Research Article

Preparation and Characterization of Thermochemical Organic Fertilizer and Its Fortified Form

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Abstract

The present investigation was done to study the behavior of the new nonconventional organic manure - TOF and its fortified form in comparison to other popular conventional organic manures. The organic manures used for the study were prepared in four different methods - aerobic composting, accelerated composting using microbial inoculum, vermi composting and KAU rapid thermochemical decomposition method. The aerobic compost (AC), microbial compost (MC), vermi compost (VC), and thermo chemical organic fertilizer (TOF) were prepared from identical wastes with a definite proportion so as to make effective comparison between the treatments. For the study TOF-F was prepared by fortifying the TOF with N (1.5%) as groundnut cake, P (1%) as rock phosphate, Ca (1%) as calcium carbonate, Mg (0.5%) as magnesium sulphate, Zn (50 ppm) as zinc sulphate, and B (5 ppm) as borax. The prepared manures and FYM were analyzed and compared for their various physical, electrochemical and nutritional properties as per standard procedures. The physical characteristics of the organic manures were found to be similar. An analysis of the waste conversion efficiency revealed that the most efficient method was thermochemical decomposition and the waste to manure conversion rate was also the highest in this process. All the organic manures had an acidic pH and a safe EC and highest value was recorded by TOF-F for pH (6.98) and EC (0.657 dS m^{-1}). The total organic content (TOC) of all manures remained significant and the highest TOC (48%) was observed for TOF and the highest N and Mg content were recorded by MC. The concentration of P and S in VC and K in TOF-F were higher than the other manures under study. In the case of micronutrient content, the manures MC and VC were found to be superior to others. The method of preparation did not affect the germination percentage of seeds of test plants and none of them expressed phytotoxicity.

Keywords: Organic manure, Thermochemical organic fertilizer (TOF), compost, nutrient content, phytotoxicity

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Introduction

Soil organic matter (SOM) is vital in maintaining soil quality and agricultural sustainability. SOM depletion, acidification, soil structural degradation, heavy metal contamination, greenhouse gas emissions from soil, and increased production of organic wastes all represents serious concerns to the long-term viability of tropical agricultural production systems [1].

Organic amendments can provide both macro and micronutrients directly with the rate of mineralisation of the additional organics regulating the long-term supply of N in particular. The addition of organic amendments to the soil resulted in an increase in the microbial biomass pool [2]. However, the nutrient content is highly dependent upon the source and quality of the organics [3]. In the current situation wide gap existed between demand and supply for organic manures and fertilizers needed for large scale commercial application both in organic farming as well as in farms adopting good agricultural practices. In India, the most commonly used organic manure is farmyard manure [4]. Availability of conventional organic manures like farmyard manure, poultry manure, bone meal, groundnut cake, neem cake etc. are very limited and are comparatively costly.

Composting organic wastes is an effective method of restoring organic matter to depleted soils through carbon restitution via organic amendments. Composting is a type of waste processing that has grown in popularity over the years. As it is a microbiological process, long time period is needed for its preparation. Large scale dumping of wastes for long periods will lead to environmental and human health hazards. The new thermochemical waste processing method known as Suchitha technology, as reported by [5] provides a quick and sustainable solution for hygienic waste disposal and the production of organic manure. Characterization of the nonconventional organic manure produced by thermochemical treatment [6] and plant growth trials [7] have shown that it could well be used for crop production. The present study was done to study the behavior of the new nonconventional organic manure - TOF and its fortified form in comparison to other popular conventional organic manures.

Materials and Methods

The organic manures used for the study were prepared in four different methods. Three conventional methods i.e. aerobic composting, accelerated composting using microbial inoculum, vermi composting and one non conventional method i.e. KAU rapid thermochemical decomposition. The aerobic compost (AC), microbial compost (MC), vermi compost (VC), and thermo chemical organic fertilizer (TOF) were prepared from identical wastes with a definite proportion so as to make effective comparison between the treatments. The TOF was fortified for N (1.5%) as groundnut cake, P (1%) as rock phosphate, Ca (1%) as calcium carbonate, Mg (0.5%) as magnesium sulphate, Zn (50 ppm) as zinc sulphate, and B (5 ppm) as borax.

The composition of wastes for composting were as follows – Food waste (83%), fruit waste (5%), leaf litter (10%) and inert material (2%). The food wastes used for composting comprised of rice (10%), vegetable wastes (85%), meat (3%) and fish (2%). From 10 kg of total waste taken for each compost preparation, 2.26 kg of AC, 1.18 kg of MC, 1.28 kg of VC and 2.78 kg of TOF were obtained. All the three compost namely AC, VC and MC were prepared in mud pots which were lined with coconut fibre to absorb moisture oozing out from the wastes during decomposition process. For AC, wastes were spread as layers in pots having holes for drainage with small addition of cow dung slurry which served as microbial inoculums and pots were covered with other pots which had aeration holes. For proper aeration wastes in pots were turned out at every alternate day for better decomposition by providing proper aeration. For MC preparation, microbial inoculum was obtained from the Department of Agricultural Microbiology at College of Agriculture, Vellayani. Waste was spread as layers in earthen pots and required quantity of microbial inoculum and moisture absorbing powder were spread above each layer. Pots were covered with tile pieces so as to prevent entry of insects for egg laying. The wastes were turned out twice in a week. For VC preparation pots were lined with plastic sheet with small holes. A layer of soil of depth 3 cm and a layer of coconut fibre of 5 cm depth were added above it. The wastes were spread as layers by mixing with cow dung slurry. The earthworms were introduced into the pots @ 100 nos per pot after one week of waste addition to avoid injury by heat generated during decomposition process. The pots were covered with moist gunny bag to provide favorable conditions for earthworms and turning of wastes were done once in a week.

Thermo chemical organic fertilizer was produced by KAU rapid thermochemical processing [5]. Fresh waste was ground to uniform consistency in the grinder unit of the KAU Suchitha waste processing machine and was boiled at 100 ^{0}C in the reactor unit after adding the chemical reagents like HCl (0.25 N, 50 ml kg $^{-1}$ waste) for 30 min followed by KOH (0.5 N, 100 ml kg $^{-1}$ waste) for 30 min. Processing was completed within one hour and TOF was produced. Coir pith @ 40 g kg^{-1} waste and charcoal powder @ 30 g kg $^{-1}$ was added and sun dried to reduce the moisture content.

The prepared manures and FYM were analyzed and compared for their various physical, electrochemical and nutritional properties as per standard procedures. The physical parameters like color and odour -by sensory perception [8], texture - by feel method [8] and bulk density – by tap volume method [9]. The electrochemical parameters – pH by potentiometry [8] and EC - conductometry [8]. The total organic C content by weight loss on ignition [8], dissolved organic C - titrimetry [10], $SUVA_{254}$- Absorbance at 254 nm [11], cellulose – colorimetry [12], hemicellulose and lignin – gravimetry [13]. The nutrient content – N by Microkjeldahl distillation after digestion with H_2SO_4 [14], P – diacid digestion and spectrophotometry [15], K- diacid digestion and flame photometry [8], Ca, Mg, S, Fe, Mn, Cu, Mn, Zn- diacid digestion and atomic absorption spectrometry [8] and B – azomethine – H method [16].The phytotoxicity levels was determined by conducting germination bioassays studies as per [17]as well as by figuring out germination index developed by [18] with cucumber, amaranthus and tomato seeds. Statistical analysis of the data was done by using ANOVA table by OPSTAT software.

Results and Discussion

Physical properties

The physical properties of all the organic manures under study conformed to the quality standards of FAI [8]. As depicted in **Table 1**, organic manures AC, MC and VC had a blackish brown color while TOF and TOF-F had dark brown to black color and FYM a brownish black color. All the manures were odourless with free-flowing texture except FYM which exhibited a lumpy texture when dried. The highest BD was recorded by AC (6.57 Mg m^{-3}) while the lowest was recorded by TOF (0.90 Mg m^{-3}).

The physical characteristics of the organic manures were found to be similar. An analysis of the waste conversion efficiency of the different techniques used in the present study revealed that the most efficient method was thermo chemical decomposition since it took only one day for processing and production of TOF. The waste to manure conversion rate was also the highest in this process. Manure production efficiency (**Figure 1**) of the nonconventional thermo chemical treatment producing TOF was 2.35, 2.17 and 1.23 times more than MC, VC and AC respectively.

Table 1 Physical characteristics of organic manures

Manure	Color	Odour	Texture	Bulk density (Mg m^{-3})
AC	Blackish brown	Odourless	Free flowing	1.12
MC	Blackish Brown	Odourless	Free flowing	1.01
VC	Blackish Brown	Odourless	Free flowing	0.91
TOF	Dark brown to Black	Odourless	Free flowing	0.90
TOF-F	Dark brown to Black	Odourless	Free flowing	0.95
FYM	Brownish Black	Odourless	Lumpy when dried	0.91
CD(0.05)				0.018
SEm(±)				0.006

AC: Aerobic compost; MC: Microbial compost; VC: Vermi compost; TOF-Thermochemical Organic Fertilizer; TOF-F: Thermochemical Organic Fertilizer –Fortified; FYM – Farmyard manure; C: Control

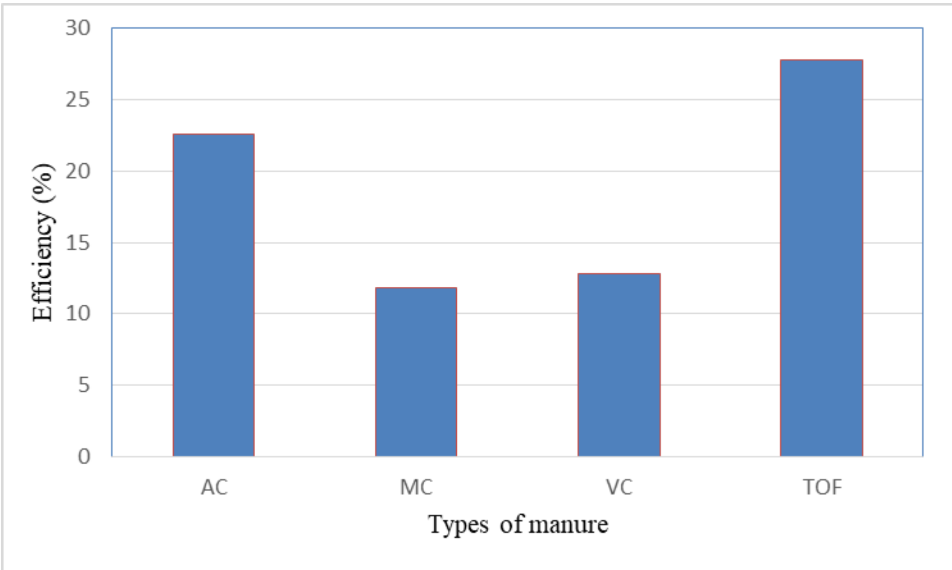

Figure 1 Manure production efficiency of various waste processing methods

In conventional composting methods like AC, the breakdown of large and complex structured organic molecules is achieved in several steps through the activity of different types of heterotrophic organisms that become dominant during the different stages of composting. Moreover, they require longer duration for compost maturity leading to loss of compounds resulting in reduction of final mass [19]. Vermi composting is faster compared to aerobic composting and the process is mediated by earthworms. They are voracious eaters and consumes approximately their body weight per day and achieve higher mass reduction than traditional composting [20]. Faster composting techniques like MC utilize the activity of a consortium of microbial inoculum to accelerate the composting process [21] but the waste to manure conversion efficiency was the lowest in this method, as a result of voracious consumption by the organisms involved in the process. However all these methods are slow because they are mediated through biological activity.

Chemical properties

The pH of all the organic manures was in the acidic range and the highest pH was recorded by TOF-F (6.98). The **Table 2a**. revealed that all organic manures had a safe EC, the highest being recorded by TOF-F (0.657 dS m^{-1}). The total organic content (TOC) of all manures remained significant and the highest TOC (48%) was observed in the case of TOF. The dissolved organic carbon was detectable in traces in all manures. The organic manure MC had the highest value for $SUVA_{254}$.

The reaction of the organic manures in the present study (Table 2a.), whether conventional or nonconventional, was slightly acidic to neutral consequent to the inherent reaction of the waste materials (3.5 -6.5) used for organic manure preparation. An acidic reaction for the food waste is reported [22] which might have resulted in acidic pH values. Formation of organic acids and ammonia during the different phases of composting also might have contributed to a near neutral to slightly acidic reaction. It should also be noted that TOF when fortified (TOF-F) exhibited a slightly lower pH than TOF because of the influence of materials used for fortification. The lowest pH was recorded by FYM and this may be because of the low content of soluble salts. The FYM is usually dumped in the open exposing it to the influence of natural elements. Thus most of the salts released as a result of mineralization of organic matter in the cow's manure will be lost during the storage period either by leaching or volatilization. However, a statistically significant difference could not be recorded between any of the organic manures in terms of pH. The EC values which indicate the soluble salt content in the manure were also safe for plant growth in all the studied manures. All these organic manures conform to the prescribed standard values of pH and EC as per [8]. A slight increase recorded in MC and VC may be due to a higher rate of mineralization observed in these treatments as a result of higher microbial activity. The release of exchangeable cations, such as Ca, Mg, and K, in vermicompost increases the EC of vermicompost [23]. On the other hand, in the thermochemical process, the stoichiometry of the acid–alkali reaction was adjusted to have a near neutral product which will not impair plant growth and development. [5].

Table 2a Chemical characteristics of organic manures

Manures	pH	EC (dS m^{-1})	TOC (%)	$SUVA_{254}$
AC	6.41	0.526	20	1.54
MC	6.84	0.606	39	1.58
VC	5.57	0.576	24	1.32
TOF	6.35	0.610	48	1.54
TOF-F	6.98	0.657	40	1.56
FYM	6.19	0.066	36	1.46
CD(0.05)	NS	0.002	0.018	0.036
SEm (±)	0.577	0.001	0.006	0.012

AC: Aerobic compost; MC: Microbial compost; VC: Vermi compost; TOF-Thermochemical Organic Fertilizer; TOF-F: Thermochemical Organic Fertilizer –Fortified; FYM – Farmyard manure; C: Control

The most important property as far as organic manures is concerned is the organic carbon content (TOC). The value for TOC was the highest in TOF and can be attributed to the chemical method of processing of waste which does not depend on biological activity for organic matter decomposition which have minimised C losses. However, in TOF-F the value is slightly lower than TOF as a result of dilution effect. TOC is the lowest in AC. This might be partly due to consumption by microorganisms and partly due to the leaching and volatilization losses occurring during the process. In conventional methods, loss of C as CO_2 occurs through microbial respiration during the degradative phases of composting [19]. Although the DOC content was negligible in all the manures, $SUVA_{254}$ was significantly lower in VC than other treatments. $SUVA_{254}$ values for the conventional manures MC and AC and nonconventional manure TOF were on par. Specific ultraviolet absorbance is defined as the UV absorbance of a solution sample at a given wavelength normalized for dissolved organic carbon concentration. SUVA at 254 nm (SUVA254) is a non-destructive method for determining aromaticity and is strongly correlated with percent aromaticity of DOM, which is caused by C double bonds in benzene type structures. In studying the optical properties of DOC, [24] reported that samples which have $SUVA_{254}$ values >3 are more humic-like and those with values < 3 are more fulvic like in character. Hence if we follow this classification, then all the studied organic manures expressed only fulvic – like character in DOC. However, the reaction of the sample influences $SUVA_{254}$ values, an alkaline reaction dissolves more organic carbon in to the solution [25].

Nutritional properties

The nutritional characters of the different organic manures studied are depicted in **Figure 2** and **Table 2b**.

Among the different manures used in the experiment, the highest N content was recorded by MC. The N content in MC was 2.2, 2.4 and 1.34 times higher than that in AC, FYM and TOF respectively. Although MC had significantly higher N content than other treatments, it was on par with TOF-F. This might be due to the effect of the microbial inoculum used in this treatment for preparation of compost which might have enhanced the nitrogen fixation process. The highest content in TOF-F is due to the effect of fortification. The longer duration of conventional composting in AC might have resulted in the loss of some of the mineralized N through leaching and volatilization [19], accounting for the lower values. As reported by [20], the major part of FYM is cattle dung and cattle shed wastes, which provide the major portion of dry matter and N, P and K. They calculated that about 39% of N, 20% of P and 32% of K are lost during preparation of FYM by conventional methods and the major loss is through leaching.

The concentration of P in VC and FYM were higher than all the other conventional and nonconventional manures. It is reported that phosphorus occurs in animal manure in a combination of inorganic and organic forms. In general, 45 to 70 percent of manure P is inorganic. Even the organic P is easily decomposable by soil microorganisms to the inorganic form. The lowest P content was observed in AC. The P content in MC was more than 2, 3 and 4 times that of AC, TOF and TOF-F respectively as a result of action of P solubilising capacity of the microbes used for composting. The values for K content in TOF and VC were on par but significantly superior to the other manure types. The high content of K in TOF is due to the addition of dilute KOH which is used for processing of waste. The release of exchangeable cations, such as Ca, Mg, and K, in vermin compost is already reported [23]. The values in AC and MC were on par, but was significantly higher than that of FYM. The low content of K in FYM is due to leaching losses and [26] reported that about 32% of K is lost from FYM by leaching.

Table 2b. Chemical properties of organic manures

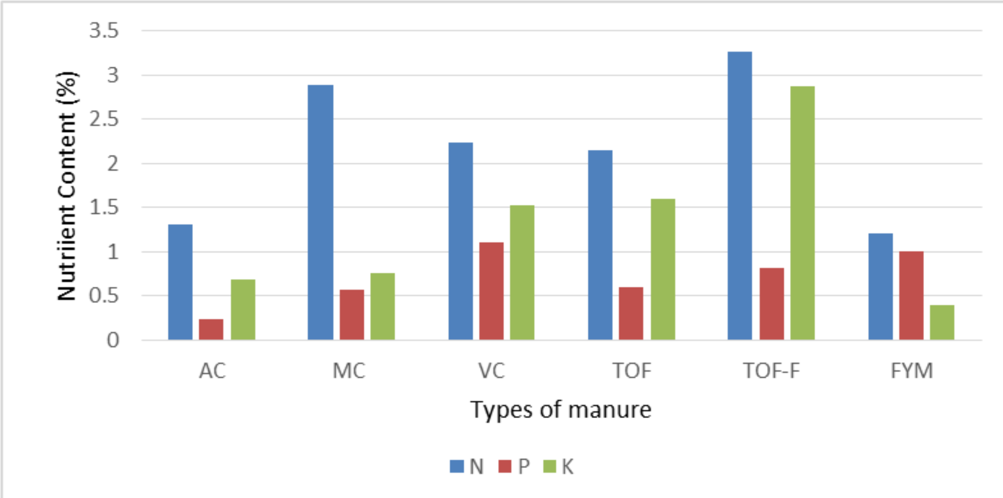

Figure 2 NPK content of different organic manures

Table 2b Chemical properties of organic manures

Manures	Ca (%)	Mg (%)	S (mg kg^{-1})	Fe	Mn	Zn	Cu	B
AC	0.63	0.19	14.60	1,710.00	12.92	53.68	3.48	0.27
MC	1.39	0.36	23.80	3,945.20	111.76	215.44	8.27	12.60
VC	0.62	0.25	28.85	6,960.00	81.12	215.28	18.05	12.52
TOF	1.22	0.20	18.70	1,830.00	17.62	56.24	5.28	11.80
TOF-F	1.69	0.25	42.70	4,392.00	244.36	219.76	4.79	13.88
FYM	0.69	0.23	18.70	2,852.00	29.59	132.84	1.88	1.17
CD(0.05)	0.480	0.004	0.29	71.951	0.717	4.619	0.719	0.137
SEm(±)	NS	0.013	0.899	23.095	0.230	14.390	0.231	0.428

AC: Aerobic compost; MC: Microbial compost; VC: Vermi compost; TOF-Thermochemical Organic Fertilizer; TOF-F: Thermochemical Organic Fertilizer –Fortified; FYM – Farmyard manure; C: Control

Significant difference could not be obtained for Ca content of the manures, but MC had significantly higher values for Mg content whereas S content was the highest in VC when the treatment TOF-F is excluded. In the case of micronutrient content, the manures MC and VC were superior to others. In these two processes, microbial activity is very high leading to mineralization of organic matter releasing the plant nutrients.

Phytotoxicity - Germination Bio assays

Assessment of phytotoxicity of manures or composts is an essential step for ensuring their safety for agricultural use. The maturity and safety of conventional composts are evaluated by biological methods most commonly germination tests [27]. In the present study, germination bioassay with three different types of vegetable seeds (**Table 3**) showed that all the manures were safe for soil application for crop production.

The method of preparation did not affect the germination percentage of seeds of the test plants and none of them expressed phytotoxicity. However, fortification has enhanced GI in the case of all the crops, showing the beneficial influence of balanced nutrition on germination of seeds. All the manures recorded a GI >50 %. Composts with a germination index (GI) >50% are found to be free of phytotoxic compounds and a GI < 50% is treated as immature and highly phytotoxic.

Table 3 Germination bioassay results of organic manures – Germination % (GP) and Germination Index (GI)

Manures	Cucumber		Amaranthus		Tomato	
	GP (%)	GI	GP (%)	GI	GP (%)	GI
AC	80	62	80	69	80	77
MC	80	76	90	71	90	72
VC	80	60	80	78	90	76
TOF	70	68	70	67	80	60
TOF-F	80	73	80	81	90	75
FYM	70	68	80	65	80	63

AC: Aerobic compost; MC: Microbial compost; VC: Vermi compost; TOF-Thermochemical Organic Fertilizer; TOF-F: Thermochemical Organic Fertilizer –Fortified; FYM – Farmyard manure; C: Control

Conclusions

The new thermochemical waste processing method serves as a quick and sustainable practice for hygienic waste disposal and for the production of good quality organic manure. The waste conversion efficiency is much higher for TOF and fortification improved all the properties and can be safely used for agricultural production. The fortified TOF and MC were found to be superior in terms of physical chemical and nutritional parameters.

References

[1] N. Ramankutty, Z. Mehrabi, K. Waha, L. Jarvis, C. Kremen, C. Herrero, H. Loren. Trends in global agricultural land use: implications for environmental health and food security. Annual Review of Plant Biology. 2018, 83: 238-244.

[2] Y.Chen, M. Camps-Arbestain, Q. Shen, B. Singh, L. M. Cayuela. The long-term role of organic amendments in building soil nutrient fertility: a meta-analysis and review. Nutrient Cycling in Agroecosystems. 2018, 111: 103–125.

[3] S. Mukai. Historical role of manure application and its influence on soil nutrients and maize productivity in the semi-arid Ethiopian Rift Valley. Nutrient Cycling in Agroecosystems. 2018, 111: 127–139

[4] K. S. Reddy, M. Mohanty, D. Rao, M. Singh, A. S. Rao, M. Pandey, F. P.C. Blamey, R. C. Dalal, S. K. Dixit, N. W. Menzies, N. W. Nutrient mass balances and leaching losses from a farmyard manure pit in Madhya Pradesh. Journal of Indian Society of Soil Science. 2015, 63(1): 64–68.

[5] C. R. Sudharmaidevi, K. C. M. Thampatti, N. Saifudeen. Rapid production of organic fertilizer from degradable waste by thermo chemical processing. International. Journal of Recycling of Organic Waste in Agriculture. 2017, 6: 1–11.

[6] N. Leno, C. R. Sudharmaidevi, P. B. Mathew. Nutrient Availability from an Organic Fertilizer Produced by Chemical Decomposition of Solid Wastes in Relation to Dry Matter Production in Banana. 2017, Advances in Research, 12(5): 1-9.

[7] J. Jayakrishna. Evaluation of thermochemical digest of degradable waste for container cultivation of chilli. M.Sc. (Ag.) thesis, Kerala Agricultural University, 2017, Thrissur. 123p.

[8] FAI (Fertilizer Association of India), The Fertilizer (Control) Order, 1985. The Fertilizer Associoation of India, New Delhi, 2017. Available: http://www.astaspice.org/food-safety/astas-analytical-methods-manual

[9] J. K. Saha, N. Panwar, M. V. Singh. An assessment of municipal solid waste compost quality produced in different cities of India in the perspective of developing quality control indices. Waste Mangement. 2010, 30: 192-201.

[10] D. L. Jones, V.B. Willett. Experimental evaluation of methods to quantify dissolved organic nitrogen (DON) and dissolved organic carbon (DOC) in soil. Soil Biology and Biochemistry. 2006. 38: 991-999.

[11] J. L. Weishaar, G. R. Aiken, B. A. Bergamaschi, K. Mopper. Evaluation of specific ultraviolet absorbance as an indicator of the chemical compound and reactivity of dissolved organic carbon. Environmental Science and Technology. 2003, 37: 4702-4708.

[12] D. M. Updegraff. Semimicro determination of cellulose in biological materials. Annals Biochemistry. 1969, 32: 420- 424.

[13] H. K. Georing, P. J. Van Soest, Forage Fibre Analysis. U.S. Agricultural Research Service, Washington. 1970, 20p.

[14] M. L. Jackson. Soil Chemical Analysis (2nd Ed.), Prentice hall of India, New Delhi, 1973, 498p.

[15] A. E. Greenberg, L. S. Clesceri, A. D. Eaton. Standard Methods for the Examination of Water and Waste Water, 18th (Ed.). American Public Health Association, Washington.1992, 75p.

[16] A. Roig, A. Lax, F. Costa, J. Cegarra, T. Hernandez. The influence of organic materials on the physical and physico-chemical properties of soil. Agric. Medit. 1996. 117: 309-318.

[17] R. Paradelo, A. Villada, D. Gonzalez, M. T. Barral, M.T. Evaluation of the toxicity of heavy metals and organic compounds in compost by means of two germination-elongation tests. Fresenius Environmental Bulletin. 2010, 19: 956-962.

[18] N. F. Gariglio, M. A. Buyatti, R. A. Pilatti, M. R. Acosta. Use of a germination bioassay to test compost maturity of willow (Salix sp.) sawdust. New Zealand Journal of Crop and Horticultural Science 2002, 30(2): 35-139.

[19] Chan, M. T., Selvam, A, and Wong, J. W. C. 2016 a. Reducing nitrogen loss and effects of straw incorporation on the soil nutrient contents, enzyme activities, and crop yield in a semiarid region of China. Soil Tillage Res. 160: 65–72.

[20] S. Pattnaik, M. V. Reddy. Nutrient status of vermicompost of urban green waste processed by three earthworm species—Eisenia foetida, Eudrilus eugeniae, and Perionyx excavates. Applications in Environmental Soil Science. 2010, 13: 652-671.

[21] P. Saravanan, S. S. Kumar, C. Ajithan, Eco-friendly practice of utilization of food wastes. International Journal of Pharmaceutical Science and Innovations. 2013. 180: 14–17.

[22] X. He, B. Xi, Z. Wei, X. Guo, M. Li Spectroscopic characterization of water extractable organic matter during composting of municipal solid waste. Chemosphere. 2018. 82: 541–548.

[23] N. Hussain, S. A. Abassi. Efficacy of the vermicomposts of different organic wastes as “clean” fertilizers: State-of-the-art. Sustainability. 2018, 10(4): 1205.

[24] R. K. Surampalli, K. D. Tyagi. Advances in Water and Waste Water Treatment. American Society of Civil Engineering, Reston, USA, 2004,312.

[25] I. W. F. Li, S. Vincent, D. K. Swanson, A. Cozar. Global trends in fluorescence characteristics and distribution of marine dissolved organic matter. Marine Chemistry. 2017,126: 139-148.

[26] K. Sammi, F. Pax, B. Blamey, C. Dalal, R. Mohanty, M. Singh, M. Rao, A. Pandey, M. Menzies, Neal. Leaching losses of nutrients from farmyard manure pits in Central India. Journal of Indian Society of Soil Science. 2010. 63: 64-68.

[27] E. R. Emino, and P. R. Warman. Biological assay for compost quality. Compost Science Utilization. 2004, 12 (4): 342-348.

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