ORIGINAL RESEARCH

Assessment of physicochemical changes during composting rice straw with chicken and donkey manure

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Abstract

Purpose Traditional methods of composting are limited in timely production of good-quality compost due to recalcitrant nature of materials of plant origin. This study focused on evaluating the use chicken and donkey manure as starter cultures to biostimulate bioconversion of rice straw into bioorganic fertilizer. Use of starter cultures would enhance composting as a strategy for rice straw management to enhance soil fertilization and reduce environmental pollution.

Methods In this study, chicken manure and donkey manure were used as starter cultures to enhance bioconversion of recalcitrant and abundant rice straw in Mwea, the main rice-producing area in Kenya. Treatments of the study included rice straw co-composted with chicken manure (T1), rice straw co-composted with donkey manure (T2) and a control (T0) consisting of un-treated rice straw. Temperature, pH and electrical conductivity (EC) were monitored throughout the composting period. Resultant compost types were characterized in respect to their macro-nutrient concentrations, cation exchange capacity, pH and heavy metal content.

Results Levels of temperature, pH and EC among the treatments of the study revealed significant differences at 5% level of confidence using Tukey's test. The three resultant compost types obtained were also physicochemically different as revealed by analysis of variance of cation exchange capacity, phosphorus, nitrogen and carbon content.

Conclusion Results indicated that use of chicken and donkey manure significantly improved the composting process and the quality of resultant compost.

Keywords Rice straw · Composting · Crop residue · Bioorganic fertilizer · Soil quality

Introduction

Agriculture, especially in developing countries faces many challenges that hinder the system from attaining its main goal of feeding the world's population (Sasson 2012). Food production is currently threatened by issues of increasing land degradation, high cost of inputs, unavailable farm inputs and climate change among others (Pimentel and Burgess 2013). Use of compost in crop farming is one way of addressing these problems.

Composting is a good strategy towards improved and sustainable agricultural productivity (Sarkar and Chourasia 2017). Composting ensures reclamation of nutrients within plant biomass to improve soil fertility and enhance crop productivity (Chandra et al. 2009). Compost acts as soil conditioner leading to high nutrient concentrations, high organic matter content and greater soil water-holding capacity in the soil (Insam and de Bertoldi 2007). It also results in increased load, diversity and activity of beneficial soil microorganisms (Zhen et al. 2014). Production of compost from rice straw is, therefore, a better alternative to burning, direct incorporation of the straw into soil and heaping in rice fields.

Composting is a dynamic process of rapid successive reactions that involve the breaking down of organic matter under controlled aerobic conditions into usable products (Kumar 2011). Effects of compost on soil quality and consequently on crop productivity is determined by the properties of the compost applied (Insam and de Bertoldi 2007). Compost properties

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vary greatly depending on the composting feedstock and composting procedures (Bernal et al. 2009).

Although the practice of composting is well known, farmers, especially in developing countries do not make the best use of the recycling opportunities available to them (Gajalakshmi and Abbasi 2008). This is mainly due to various hindrances in the composting process which among others include the long time span required for the compost to mature (Sarkar and Chourasia 2017). Waste materials of plant origin including rice straw are recalcitrant due to their lignocellulolytic structure which have practical implications in biodegradation (Anwar et al. 2015; Van Soest 2006).

Rice straw has a unique chemical composition relative to other cereal straw. On average, rice straw consists of lignin (10–15%), silica (75%), 40–50% cellulose and 9–12% hemicelluloses, on a dry weight basis (Knauf and Moniruzzaman 2004). All these compounds are hard to decompose rapidly under natural environmental conditions.

The composting process can be hastened and quality of the final compost improved through certain treatments on the organic material being composted (Anwar et al. 2015). Modern composting methods make use of treatments such as shredding, mechanical turning, biostimulation and watering (Sarkar and Chourasia 2017). These treatments affect the process through several mechanisms such as increased surface area for action by microorganisms, ensured heat build up within the composting materials and increased microbial activity among others (Patidar et al. 2012).

Biostimulation can accelerate the breaking down of lignocellulose components while improving on quality of the final product (Lim et al. 2015). Biostimulation affects the microbial activity within the composting materials by influencing availability of nutrients (Goyal and Sindhu 2011; Zeng et al. 2011). Biostimulation as a strategy of enhancing lignocellulose degradation can be achieved using animal manure that provides extra nutrients to microbial decomposers (Higashikawa et al. 2010; Lim et al. 2015). Livestock manure is actually known to harbour microorganisms that are important for composting and for soil development (Devi et al. 2012).

With the objective of improving the process of composting lignocellulosic materials such as rice straw, we designed and performed an experiment on biostimulation using chicken and donkey manure. Our hypothesis was that inoculation with chicken and donkey manure would accelerate the process of composting and improve the quality of final compost.

Materials and methods

Pre-analysis of the raw materials

Dry rice straw, donkey manure and chicken manure were obtained from farmers at Mwea Rice Irrigation Scheme in Kenya. The raw materials were analyzed for heavy metal concentrations and nutrient levels.

Composting

The rice straw was chopped to moderate length of about 3–5 cm and 10 kg of the straw was used for each treatment of the study. The rice straw was watered and inoculated with the various starter cultures. The experiment consisted of three treatments, T1, T2 and T0 (control). T0 contained rice straw which was watered but nothing else was added to it. T1 consisted of rice straw mixed with chicken manure in the ratio of 10:1 (w/w), while T2 contained rice straw mixed with donkey manure in the ratio of 10:1 (w/w). The mixture was thoroughly mixed, arranged in perforated gunny bags and the bags closed. Further watering was done whenever necessary using a watering can to maintain moisture. The composting materials were also turned regularly for aeration (Jusoh et al. 2013). The composting experiments were arranged inside an open structure in a completely randomized design with three replications.

Levels of pH, temperature and electrical conductivity were measured immediately after setting up the experiment (at day zero). These parameters were then monitored throughout the composting process. The composting process was complete within 62 days after which the physicochemical parameters (temperature, pH, and electrical conductivity) stabilized.

Physicochemical analysis during composting

Temperature, pH and electrical conductivity (EC) readings were taken on daily basis throughout the composting period. Temperature was measured by inserting a thermometer into the composting materials. Three readings were taken in every composting setup; the first one close to the surface, second one at the centre and the third one close to the bottom of the composting materials. An average value was later computed.

For pH and electrical conductivity tests, 10 g of compost was collected at five different points within the composting materials into a sterile plastic bag. Each sample was put into a 250-ml glass beaker containing 90 ml distilled water and the mixture stirred for 20 min. It was then allowed to settle and pH and electrical conductivity readings taken using a digital electrode pH and EC multimeter. The electrode probes were thoroughly washed and rinsed with distilled water before and after use. The metres were also calibrated regularly using appropriate standards to ensure high levels of accuracy.

Characterization of the mature compost

Analysis for physicochemical properties

Compost obtained from the composting experiment was analyzed for various physicochemical properties. Test for total nitrogen and available phosphorus was done using Kjeldahl and Olsen methods, respectively. To quantify the total nitrogen, 0.1 g of compost was weighed in a glass tube and 3 ml of concentrated H_2SO_4 added in a mixture of K_2SO_4 and $CuSO_4$ to each tube. The samples were digested in a digester block, with gradual elevation of the temperature to 350 °C until the extracts of the mixtures formed a greenish colour. Phosphorus and magnesium were measured in Milton Roy Spectronic 100, a digital UV–visible spectrophotometer at 880 nm wavelength. Potassium, sodium and calcium were analyzed by flame photometer method, model AA500 pg instruments. The content of organic carbon was analyzed by Walkley–Black method (Walkley 1947). Carbon–nitrogen (C:N) ratio was calculated using the carbon and nitrogen contents. pH and electrical conductivity (EC) were measured using digital electrode pH and EC metres, Metrohm 632 and Bridge model 31, respectively. Cation exchange capacity was tested using ammonium acetate method (Chapman 1965). The equipment used was calibrated with known and unchangeable content of these elements to control any anomalies.

Heavy metal extraction and analysis

1 g of each compost type was placed in a 250-ml digestion tube and 50 ml of concentrated nitric acid added (Hseu 2004). The sample was then heated for 45 min at 90 °C and the temperature increased to 150 °C at which the sample was boiled until a clear solution was obtained. A few drops on hydrogen peroxide were added followed by addition of a concentrated nitric acid (5 ml added three times). Digestion was left to take place until the volume reduced to about 5 ml. The inside of the walls of the tube were rinsed with distilled water and the tube swirled throughout the digestion to prevent loss of the sample. The sample was then allowed to cool and 5 ml of 1% nitric acid was added to the sample. The solution was filtered with Whatman No. 42 filter paper and a 0.45 μm Millipore filter paper. The solution was quantitatively transferred to a 50 ml volumetric flask by adding distilled water ready for analysis (Ayari et al. 2008).

Concentration of total heavy metals was determined using Buck Scientific 210VGP Atomic Absorption Spectrophotometer. The operating parameters of the machine were set according to the manufacturers specifications (Buck 2003). Samples were mixed by shaking vigorously before aspiration into Atomic Absorption Spectrophotometer for specific metal concentration determination. Values were expressed in mg kg^{-1}.

Data obtained were analyzed by one-way analysis of variance (ANOVA) and means separated by Tukey's Honest Significant Difference (HSD) test ($p < 0.05$). Pearson's correlation coefficient was used to determine relationships between various parameters. All statistical analyses were performed in SPSS version 16 software.

Results and discussion

Evolution of composting

Temperature readings showed very wide variations among days and were within the range of between 23 and 56 °C. The highest temperature (56 °C) and the lowest (23 °C.) were observed in treatments T0 and Treatment T2, respectively (Fig. 1). Three phases (mesophilic, thermophilic and cooling) in relation to temperature changes were observed in all the treatments of the present study (Fig. 1). Changes in temperature indicated significant differences in T1 and T0. Mean temperature value in T1 was significantly higher than in the control ($p < 0.001$) at 5% level of significance. The differences observed in temperature readings among the treatments are due to variations in microbial biochemical activities in the compost as affected by the treatments on the rice straw (Davis et al. 1992; Peters et al. 2000). Low mean temperature value (33.25 ± 5.98) °C in the control relative to other treatments confirms this inference. Thermophilic phase was first attained in treatment T1 and lastly in T2. This can be explained by the fact that chicken manure is a nutrient rich medium compared to donkey manure and rice straw; hence it activated a more rapid microbial degradation. A prolonged thermophilic phase observed in this study is indicative of the high initial C:N ratio of the rice straw (Eiland et al. 2001).

The composting process started at generally low pH in all the treatments of the study. The pH then rose gradually as decomposition of materials set in. Initiation of active decomposition of materials led to a slight decline in pH with the lowest pH of 6.56 being recorded in treatment T1. The pH then increased steadily attaining alkaline conditions followed by a decline to almost neutral conditions at the end of the composting period. There were, however, some random fluctuations from neutral, acidic and alkaline pH at different times among the treatments. The pH generally stabilized at 7.50–8.50 but peaks were detected on some days of the composting period, for example, there was a sudden rise to 10.46 on day 23 in T1.

The pH readings observed in this study were closely related among all the treatments for the most part of the composting period (Fig. 2). By day 21, a pronounced difference
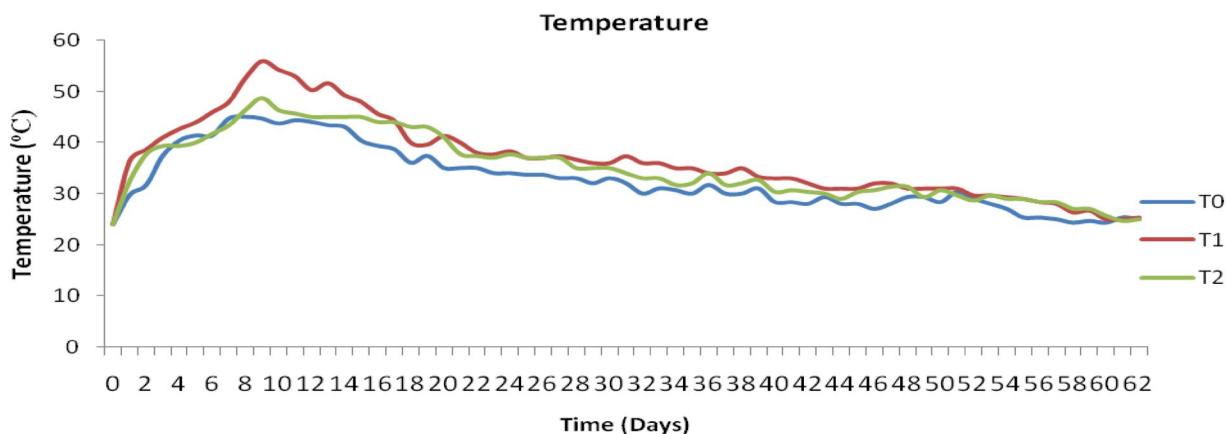
Fig. 1 Temperature readings during the composting period

in the pattern of the pH was observed. This was followed by a sharp increase in pH at day 33 till close to the end of the composting process when the pH decreased. Mean pH readings in the control were significantly lower than T1 and T2 ($p < 0.002$). Analysis of covariance (ANCOVA) indicated that pH values recorded on day 8 were significantly different from those made on days, 13, 14, 15, 16, 19, 20 and 27.

Electrical conductivity (EC) values of the composting materials were within the range of 217–2147 µS/l (Fig. 2). The lowest and the highest EC reading occurred in T0 and T1, respectively. Mean EC values in all the treatments were significantly different ($p < 0.001$). The electrical conductivity of the compost increased gradually during the composting period with a sharp decrease occurring between day 14 in treatment T1. T1 also recorded the highest EC readings in most of the days while T0 usually had the lowest EC readings (Fig. 2). Analysis of covariance (ANCOVA) revealed that the EC readings recorded on day 8 of the composting period were significantly different from those of all other days except day 18, 11 and 15 ($p = 0.101$, $p = 0.997$ and $p = 0.479$, respectively) at 5% level of significance. There was also a significant negative correlation between EC values with the temperature ($r = -0.528$, $p = 0.01$). Mean EC values were significantly different as revealed by ANOVA ($p < 0.001$) at 5% level of confidence.
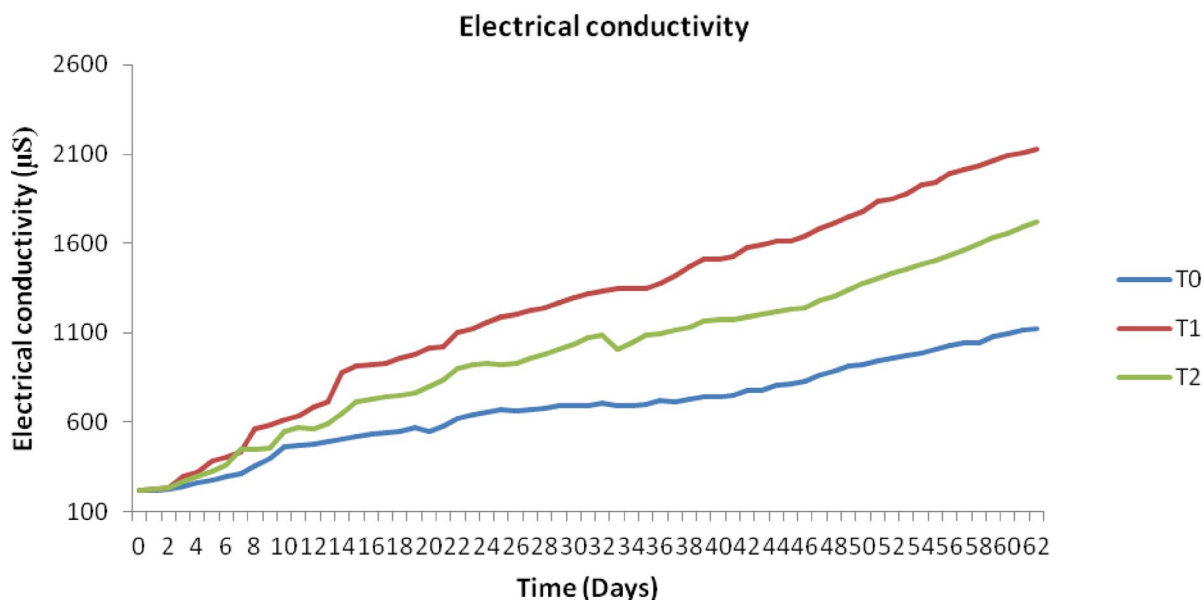

Fig. 2 Electrical conductivity readings during the composting process. *T0* control, *T1* rice straw treated with chicken manure, *T2* rice straw treated with donkey manure

The relatively high electrical conductivity (EC) levels in the rice straw treated with chicken manure (T1) indicate that the manure had the highest degradative effect on rice straw leading to a high release of free ions as compared to other treatments of the study (Smith and Doran 1996). Chicken manure is known to harbour high numbers of microorganisms suggesting that the manure can be exploited as a possible source of lignocellulolytic microorganisms for industrial applications (Devi et al. 2012). Moreover, chicken manure contains readily available nutrients that can enhance the microbial populations in compost through biostimulation (Das and Chandran 2011).

Active decomposition and eventual completion of the composting process was accompanied by several physical and chemical changes on the feedstock materials. During active decomposition, a pleasant earthy smell was noted in all treatments when the composting materials were being turned. There were also visible changes in the appearance of the composting materials in terms of colour and texture as the process progressed. Gradual consistent reduction of the volume of the composting materials as was also observed as decomposition proceeded.

The pleasant earthy smell detected during the composting process is an indicator of proper aeration and the absence of anaerobic conditions. Changes in colour and texture of the compost also signalled completion of the composting process (Peters et al. 2000). Changes in the physicochemical parameters greatly determine the progress and the outcome of every composting process (Lim et al. 2015).

Properties of final composts

By 62nd day of composting, all the composting materials showed temperature stability, fine texture, much darker brown or black colours and homogeneity of materials. The composting process was, therefore, halted and samples collected for compost analysis. The quality of the various compost types varied significantly in relation to their physical and chemical characteristics (Plate 1, Table 2).

Cation exchange capacity of the final compost was affected significantly by the treatments of the study. The highest CEC reading (25.25 ± 2.90 Cmol/kg) was observed in setup treated with chicken manure (Table 2). This value was significantly higher than that of the control and that of donkey manure ($p = 0.005$). Pearson's correlation coefficient revealed a strong positive significant relationship between CEC values with phosphorus concentrations ($r = 0.730$, $p = 0.01$). The positive correlation between CEC with phosphorus contents ($r = 0.730$, $p = 0.01$) supports the fact that humic acids, the main components of compost bind the positively charged multivalent ions (Pedra et al. 2008). Composts generally have high cation exchange capacity levels which increase the soil CEC when added into soil (Fuchs 2002).

pH values of the final composts obtained in various treatments did not show any significant differences ($p = 0.410$). Pearson's correlation coefficient revealed a negative significant relationship between pH and nitrogen content of the composts ($r = -0.527$, $p = 0.05$). All the compost types produced by the present study attained the recommended pH level of between 6 and 8 (Troy et al. 2012), with the values being close to neutrality (7.16–7.56).

Organic carbon content of the final compost was significantly affected by the treatments used in the study. Organic carbon content in T1 was significantly lower than that of T0 and T2 ($p = 0.001$). A huge reduction in the organic carbon from the initial carbon is seen in the C:N ratios. The C:N ratio values of the final composts were lower than those in the feedstock. However, the differences were not statistically significant at 5% (Table 1). Treatment T0 produced compost with the highest C:N ratio while treatment T1 produced compost with the lowest C:N ratio (Table 2). C:N ratio values of the composts produced by the treatments of this study were all within the recommended range of between 10 and 18 except in the control (T0). High C:N ratio in compost indicates the presence of unutilized complex nitrogen and

Plate 1 Compost samples from the resultant composts

carbon while complete breakdown of these materials is indicated by low C:N ratios (Dobermann and Fairhurst 2002).

Concentrations of available phosphorus in the resultant composts varied widely among the treatments of the study with the lowest concentration being obtained in the control (T0) and the highest in T1, respectively (Table 2). ANOVA revealed significant differences among all treatments ($p < 0.001$). Available phosphorus concentrations in T1 were significantly higher than in T2 ($p < 0.001$). The phosphorus values correlated negatively with EC values ($r = -0.724$, $p = 0.01$). Pearson's correlation coefficient also revealed a strong negative significance relationship between phosphorus concentrations and carbon content ($r = 0.710$, $p = 0.01$). The composts produced in this research had phosphorus concentrations within the recommended levels of between 800 and 2500 mg kg^{-1} (Brinton 2000), except for the compost from the control experiment, T0 (731.55 ± 19.62 mg kg^{-1}). Compost quality is directly related to the microbial communities involved in composting (Pan and Sen 2013; Peters et al. 2000).

Total nitrogen levels in the treated rice straw were significantly higher than in the control (T0) ($p = 0.005$). The nitrogen content, however, did not differ significantly between treatments T1 and T2, at 5% level of significance. Nitrogen readings recorded among all the compost types were within a narrow range of between 1.04 and 2.24%. Pearson's correlation coefficient revealed a strong negative significant relationship between nitrogen concentrations and carbon content ($r = -0.704$, $p = 0.01$).

Statistical analysis of the potassium content in final compost indicated no significant differences among treatments. The levels of potassium ranged narrowly from 6.91 to 8.90 Cmol/kg. The highest content was obtained in treatment T1 while the lowest was obtained in T0 (control). Calcium content varied within a range of between 25.98 and 30.65 Cmol/kg. However, these values were not statistically different (Table 2). Potassium content levels of resultant composts of the present study also indicated that the composts were well matured. Potassium concentration mean value of 1.65 ± 0.01 observed by Li-li et al. (2013) in a study on composting rice straw using rabbit manure was lower than 7.53 ± 0.80, obtained for compost T2 (treated with donkey manure) in the present study. Similar to a study by Kausar et al. (2014), results of the present research demonstrated that amendment of rice straw with manure is able to increase the levels of organic compounds in the final compost.

Various heavy metals tested in this study (cadmium, lead, copper and zinc) were all at detectable and varying concentrations among the three compost types. ANOVA indicated that mean concentration values of various metals differed significantly among treatments. Lead concentration in the control (T0) was significantly higher than in the other samples ($p < 0.001$) (Table 3). Copper levels in T0 and T1 were significantly lower than those in T2 ($p < 0.001$). Zinc mean levels ranged from 5.10 to 6.50 mg kg^{-1} which were detected in T2 and T1, respectively.

Levels of the heavy metals (Zn, Pb, Cu and Cd) analyzed in the present study were all below limits in the guidelines for countries with set standards for compost utilization (Table 4) (Paradelo et al. 2009). However, low levels of heavy metals in compost can still cause negative impacts to seed germination (Munzuroglu and Geckil 2002). The levels obtained in this study were significantly lower than those reported by Prempeh (2010).

Table 1 Nutritional properties of the starting substrates

Substrate	Mg (Cmol/kg)	Ca (Cmol/kg)	K (Cmol/kg)	P (mg kg^{-1})	CEC (Cmol/kg)	Initial C:N ratio
RS	3.68	24.07	6.85	697.17	13.84	60.33
CM	17.99	39.41	10.00	881.83	24.82	58.67
DM	13.85	30.38	8.81	950.00	29.19	52.00

RS rice straw, *CM* chicken manure, *DM* donkey manure

Table 2 Chemical properties of the final compost

Treatment	P (mg kg^{-1})	Nitrogen (%)	Potassium (Cmol/kg)	CEC (Cmol/kg)	C:N ratio	pH
T0	731.55 ± 19.62c	1.12 ± 0.09b	7.93 ± 0.84	19.98 ± 4.70b	23.75 ± 2.70a	7.57 ± 0.30
T1	1113.50 ± 65.39a	1.87 ± 0.38a	8.15 ± 0.86	25.25 ± 2.90a	10.84 ± 1.28b	7.16 ± 0.48
T2	845.50 ± 17.32b	1.87 ± 0.40a	7.53 ± 0.80	21.70 ± 1.60b	11.32 ± 2.08b	7.32 ± 0.21
p value	< 0.001	< 0.005	0.581	0.005	< 0.001	0.410

p is significant, values followed by the same letters within the columns are not significantly different from each other according to Tukey's honest significant difference (HSD) at 5% level

T0 control, *T1* rice straw treated with chicken manure, *T2* rice straw treated with donkey manure, *CEC* cation exchange capacity

Table 3 Concentrations of heavy metals in various compost types (mg kg^{-1})

Treatment	Cadmium	Copper	Lead	Zinc
T0	0.06 ± 0.02a	1.12 ± 0.06b	3.18 ± 0.21a	6.30 ± 0.13a
T1	0.04 ± 0.00b	1.01 ± 0.11b	1.54 ± 0.37b	6.50 ± 0.14a
T2	0.04 ± 0.00b	1.35 ± 0.03a	1.82 ± 0.31b	5.44 ± 0.39b
p value	0.004	0.001	< 0.001	< 0.001

p is significant, values followed by the same letters within the columns are not significantly different from each other according to Tukey's honest significant difference (HSD) at 5% level

T0 control, *T1* rice straw treated with chicken manure, *T2* rice straw treated with donkey manure

Table 4 Limits of heavy metals (mg kg^{-1}) for countries with compost standards

Element	Cadmium	Copper	Lead	Zinc
Country				
Austria (class 1)	8	1200	9600	4000
Belgium (Agr)	12	750	600	1800
Switzerland	6.2	2500	208	5000
Denmark	5.6	7000	840	28,000
France	15	1000	900	3000
Germany (class 2)	10	700	1000	3000
Italy	15	3000	500	1000
Netherlands (class A)	6	360	600	1200
Spain	150	12,000	15,000	30,000
Canada	1900	75,000	15,000	140,000

Class 1 versus class 2 or class A versus class AA are calculated on 30% organic matter basis

Agr agricultural use (Brinton 2000).

The results of this study generally indicate that the concentration of the heavy metals in the final product either increased or decreased in the treated rice straw compared to the concentrations in the un-treated rice straw. This can be explained by the fact that when microorganisms interact with various chemical elements, the end result is either the creation of a less toxic or a more toxic environment (Chibuike and Obiora 2014).

The presence of lead in the rice straw suggests that the soil might have been contaminated with the heavy metals which ended up being absorbed by the rice crop. This is because conventional rice farming involves intense application of chemical fertilizers. Excessive application of the chemical fertilizers may lead to accumulation of heavy metals in soil which then bioaccumulate in plants growing in such soils (Malidareh et al. 2014; Atafar et al. 2010).

The significantly high-lead concentrations in T0 (control) compared to other treatments indicates that the amendments in the other treatments significantly contributed towards reducing lead from the compost materials during composting (Ingelmo et al. 2012).

Conclusion

Results of the present study indicate that composting of rice straw becomes more enhanced when the straw is treated with chicken manure than with donkey manure. It also shows that thermophilic conditions are attained faster in treated rice straw than in un-treated straw. This study has also shown that co-composting rice straw with chicken and donkey manure has the effect of reducing cadmium and lead metals in the final compost. Composting also improves the nutritional quality of final compost hence the starter cultures in this study could be recommended for co-composting of materials of plant origin.

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