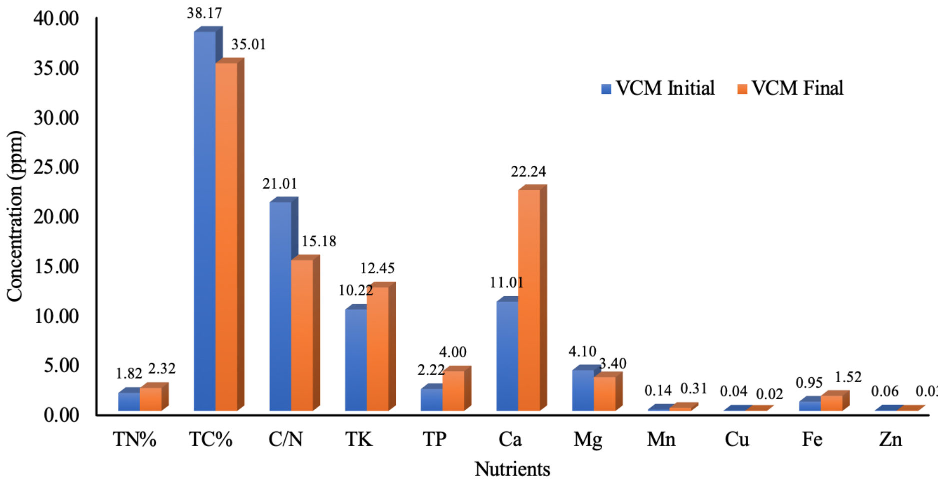

Fig. 1. Variation in concentrations of nutrients in VCM (cow manure) treatment.

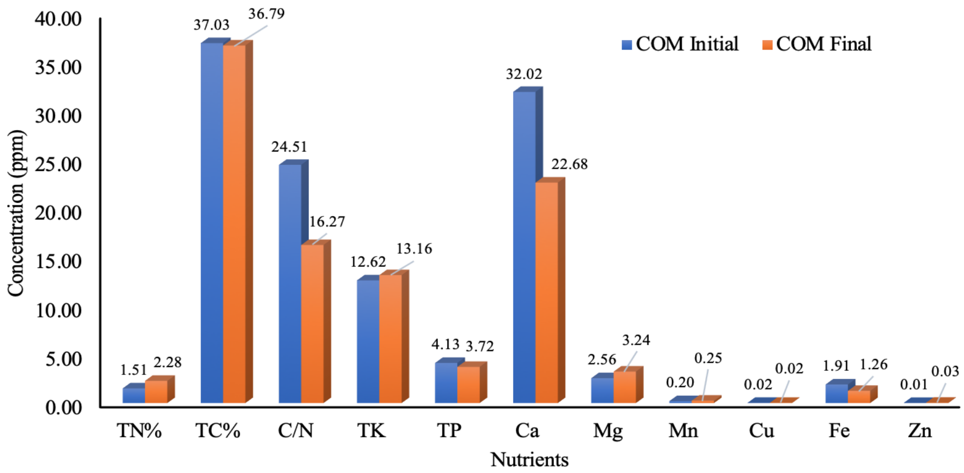

Fig. 2. Variations in concentrations of nutrients due to COM (composting).

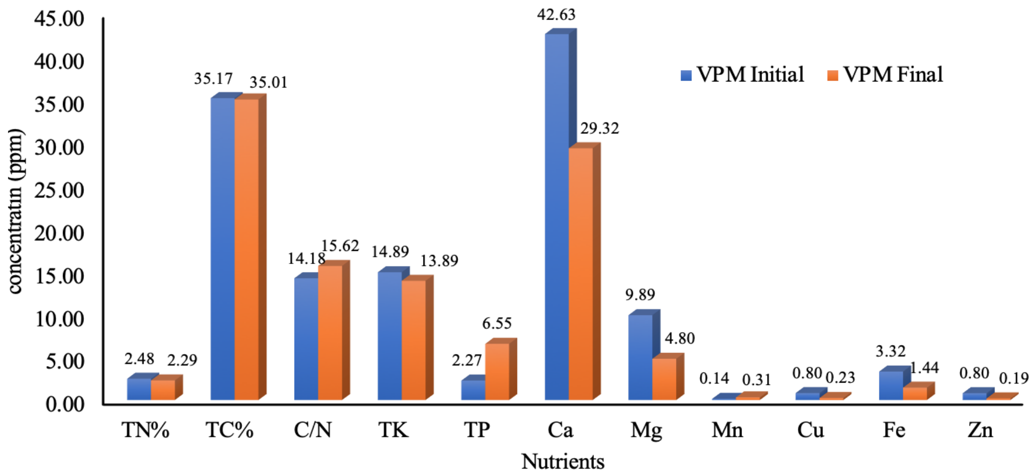

Fig. 3. Variation in concentrations of nutrients in VPM (pig manure) treatment.

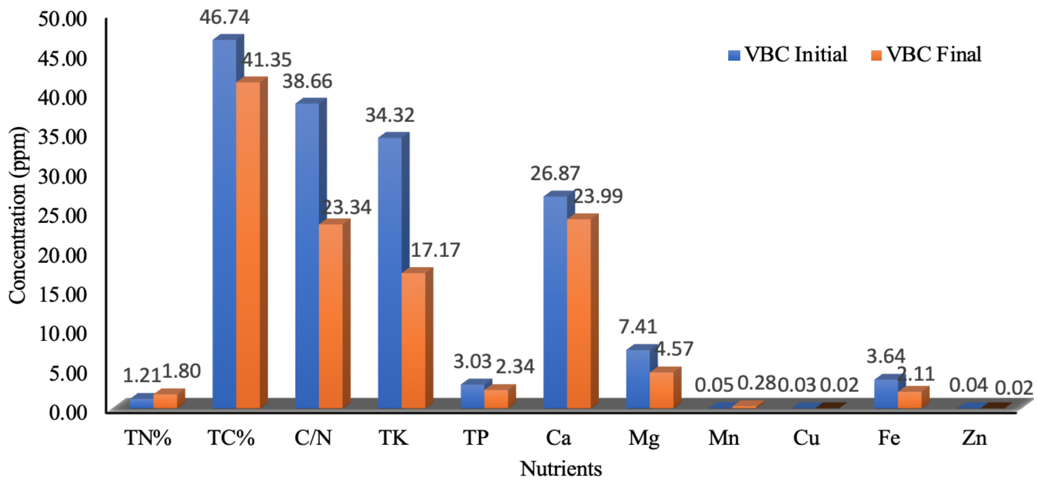

Fig. 4. Variation in concentrations of nutrients in VBC (biochar) treatment.

maize straw, wheat straw is an ineffective substrate for rapid natural composting (Zhang *et al*., 2016). The amount of total phosphate increased with time in VCM and VPM while showed decreased concentration in COM and VBC treatments (minimum variation in compost) while maximum increase was observed in vermicomposting with pig manure. Lazcano (2010) also reported increase in phosphorus concentration due to pig slurry. When the soil was amended with cow manure based vermicompost, it caused increase in total phosphorus content (Dass *et al*., 2008). Increase in concentration of phosphorus is attributed to phosphorization of organic matter due to earthworms (Manna *et al*., 2003). Significant variations were observed in level of calcium. It increased significantly in VCM while decreased in other treatments while magnesium, copper and zinc concentration increased in COM and decreased in rest of treatments. Iron concentration increased in VCM while decreased in other treatments as compared to the initial value. These results are inconsistent with previous results of vermicomposting with maize crop residue.

Manyuchi *et al*. (2017) also recorded increase in calcium with time and attributed it as earthworms' catabolic activity on carbonic anhydrase which are found in calciferous glands of worms in the presence of maize as a substrate. El-Haddad *et al*. (2014) concluded that earthworms can consume all kinds of organic matter and converted the quantity into vermicast equal to their body weight per day that was rich in magnesium, nitrate, phosphorus and calcium. According to Dortzbach *et al*. (2010), pig manure significantly enhanced the accumulation of Mn, Cu and Zn in soil, which is consistent with our results. Accumulation of Zn and Cu in soil is inconsistent with results of de Conti *et al*. (2016) and L'Herroux *et al*. (1997), later found increased concentration of these elements with application of pig manure for four years. Addition of earthworms to the soil increased potassium, phosphorus and nitrogen along with micronutrients *i.e.* copper, iron, zinc and manganese (Mondal *et al*., 2015) but these results are relatively inconsistent with current research but significant increase of N content in nutrients and reduction in C:N ratios during this process shows conversion of harmful wastes into useful fertilizer.

CONCLUSION

The study clearly highlighted the importance of using earthworms to convert organic waste into bio fertilizer that would help in economical sustainability. Vermicomposting helps in getting rid of various organic waste materials and agricultural residues. Nitrogen is an important component in soil for plant growth. Increase in nitrogen content of soil and reduction in C:N ratio make vermicomposting efficient source as fertilizer. Different VC treatments were prepared using wheat straw and rapeseed residues that resulted in soil nutrient enrichment but varied with reference to different nutrients, but these treatments were relatively less efficient than other substrates used for vermicomposting.

ACKNOWLEDGEMENT

This study was supported by International College, University of Chinese Academy of Sciences (IC-UCAS) and The World Academy of Sciences (TWAS) and National Key R&D Program (Grant No. 2016YFD0200309-7).

Statement of conflict of interest

There is no conflict of interest.

REFERENCES

Amossé, J., Bettarel, Y., Bouvier, C., Bouvier, T., Tran, D.T., Doan, T.T. and Jouquet, P., 2013. The flows of nitrogen, bacteria and viruses fromthe soil to water compartments are influenced by earthworm activity and organic fertilization (compost vs. vermicompost). *Soil Biol. Biochem.,* **66**: 197-203. https://doi.org/10.1016/j.soilbio.2013.07.007

Ashiya, P., 2017. C:N ratio of vermicompost of eisenia foetida treated with nitrogenous fertilizer urea. *Int. J. environ. Sci. Technol.,* **6**: 1161-1165.

Barrow, C.J., 2012. Biochar: Potential for countering land degradation and for improving agriculture. *Appl. Geogr.,* **34**: 21-28. https://doi.org/10.1016/j.apgeog.2011.09.008

Bhattacharya, S.S., Iftikar, W., Banashree, S. and Chattopadhyay, G.N., 2012. Vermicomposting converts fly ash to enrich soil fertility and sustain crop growth in red and lateritic soils. *Resour. Conserv. Recycl.*, **65**: 100-106. https://doi.org/10.1016/j.resconrec.2012.05.008

Borchard, N., Wolf, A., Laabs, V., Aeckersberg, R., Scherer, H.W., Moeller, A. and Amelung, W., 2012. Physical activation of biochar and its meaning for soil fertility and nutrient leaching-A greenhouse experiment. *Soil Use Manage*., **28**: 177-184. https://doi.org/10.1111/j.1475-2743.2012.00407.x

Cabrera, M.L., Kissel, D.E. and Vigil, M.F., 2005. Nitrogen mineralization from organic residues: Research opportunities. *J. environ Qual*., **34**: 75-79. https://doi.org/10.2134/jeq2005.0075

Choudhary, M., Bailey, D. and Cynthia, G., 1996. Review of the use of swine manure in crop production: Effects on yield and composition and on soil and water quality. *Waste Manage. Res.,* **14**: 581-595. https://doi.org/10.1177/0734242X9601400606

Clough, T.J. and Condron, L.M., 2010. Biochar and the nitrogen cycle: Introduction. *J. environ. Qual*., **39**: 1218-1223. https://doi.org/10.2134/jeq2010.0204

Clough, T.J., Condron, L.M., Kammann, C. and Müller, C., 2013. A review of biochar and soil nitrogen dynamics. *Agronomy*, **3**: 275-293. https://doi.org/10.3390/agronomy3020275

Dass, A., Lenka, N.K., Patnaik, U.S. and Sudhishri, S., 2008. Integrated nutrient management for production, economics, and soil improvement in winter vegetables. *Int. J. Veg. Sci.,* **14**: 104-120. https://doi.org/10.1080/19315260801934266

de Conti, L., Ceretta, C.A., Ferreira, P.A.A., Lourenzi, C.R., Girotto, E., Lorensini, F., Tiecher, T.L., Marchezan, C., Anchieta, M.G. and Brunetto, G., 2016. Soil solution concentrations and chemical species of copper and zinc in a soil with a history of pig slurry application and plant cultivation. *Agric. Ecosyst. Environ*., **216**: 374-386. https://doi.org/10.1016/j.agee.2015.09.040

Doan, T.T., Jusselme, D.M., Lata, J.C., Nguyen, B.V. and Jouquet, P., 2013a. The earthworm species *Metaphire posthuma* modulates the effect of organic amendments (compost vs. vermicompost from buffalo manure) on soil microbial properties: A laboratory experiment. *Eur. J. Soil Biol.,* **59**: 15-21. https://doi.org/10.1016/j.ejsobi.2013.08.005

Doan, T.T., Ngo, P.T., Rumpel, C., Nguyen, B.V. and Jouquet, P., 2013b. Interactions between compost, vermicompost and earthworms influence plant growth and yield: A oneyear greenhouse experiment. *Sci. Hortic.,* **160**: 148-154. https://doi.org/10.1016/j.scienta.2013.05.042

Dortzbach, D., Léis, C.M., Comin, J.J., Filho, P.B. and Pereira, M.G., 2010. *Accumulation of zinc, copper and manganese in soil fertilized with pig manure and urea in Southern State of Santa Catarina (Brazil)*. 19th World Congress of Soil Science, Soil Solutions for a Changing World Brisbane, Australia.

El-Haddad, M., Zayed, M.S., El-Sayed, G., Hassanein, M. and El-Satar, A.A., 2014. Evaluation of compost, vermicompost and their teas produced from rice straw as affected by addition of different supplements. *Annls. Agric. Sci.,* **59**: 243-251. https://doi.org/10.1016/j.aoas.2014.11.013

Elvira, C., Jorge, D., Luis, S. and Salustiano, M., 1995. Vermicomposting for the paper pulp industry. *Biocycle,* **36**: 62-63.

Eskandari, H. and Kazemi, K., 2012. Changes in germination properties of rape (*Brassica napus* L.) as affected by hydropriming of seeds*. J. Basic appl. Sci. Res.,* **2**: 3285-3288.

Farrell, M., Macdonald, L., Butler, G., Chirino-Valle, I. and Condron, L.M., 2014. Biochar and fertiliser applications influence phosphorus fractionation and wheat yield. *Biol. Fertil. Soils*, **50**: 159-178. https://doi.org/10.1007/s00374-013-0845-z

Gandhi, M., Sangwan, V., Kapoor, K.K. and Dilbaghi, N., 1997. Composting of household wastes with and without earthworms. *Environ. Ecol.,* **15**: 432-434.

He, M., Tian, G. and Liang, H., 2009. Phytotoxicity and speciation of copper, zinc and lead during aerobic composting of sewage sludge. *J. Haz. Mat.,* **163**: 671-677. https://doi.org/10.1016/j.jhazmat.2008.07.013

Jouquet, E.P., Bloquel, E., Doan, T.T., Ricoy, M., Orange, D., Rumpel, C. and Duc, T.T., 2011. Do compost and vermicompost improve macronutrient retention and plant growth in degraded tropical soils? *Compost. Sci. Util.,* **19**: 15-24. https://doi.org/10.1080/1065657X.2011.10736972

Joy, A., 2017. Management of industrial sludge by vermicomposting: A pilot scale study. *Int. J. Civil Engin.,* **8**: 1471-1478.

Kaviraj and Sharma, S., 2003. Municipal solid waste management through vermicomposting employing exotic and local species of earthworms. *Bioresour. Technol.,* **90**: 169-173. https://doi.org/10.1016/S0960-8524(03)00123-8

L'Herroux, L., Roux, L.E.S., Appriou, P. and Martinez, J., 1997. Behaviour of metals following intensive pig slurry applications to a natural field treatment process in Brittany (France). *Environ. Pollut.,* **97**: 119-130. https://doi.org/10.1016/S0269-7491(97)00072-9

Lalander, C.H., Fidjeland, J., Diener, S., Eriksson, S. and Vinner, B., 2015. High waste-to-biomass conversion and efficient *Salmonella* spp. reduction using black soldier fly for waste recycling. *Agron. Sustain. Develop.*, **35**: 261-271. https://doi.org/10.1007/s13593-014-0235-4

Lazcano, C. and Dominguez, J., 2010. Effects of vermicompost as a potting amendment of two commercially-grown ornamental plant species. *Span. J. agric. Res.,* **8**: 1260-1270. https://doi.org/10.5424/sjar/2010084-1412

Lazcano, C., Maria, G. and Domínguez, J., 2008. Comparison of the effectiveness of composting and vermicomposting for the biological stabilization of cattle manure. *Chemosphere,* **72**: 1013-1019. https://doi.org/10.1016/j.chemosphere.2008.04.016

Lu, R.K., 1999. *Soil and agrochemical analytical methods*. China Agricultural Science and Technology Press, Beijing, China.

Mahaly, M., Senthilkumar, A.K., Arumugam, S., Kaliyaperumal, C. and Karupannan, N., 2018. Vermicomposting of distillery sludge waste with tea leaf residues. *Sustain. Environ. Res.,* **28**: 223-227. https://doi.org/10.1016/j.serj.2018.02.002

Manna, M.C., Jha, S., Ghosh, P.K. and Acharya, C.L., 2003. Comparative efficacy of three epigeic earthworms under different deciduous forest litters decomposition. *Bioresour. Technol.,* **88**: 197-206. https://doi.org/10.1016/S0960-8524(02)00318-8

Manyuchi, M., Mbohwa, C. and Muzenda, E., 2017. *Vermicomposting of soybean and maize straw residues as an agro waste management initiative*. 6th International Conference on Sustainability, Technology and Education 2017, 11- 13 December, Sydney, Australia, pp. 11-18.

Mondal, T., Datta, J.K. and Mondal, N.K., 2017. Chemical fertilizer in conjunction with biofertilizer and vermicompost induced changes in morpho-physiological and bio-chemical traits of mustard crop. *J. Saudi Soc. agric. Sci.*, **16**: 135-144.

Nagavallemma, K.P., Wani, S.P., Lacroix, S., Padmaja, V.V., Vineela, C., Babu-Rao, M. and Sahrawat, K.L., 2004. *Vermicomposting: Recycling wastes into valuable organic fertilizer. Global Theme on Agroecosystems Report No. 8. Monograph*. International Crops Research Institute for the Semi-

Arid Tropics, Patancheru, Andhra Pradesh, India. Available at: http://oar.icrisat.org/3677/ (Accessed on 21 March, 2019).

Ngo, P.T., Rumpel, C., Dignac, M.F., Billou, D., Tran, D.T. and Jouquet, P., 2011. Transformation of buffalo manure by composting or vermicomposting to rehabilitate degraded tropical soils. *Ecol. Engin.,* **37**: 269-276. https://doi.org/10.1016/j.ecoleng.2010.11.011

Pascal, J., Plumere, T., Thu, T.D., Rumpel, C., Duc, T.T. and Orange, D., 2010. The rehabilitation of tropical soils using compost and vermicompost is affected by the presence of endogenic earthworms. *Appl. Soil Ecol.,* **46**: 125-133. https://doi.org/10.1016/j.apsoil.2010.07.002

Pattnaik, K.S. and Reddy, M.V., 2010. Nutrient status of vermicompost of urban green waste processed by three earthworm species- *Eisenia fetida, Eudrilus eugeniae* and *Perionyx excavates*. *Appl. environ. Soil Sci.,* **2010**: 1-13. https://doi.org/10.1155/2010/967526

Roberts, P., Jones, D.L. and Edward-Jones, G., 2007. Yield and vitamin C content of tomatoes grown in vermicompost wastes. *J. Sci. Fd. Agric.,* **87**: 1957-1963. https://doi.org/10.1002/jsfa.2950

Sánchez-Monedero, M., Cayuela, L., Asuncion, R., Jindo, K., Mondini, C. and Bolan, N., 2017. Role of biochar as an additive in organic waste composting. *Bioresour. Technol*., **247**: 1155-1164. https://doi.org/10.1016/j.biortech.2017.09.193

Silva, A.N., José-Basso, C., Muraro, D.S., Ortigara, C. and Pansera, E., 2016. Pig slurry composting as a nitrogen source in proso millet crop. *Pesq. Agropec. Trop.,* **46**: 80-88. https://doi.org/10.1590/1983-40632016v4638457

Singh, M. and Wasnik, K., 2013. Effect of vermicompost and chemical fertilizer on growth, herb, oil yield, nutrient uptake, soil fertility, and oil quality of rosemary. *Commun. Soil Sci. Pl. Analy*., **44**: 2691-2700. https://doi.org/10.1080/00103624.2013.813532

Zhang, J.H., Wang, Y. and Li, F.C., 2016. Soil organic carbon and nitrogen losses due to soil erosion and cropping in a sloping terrace landscape. *Soil Res*., **53**: 87-96. https://doi.org/10.1071/SR14151

Zheng, S.A., Zheng, X.Q. and Chen, C., 2013. Transformation of metal speciation in purple soil as affected by waterlogging. *Int. J. environ. Sci. Technol.,* **10**: 351-358. https://doi.org/10.1007/s13762-012-0146-3

Zhou, H.B., Ma, C., Gao, D., Chen, T.B., Zheng, G.D., Chen, J. and Pan, T.H., 2014. Application of a recyclable plastic bulking agent for sewage sludge composting. *Bioresour. Technol.,* **152**: 329-336. https://doi.org/10.1016/j.biortech.2013.10.061