Biodegradation (2009) 20:307–317
DOI 10.1007/s10532-008-9223-1

ORIGINAL PAPER

Quality evaluation of co-composted wheat straw, poultry droppings and oil seed cakes

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Received: 1 February 2008 / Accepted: 12 September 2008 / Published online: 18 November 2008

Abstract Poultry droppings, neem cake, castor cake, jatropha cake and grass clippings were used separately as organic nitrogen additives to decrease the high C:N ratio of wheat straw. Composting was carried out aerobically in presence of fungal consortium developed by including *Aspergillus awamori, Aspergillus nidulans, Trichoderma viride* and *Phanerochaete chrysosporium*. The degraded product was characterized to assess the technical viability of organic nitrogen supplements as well as fungal consortium in improving the quality of compost and hastening the process of decomposition of high lignocellulolytic waste. Evaluation of maturity showed that mixture of wheat straw, poultry dropping and jatropha cake had the lowest C:N ratio of 10:1, the highest humic acid fraction of 3.15%, the lowest dehydrogenase activity and a germination index exceeding 80% in 60 days of decomposition. Inoculated and grass clipping amended wheat straw–poultry dropping mixture resulted in compost with highest humus content of 11.8% and C:N ratio of 13.5, humic acid fraction of 2.84% and germination index of 59.66%. Fungal consortium was effective in improving the humus content of all the composted mixtures. In some treatments, germination index could not be correlated with C:N ratio. Non edible oil seed cake supplemented substrate mixtures did not respond to fungal inoculation as far as C:N ratio was concerned.

Keywords Castor cake · Composting · Grass clippings · Jatropha cake · Maturity · Neem cake · Poultry droppings

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Introduction

The green revolution though has made India self sufficient in food production, but at the cost of soil health. Persistent use of chemical fertilizers, pesticides and increase in irrigation has affected the soil health (Nair 2006). Moreover, the low input of organic material to soil could have reduced the organic matter content, thereby stagnating the food grain production at around 1.5%. To restore the productivity of soil, efforts are being made to give a new meaning to green revolution through the use of organic materials as nutrient sources. In a country like India, where rice–wheat cropping system is the most acceptable crop rotation, being practiced on about 10.5×10^6 ha of land (Narang and Virmani 2001), residue yield for wheat amounts to 3.2–5.6 tons ha^{-1}. For every 4 tons of wheat grain, there is 6 tons of straw produced. After harvesting wheat, 70% of wheat straw is used for animal feed (Bahl and Aulakh 2002) and a little is used for mushroom growth (Blanco and Almendros 1995). The rest is disposed of by burning in the field itself, the most convenient method of waste disposal adopted by farmers. Burning of straw results in the emission of poisonous gasses such as methane, carbon monoxide, carbon dioxide and nitrous oxide, that have both ecological and environmental implications (Westerman and Bicudo 2005; Badrinath et al. 2006). In view of the health hazards created due to straw burning, an economical, environment friendly and low labor intensive strategy may not only eliminate adverse environmental impact, but may also reduce chemical fertilization. The emphasis should be, to make this valuable cereal waste, a resource that can be utilized and not just discarded. The biological conversion of this waste into added value product as compost and its use as soil amendment may be the most sought out options with multiple benefits. The recycling of waste through composting not only reduces disposal of organic wastes but its application to soil allows cultivation in places where soil is a limiting factor and improves the quality of crop by providing nutrients (Raviv et al. 1999; Gaind et al. 2006b). Conversion of any waste into organic fertilizer such as compost is strictly influenced by the nutrient status of the composting substrates. Although, wheat straw is cheap, easily available, and a rich source of carbohydrate (53.0%), but its high lignin content (17%) and a high C:N of 110, puts severe constraints on its biological degradation to prepare compost. In India, most of the research is confined to the use of urea, for lowering the high C:N ratio of agro residues, but this practice is no more desirable. Therefore, the substitution of chemical nitrogen with an organic form is the need of the hour. A wide range of wastes such as soybean meal, dry blood, fish meal etc., have been studied as nitrogen supplement for reducing the high C:N (Blanco and Almendros 1995), but there is dearth of literature on use of agro-industrial residues as nitrogen amendment. The non edible oil seed cakes such as neem cake (*Azadirachin indica*), castor cake (*Ricinus communis*), jatropha cake (*Jatropha curcas*) along with poultry droppings and grass clippings are a few nitrogen, phosphorus and potassium rich wastes that can be explored to improve the nitrogen content of cellulosic wastes with high C:N ratio. Moreover, inoculation with cellulolytic fungi may ease the process of decomposition of straw and improve the quality of finished compost as reported in the literature (Gaur et al. 1982; Gaind and Nain 2007). So the scopes of the present investigation were (i) to compare the different organic nitrogen sources as substitute to urea in order to select the most efficient material for preparing organic compost (ii) to study the compatibility of oil seed cakes with inoculated fungal consortium (iii) to investigate the effect of de-oiled seed cakes on the compost quality (iv) to assess the bioavailability of heavy metals for safe use of mature compost in farm land.

Materials and methods

Microorganisms

Four mesophilic fungal strains of genus *Aspergillus, Trichoderma* and *Phanerochaete* collected from different sources (Table 1) were selected on the basis of cellulase, cellobiase and xylanase activity (Wood and Bhat 1988), using minimal medium containing 1% paddy straw as the sole carbon source. A consortium of four fungi (*Aspergillus awamori, Aspergillus*

Table 1 Cellulolytic and xylanolytic activity (IU g^{-1}) of fungi used as consortium in composting

Fungal culture	Strain no.	Origin	Filter paper cellulase	Carboxy methylcellulase	Cellobiase	Xylanase
Aspergillus awamori	F18	Microbiology Div. IARI, New Delhi	6.01	5.12	0.85	2.16
Aspergillus nidulans	ITCC 2011	Microbiology Div. IARI, New Delhi	4.63	44.46	14.71	32.91
Trichoderma viride	ITCC 2211	Microbiology Div. IARI, New Delhi	11.01	42.91	14.32	30.51
Phanerochaete chrysosporium	NCIM 1073	NCIM, Pune	7.94	27.19	20.28	22.10

nidulans, Trichoderma viride and *Phanerochaete chrysosporium*) was used as inoculum to degrade organic nitrogen amended wheat straw.

Inoculum development

Sorghum grains were used as substitute for fungal strain growth. The grains were softened by keeping them in boiled water for 1 h and mixed with 2% calcium carbonate and 4% calcium sulphate. A loopful of individual culture was inoculated in each set of 500 g grains in flasks (sterilized at 15 lb pressure for 1 h) and incubated at 25°C for 15 days. The whole growth of each strain including mycelium, spores and the grains were used as the inoculum. Equal quantities of each fungal inoculum were mixed together to make a consortium.

Composting substrates

Wheat straw used as the primary substrate for composting was obtained from Agronomy Division, Indian Agricultural Research Institute (IARI), New Delhi. Poultry droppings were procured from one of the local poultry farms. The other selected nitrogen additives, neem cake, castor cake and jatropha cake (sub products generated in agro-industrial area of India) were obtained from Division of Environmental Sciences, IARI, New Delhi. However, grass clippings were collected from Microbiology Division, IARI. Udaipur rock phosphate (32% P_2O_5) obtained from Rajasthan, was incorporated at 1% (w/w) of substrate mixture to all the treatments for phosphorus nutrition. The elemental composition of different substrates used is given (Table 2).

Preparation of composting piles

Fifty-two kilogram of wheat straw (W.S) was mixed with 8 kg poultry dropping (P.D) to reduce its high initial C:N. This treatment (T1–T2) in duplicate, referred as control. Different agro-processing de-oiled cakes viz. neem cake, castor cake, jatropha cake and grass clippings were also investigated as nitrogen supplements. The treatments T3–T10 of composting piles were prepared by mixing wheat straw (51 kg) + poultry droppings (7.5 kg) and different de-oiled cakes/grass clippings (1.5 kg) added separately. Sixty kilogram substrate mixture of each treatment was filled in cemented pits of 1 m^3, having perforations (Fig. 1), as per treatment schedule given in Table 3. The composting mixture was moistened by adding about 130 l of water/pit and left undisturbed for 12 h to absorb moisture. One set of each treatment was then inoculated with 180 g of seed based inoculum pit^{-1}, while remaining compost was the uninoculated controls. During co-composting, the material was turned manually at fortnight intervals and water was added from time to time to maintain the moisture at 50–60% during thermophilic phase

Table 2 Elemental composition of raw materials (on dry wt basis) used during composting

Parameters	Substrates					
	Wheat straw	Poultry dropping	Neem cake	Castor cake	Jatropha cake	Grass clipping
Organic matter (%)	91.30	17.24	74.68	93.69	94.69	91.09
Carbon (%)	53.01	10.01	43.32	54.35	54.99	52.84
Nitrogen (%)	0.48	2.01	2.24	5.46	3.57	2.17
C/N	110	5.00	19.34	9.95	15.38	24.35
P_2O_5 (%)	0.16	2.00	1.12	1.93	2.42	0.32
K_2O (%)	1.18	4.22	1.51	1.90	7.15	3.34
Moisture (%)	15.01	4.01	7.62	6.81	6.22	65.01
Cu (mg kg^{-1})	0.14	0.84	0.38	0.40	0.71	0.41
Fe (mg kg^{-1})	2.14	5.05	1.93	1.73	0.80	1.73
Mn (mg kg^{-1})	2.37	4.24	1.53	1.53	0.98	1.96
Zn (mg kg^{-1})	2.19	7.31	0.63	0.91	0.49	1.28
Mg (mg kg^{-1})	69.12	165.54	75.75	54.55	86.89	83.68

Fig. 1 Appearance of compost during wheat straw degradation process

Table 3 Chemical analysis of composting mixtures at different intervals of composting

Treatments	Organic matter (%)			TOC (%)			TKN (%)			C/N		
	0 days	30 days	60 days	0 days	30 days	60 days	0 days	30 days	60 days	0 days	30 days	60 days
W.S + P.D (U)	81.42	34.24	31.30	42.32	17.94	16.44	0.68	0.44	0.95	62.23	40.77	17.30
W.S + P.D (I)	81.42	36.94	31.94	42.32	19.31	16.76	0.68	0.52	1.01	62.23	37.13	16.59
W.S + P.D + N.C (U)	81.63	18.44	13.60	42.11	9.88	7.41	0.72	0.34	0.45	58.48	29.05	16.46
W.S + P.D + N.C (I)	81.63	20.26	15.36	42.11	10.48	8.31	0.72	0.47	0.49	58.48	22.29	16.62
W.S + P.D + C.C (U)	82.10	35.82	20.60	42.35	18.74	10.98	0.80	0.71	0.76	52.93	26.38	14.44
W.S + P.D + C.C (I)	82.10	40.34	29.40	42.35	21.05	15.47	0.80	0.79	0.86	52.93	26.64	17.98
W.S + P.D + J.C (U)	82.13	23.98	18.33	42.36	12.70	9.82	0.75	0.64	0.98	56.48	19.84	10.02
W.S + P.D + J.C (I)	82.13	25.68	15.50	42.36	13.57	10.93	0.75	0.59	0.86	56.48	23.00	12.71
W.S + P.D + G.C (U)	82.04	37.34	29.60	42.32	19.52	15.57	0.71	0.54	0.59	59.60	36.14	26.38
W.S + P.D + G.C (I)	82.04	30.88	17.60	42.32	16.22	9.45	0.71	0.64	0.70	59.60	25.34	13.50
LSD ($P = 0.05$)	0.42	2.02	1.82	0.22	1.23	1.48	0.03	0.06	0.07	–	–	–

W.S wheat straw, *P.D* poultry droppings, *N.C* neem cake, *C.C* castor cake, *J.C* jatropha cake, *G.C* grass clippings, *TOC* total organic carbon, *TKN* total Kjeldahl's nitrogen, *U* uninoculated, *I* inoculated

All the results are represented as mean of three replicates

and at 40–50% afterwa\ds. The composting period lasted for 60 days. The composting temperature was measured with a thermometer at a depth of 50–60 cm at an interval of 0, 2, 4, 7, 10, 30 and 60 days (Fig. 2). The change in color and texture were also recorded with the progressive decomposition (Fig. 1).

Sampling and chemical analyses

A 200 g composted material was drawn from three different depths of each pit after an interval of 30 days and mixed to make a composite sample. A representative sample was taken from each composite

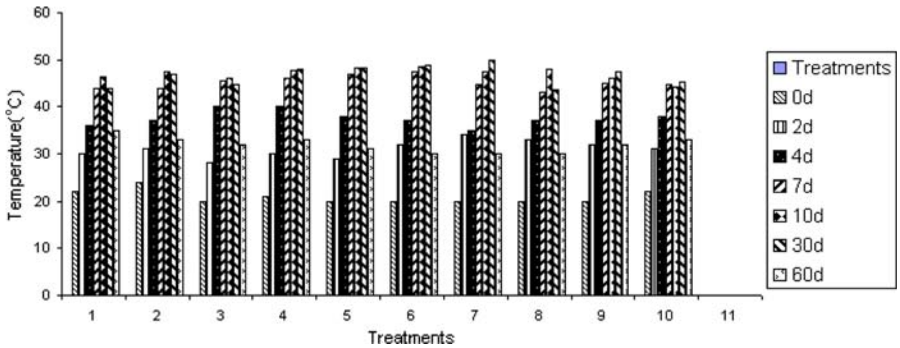

Fig. 2 Temperature variation during different intervals of composting. Treatments: T1, W.S + P.D (U); T2, W.S + P.D (I); T3, W.S + P.D + N.C (U); T4, W.S + P.D + N.C (I); T5, W.S + P.D + C.C (U); T6, W.S + P.D + C.C (I); T7, W.S + P.D + J.C (U); T8, W.S + P.D + J.C (I); T9, W.S + P.D + G.C (U), T10, W.S + P.D + G.C (I). *W.S* wheat straw, *P.D* poultry droppings, *N.C* neem cake, *C.C* castor cake, *J.C* jatropha cake, *G.C* grass clippings, *U* uninoculated, *I* inoculated

sample, dried in air and ground finely to pass through 1 mm sieve for chemical analyses. The other portion was kept in a refrigerator for assay of dehydrogenase enzyme. All the analyses were carried out at 30 and 60 days intervals.

Changes in different chemical parameters during the process of wheat straw decomposition were determined following the standard procedure. Analysis involved the determination of moisture content by drying samples at 105°C for 24 h. Ash content was estimated by determining the loss of weight after burning the sample in a muffle furnace at 550°C for 5 h. The pH and electrical conductivity were measured in compost: water suspension (1:5, w/v) using a digital pH meter and total dissolved solids (TDS) Scanner, respectively. Total organic carbon was calculated from organic matter according to the formula of Navarro et al. (1993):

$$\%\,\mathrm{TOC} = 0.51 \times \%\,\mathrm{O.M} + 0.48. \tag{a}$$

Extraction of water soluble carbon (Cw) fraction from the compost was carried out with compost: water ratio of 1:10 (w/v) followed by shaking for 1 h at a shaker. The contents were centrifuged at 10,000 rpm for 10 min and carbon estimated by wet digestion method as described by Walkley and Black (1934). Total N was estimated by Kjeldahl's procedure (Jackson 1973). Available P content of compost samples was determined by standard method of Dickman and Bray (1940). Humus content was extracted by shaking 5 g compost with 100 ml of 0.1 M alkaline sodium pyrophosphate for 2 h. A portion of the supernatant after centrifugation was dialyzed under running water for 24–48 h. Humic acid was precipitated in the 25 ml of the alkaline extract with 0.1 N HCl to a pH value lower than 2.0 (Kononova 1966).

Germination index

Effect of compost maturity on seedling emergence was determined by measuring germination index using Garden cress (*Lepidium sativum*) seeds. Seeds were placed on sterile filter paper soaked with 2 ml of compost: water (1:10, w/v) extract for 48–72 h in the dark at 27°C. Number of seeds germinated on the filter paper in Petri dish were recorded and root length measured. Seeds germinated in distilled water served as control (Zucconi et al. 1981). Germination index (GI) was expressed as under:

$$\mathrm{GI}\,\% = \frac{\text{Seeds germination}\,\% \times \text{Root length of treatment}}{\text{Seeds germination}\,\% \times \text{Root length of control}} \times 100 \tag{b}$$

Assay of dehydrogenase activity

The method is based on compost sample incubation with triphenyl tetrazolium chloride at 28°C for 24 h and a colorimetric determination of triphenyl formazan (TPF) formed at 485 nm (Casida et al. 1964). Enzyme concentration was represented as IUg^{-1}. One international unit (IU) is defined as μmol of TPF produced g^{-1} h^{-1}.

Estimation of extractable heavy metals

Soluble heavy metals were determined after extraction of 2.5 g compost sample of each treatment with 50 ml of 0.005 M diethylene triamine pentaacetic acid (DTPA) plus 0.1 M triethanolamine (TEA) and 0.01 M $CaCl_2$ buffered to pH 7.3 with dilute hydrochloric acid (Lindsay and Norvell 1978). The estimation was carried out at room temperature by keeping mixture for 2 h in orbital shaker. The suspension was filtered through Whatman no 42 filter paper in a dark flask and the solution analyzed for Cu, Fe, Mn, and Zn by atomic absorption spectrophotometer (Model GBC Avanta PM, GBC Scientific Equipment Pvt. Ltd., Victoria, Australia) at the most sensitive resonance wave length, respective to each trace element.

Statistical analysis

All the data (mean of determinations made on three replicates) were subjected to analysis of variance using least significance difference test comparing the difference between specific treatments (Panse and Sukhatme 1978).

Results and discussion

Quantitative evaluation of enzymes produced by consortium fungi

Table 1 represents the quantitative evaluation of four fungi for cellulase, cellobiase and xylanase production. Based on their enzyme activity, they were selected for fungal consortium to degrade lignin bound cellulose in wheat straw. *Aspergillus awamori* (F18), though producing a low amount of carboxymethylcellulase, cellobiase and xylanase compared to other three strains, was also included in the consortium because of being a potential rock phosphate solubilizer (Gaind and Gaur 1990).

Elemental composition of substrates used to prepare compost (Table 2) showed wide variation in their C, N and P content. Wheat straw because of its easy availability, high organic matter, high oxidizable organic carbon (53.0%), high moisture retention capacity and high C/N ratio, was found to be a good option as a primary substrate for composting. Similarly, poultry droppings, the de-oiled cakes and grass clippings with high nitrogen and phosphorus concentration, low heavy metal content and easy availability indicated their suitability as source of nitrogen. However, the toxicity associated with de-oiled cakes limits their use in large proportion. Therefore, poultry droppings were supplemented with a small amount of different seed cakes (1.5 kg/pit) with a purpose to trap the natural resources as well as to avoid any deleterious effect on microbes. As an initial C:N of 50 is desirable to avoid low decomposition rates due to low N levels restricting microorganisms functioning, the blend of wheat straw, poultry dropping and seed cakes/grass clippings, in a proportion of 51 + 7.5 + 1.5 kg, respectively, was considered most suitable for multiplication of both native and introduced microorganisms implicated in the process.

In general, temperature of all the pits reached >45°C within the first week of composting and ranged between 48 and 50°C for 30 days with the exception of T7 (with temperature about 52°C), showing rapid initiation of composting process (Fig. 2). Thereafter, it declined and reached at an ambient stage of 35°C. The straw was found to be colonized by fungal mycelium and *Coprinus* spp. appeared in most of the substrate mixture surface on fifth day of composting. This fungus initially gave a mushroom like appearance in which lamellae auto digested to release black ink like spores. Noticeable changes in color, odor and texture of growing mass were observed with gradual decomposition. After 2 months of composting, the finished compost was a dark brown colored, crumbled mass (Fig. 1), with no foul odor and moisture content ranging between 20% and 25%.

Table 3 represents the changes in organic matter, total organic carbon (TOC), total Kjeldahl's nitrogen (TKN) and C/N ratio. Organic matter decreased in all the substrate mixtures from their initial values with loss in the range of 55–77% indicating a good level of degradation. The loss of organic matter content was more in the first month sampling. This may be due to loss of carboxylic and phenolic functional groups of humic and fulvic acids and hydrocarbon compounds as well as due to decarboxylation of metallic hydroxides. Similarly organic carbon content also decreased with progressive degradation. At the end of 2 months, the highest and the lowest organic carbon was achieved in treatment receiving W.S + P.D and W.S + P.D + neem cake, respectively, with no statistically significant difference in the inoculated and uninoculated counterparts. High TOC may be due to low mineralizable compounds in poultry droppings. Loss of carbon as CO_2 decreased the carbon content of the compostable material. The nitrogen content decreased after 30 days and that may be due to loss of nitrogen in the form of NH_3. With progressive composting, nitrogen content increased in T1, T2, T6, T7 and T8 only. However, the high loss of organic matter, low total organic carbon and high nitrogen content resulted in a reduction of C:N ratio (Table 3).

C:N ratio is considered as one of the important parameter to check the maturity of compost. Taking this parameter into account, the results showed that the effect of fungal inoculation was most pronounced in P.D + G.C amended wheat straw mixture. The inoculation reduced the final C:N to 13.50, whereas its uninoculated counterpart had the C:N of 26.38 (Table 3). The inoculation effect was meager for poultry amended wheat straw where C:N was reduced from 17.3 to 16.59. However, the inoculation effect was not recorded for either of the de-oiled cake supplemented treatments, as their respective uninoculated treatments had the C:N lower than their inoculated counterparts. This may be due to fungicidal effect of different oil seed cakes. Some of the microbial flora may be sensitive to the metabolites of these oil seed cakes resulting in their mortality. Though, most of the composted mixtures resulted in C:N < 20, but the most desired C:N of 10 was achieved with uninoculated jatropha cake, supplemented W.S + P.D mixture. Golueke (1981) reported that C:N below 20 is indicative of acceptable maturity. A ratio <15 or even lower is preferable for agricultural crop residues as plants cannot assimilate mineral nitrogen unless C:N ratio is in the order of 10–15:1 (Edwards and Bohlen 1996). Such compost when added to well humified soil may help to maintain the microbiological equilibrium of soil (Allison 1973). The variation in degree of decomposition and mineralization may be because of the variation in substrate quality. The findings were supported by the publication of Hirai et al. (1983).

An increase in humic acid content was observed in all the inoculated treatment compared to their uninoculated counter parts with the exception of jatropha cake amendment, where uninoculated treatment showed higher values of 3.15%. However, the values for poultry dropping amended treatment (T1 and T2) did not show any variation in the uninoculated and inoculated treatments (Table 4). The value higher than 1.7% has been considered as the threshold value for the maturity of that particular mixture (Iglesias-Jimenez and Perez Garcia 1992). The higher the value of humic acid, more mature is the compost. Humification during composting of organic substrates is considered an important indicator of compost maturity as it results in the decomposition of non-humic substances and formation of humic substances (Tiquia 2005). Therefore, humic acid fraction generally increases during composting, demonstrating the humification of organic matter. Only poultry dropping amended wheat straw mixture showed the lowest values (with no change in the U and I treatment), indicating that this compost still had some humic acid carbon that can undergo degradation.

Humus content of all the substrate mixtures showed an increasing trend towards the maturity of the compost. Highest humus content of 11.8% was achieved in the inoculated grass clippings amended W.S + P.D compost (Table 4). Inoculation improved the humus content of all the composts with the exception of castor cake amended wheat straw compost where uninoculated treatment had the higher humus content in the mature compost. This may be due to the presence of allergenic protein fraction (2S albumin isoforms) that is more stable to heat compared to ricin (a protein) and ricinine (an alkaloid). This protein may be a hazard for the inoculated fungi (Oliveira et al. 2007).

Water soluble carbon (Cw) fraction of all the composted mixtures decreased during composting due to degradation of organic compounds such as sugars, amino acids, peptides etc. The values ranged

Table 4 Evaluation of maturity parameters of wheat straw compost

Treatments (%)	Humic acid (%)		Humus (%)		Cw (%)		GI (%)	
	30 days	60 days	30 days	60 days	30 days	60 days	30 days	60 days
W.S + P.D (U)	0.34	0.79	4.44	6.72	0.46	0.07	48.08	88.06
W.S + P.D (I)	0.39	0.79	4.54	8.25	0.59	0.20	32.87	58.12
W.S + P.D + N.C (U)	0.79	1.79	2.30	5.14	0.62	0.24	30.06	50.02
W.S + P.D + N.C (I)	0.89	1.84	4.18	6.47	0.63	0.13	20.32	32.04
W.S + P.D + C.C (U)	1.05	2.32	2.72	7.85	0.49	0.17	42.98	77.56
W.S + P.D + C.C (I)	1.32	2.89	3.74	6.33	0.58	0.18	53.76	87.27
W.S + P.D + J.C (U)	1.48	3.15	3.08	5.24	0.39	0.35	54.77	80.09
W.S + P.D + J.C (I)	1.22	2.36	3.06	6.05	0.53	0.16	49.98	77.55
W.S + P.D + G.C (U)	1.13	2.63	3.54	9.06	0.56	0.06	36.78	53.43
W.S + P.D + G.C (I)	1.37	2.84	3.54	11.80	0.58	0.07	39.67	59.66
LSD ($P = 0.05$)	0.21	0.32	0.54	0.68	0.047	0.012	2.86	4.76

W.S wheat straw, *P.D* poultry droppings, *N.C* neem cake, *C.C* castor cake, *J.C* jatropha cake, *G.C* grass clippings, *Cw* water soluble carbon, *GI* germination index, *U* uninoculated, *I* inoculated

All the results are mean of three replicates

between 0.38 and 0.63 after 30 days and 0.07–0.35 after 60 days (Table 4), far below the threshold value of 1.7% (Bernal et al. 1998).

Different values for germination index were recorded for different composting mixtures (Table 4). The inoculated neem cake supplemented wheat straw mixture had the lowest value of 32%, far below the threshold value of 50–60%. This may be due to some growth limiting products pre existing in raw cakes that have greater impact on germination than those formed during composting in agreement with the findings of Kuwatsuka and Shindo (1973).

The germination index and C:N ratio (both maturity parameters) could not be correlated, as the inoculated neem cake amended compost had a C:N ratio of 16.62 and germination index of 32%. However, inoculated poultry dropping amended wheat straw compost showed a C:N ratio of 16.59 and a germination index of 58.12% but its uninoculated counter part showed a C:N ratio of 17.30 and a germination index of 88.0%.

Change in pH during composting showed an increase in its values after first month of sampling in all, but grass clipping treatment (Table 5) and that may be due to the production of NH_4^+ during proteolysis. In most of the cases it was in the neutral range of 6.5–7.4 after 60 days. Neutral pH is the most desired, as at this pH there will be less volatilization of NH_3, reduced odor and balanced microbial population.

Electrical conductivity indicates the level of total dissolved salts in a compost sample at particular stage of degradation and the most desired value should be <3.0 dS m^{-1} (WERL 2000). All the substrate mixtures showed a decline in their EC values with the progressive degradation and the values were lower than 3.0 dS m^{-1} (Table 5).

Dehydrogenase activity is a measure of total biological activity in compost and an easy method to monitor compost maturity. Enzyme assay showed much higher values in the first month, followed by a declining trend as the composting proceeded. Inoculated fungi and native flora degraded the resistant component of substrate when there was scarcity of available components. It was interesting to note that uninoculated, jatropha cake amended wheat straw mixture had the lowest dehydrogenase activity compared to its inoculated counterpart at the end of 2 months. The decrease in dehydrogenase activity to low values toward end of composting indicate that there is no more active decomposition taking place and compost has reached maturity (Tiquia 2005). All other composted mixtures had dehydrogenase activity values much higher than jatropha cake amended compost (Table 5). Inoculated G.C + P.D, amended wheat straw compost had

Table 5 Chemical and biochemical parameters of nitrogen amended wheat straw

Treatments	pH			EC (dS m^{-1})			Dehydrogenase activity (μg TPF g^{-1} h^{-1})			Available P (ppm)		
	0 days	30 days	60 days	0 days	30 days	60 days	0 days	30 days	60 days	0 days	30 days	60 days
W.S + P.D (U)	7.0	6.7	6.8	1.42	2.34	0.76	118.50	1865.53	775.30	480.71	846.32	492.94
W.S + P.D (I)	7.0	6.6	7.0	1.42	2.00	0.55	120.30	2504.87	946.88	487.67	523.06	362.67
W.S + P.D + N.C (U)	6.7	7.1	7.4	2.20	2.10	0.55	137.52	1279.52	866.44	920.42	315.24	151.88
W.S + P.D + N.C (I)	6.7	7.6	7.4	2.20	1.99	0.50	143.47	1411.69	994.08	932.24	357.07	121.66
W.S + P.D + C.C (U)	6.8	6.7	7.1	2.72	1.80	0.50	127.53	1238.47	540.62	987.78	228.37	189.53
W.S + P.D + C.C (I)	6.8	6.4	7.1	2.72	2.60	0.52	119.27	1547.09	607.08	976.78	208.93	192.35
W.S + P.D + J.C (U)	6.6	6.7	7.9	1.73	1.20	0.87	115.32	740.38	500.22	590.84	82.58	131.94
W.S + P.D + J.C (I)	6.6	7.1	6.5	1.73	1.30	0.81	128.22	628.79	523.94	611.35	105.94	179.65
W.S + P.D + G.C (U)	7.0	7.8	6.8	3.53	3.00	1.40	154.22	1765.4	1537.20	970.10	664.33	553.76
W.S + P.D + G.C (I)	7.0	7.4	6.8	3.53	3.50	0.86	172.35	3524.38	986.95	976.20	808.79	564.88
LSD ($P = 0.05$)	0.1	0.1	0.1	0.12	0.23	0.16	19.67	120.23	32.89	32.27	47.89	26.47

W.S wheat straw, *P.D* poultry droppings, *N.C* neem cake, *C.C* castor cake, *J.C* jatropha cake, *G.C* grass clippings, *P* phosphorus, *EC* electrical conductivity, *U* uninoculated, *I* inoculated

All the results are mean of three replicates

dehydrogenase values much lower than their uninoculated counter part and the same was reflected in evaluation of C:N.

Maturity is also related to humic acid fraction (responsible for regulating the carbon cycle and acts as a stimulant for the proliferation of microflora) of compost generated towards the last stage of composting. An inverse relation between dehydrogenase activity and humic acid fraction was observed in agreement with the findings of Veeken et al. (2000). At the initial stage of composting, organic matter is mineralized and respiration rate is high. However, during maturity, as most of the organic matter is stabilized, and respiration rate slows down, the increase in humic acid fraction corresponds to decrease in dehydrogenase activity. Uninoculated, jatropha cake amended compost had the highest humic acid fraction and lowest dehydrogenase activity. This showed that compost was mature within 60 days of decomposition.

Available phosphorus estimations showed a declining trend as the composting progressed (Table 5). However, jatropha cake supplemented treatment showed variation, as available phosphorus was found to increase compared to first month values. It may be related to high humic acid fraction of this treatment. Humic acid formation prevents the formation of insoluble calcium phosphate (Grossl and Inskeep 1991). Highest available phosphorus in the first month of decomposition was achieved in grass clipping supplemented wheat straw and lowest in jatropha cake supplemented treatment. Lower available *P* values were recorded in treatments, showing high humic acid fraction with the exception of T9 and T10.

Bioavailability of heavy metals

DTPA extraction is considered as representing a potential source of metals for plants. Potentially

Table 6 Concentration of available micronutrients (mg kg^{-1}) in substrate mixtures at initial time

Treatments	Cu	Fe	Mn	Zn
W.S + P.D	0.98	7.19	6.61	9.50
W.S + P.D + N.C	1.36	21.12	8.14	10.13
W.S + P.D + C.C	1.38	8.92	7.74	10.41
W.S + P.D + J.C	1.69	7.99	7.59	9.99
W.S + P.D + G.C	1.40	8.92	8.57	10.78

W.S wheat straw, *P.D* poultry droppings, *N.C* neem cake, *C.C* castor cake, *J.C* jatropha cake, *G.C* grass clippings, *U* uninoculated, *I* inoculated

Table 7 Concentration of available micronutrients (mg kg^{-1}) at 60 days of composting

Treatments	Cu	Fe	Mn	Zn
W.S + P.D (U)	0.26	2.40	3.46	2.77
W.S + P.D (I)	0.15	2.10	3.38	2.06
W.S + P.D + N.C (U)	0.13	1.85	2.91	1.07
W.S + P.D + N.C (I)	0.99	1.66	2.87	0.90
W.S + P.D + C.C (U)	0.21	2.06	3.95	1.52
W.S + P.D + C.C (I)	0.15	2.26	3.48	1.20
W.S + P.D + J.C (U)	0.09	1.64	2.59	0.84
W.S + P.D + J.C (I)	0.12	2.70	3.43	6.73
W.S + P.D + G.C (U)	0.38	4.24	2.46	12.03
W.S + P.D + G.C (I)	0.24	3.84	1.88	11.63
LSD ($P = 0.05$)	0.03	0.21	0.32	0.41

W.S wheat straw, *P.D* poultry droppings, *N.C* neem cake, *C.C* castor cake, *J.C* jatropha cake, *G.C* grass clippings, *U* uninoculated, *I* inoculated

extractable form of heavy metals is more important than the total metal content of a compost sample because of their possible transfer into food chain (Canarutto et al. 1991).The concentration of extractable metals under study (Cu, Fe, Mn and Zn) decreased at maturity in all the substrate composts (Table 7). This decreased availability suggested that there may be a conversion of this fraction to non-extractable and non-exchangeable form either due to adsorption or formation of complex with humic substances. The results were in agreement with the findings of Canarutto et al. (1991) and Gaind et al. (2006a). Some metals can also become insoluble due to the formation of metal oxides, hydroxides. Availability pattern followed the order of Cu < Mn < Fe. Though, some variation in availability content of Zn was observed with grass clippings amended wheat straw compost (Tables 6, 7). The increased concentration of Zn may be due to the fact that it is less tightly held by humic substances. Field studies need to be carried out to assess the effect of compost on crop growth.

Conclusions

The present investigation was an absolute attempt to exploit natural resources, recycling them and converting them into value added product by low labor intensive and eco-friendly technology. The evaluation of chemical and biological parameters during the decomposition of wheat straw amended with nitrogen rich organic substrates suggest that most of the maturity indices applied to wheat straw compost were met with the exception of humic acid in T1 and T2 and GI in T3 and T4. A correlation between C:N and germination index could not be established. The variation in degree of mineralization and decomposition may be due to variation in substrate composition. Though, fungal consortium was not effective in lowering the C:N ratio of de-oiled seed cake amended wheat straw compost, the humus content and humic acid fraction of all the substrate mixtures was definitely improved. Using grass clippings (cheapest and easily available source of organic nitrogen) and fungal consortium, a mature compost with C:N of 13.5 can be obtained with in 2 months. However, amendment of wheat straw with jatropha seed cake, and poultry droppings resulted in compost with most desired C:N of 10 with in the same period. This preparation may be more economical from the farmer's point of view as this will save the cost of inoculum. Bioavailability analysis of heavy metal showed that finished compost had reduced level of heavy metals and can be safely applied to farm land. The composts so prepared may also be used on farm land under organic farming, as no chemical supplement was used. The seed cake amended compost may have some bio-pesticide properties and that aspect needs to be investigated. Findings also suggested that higher proportion of poultry dropping may reduce the final C:N without inoculation, but needs to be evaluated.

References

Allison FE (1973) Soil organic matter and its role in crop production. Development in soil science, vol 3. Elsevier, Amsterdam

Badrinath KVS, Kiranchand TR, Krishna Prasad V (2006) Agriculture crop burning in the Indo-Gangetic plains—a study using IRS-P6AWiFS satellite data. Curr Sci 91: 1085–1089

Bahl GS, Aulakh MS (2002) Crop residues as renewable plant nutrients resources. Agriculture Tribune Chandigarh, India, pp 1–2

Blanco MJ, Almendros G (1995) Evaluation of parameters related to chemical and agrobiological qualities of wheat straw composts including different additives. Bioresour Technol 51:125–134. doi:10.1016/0960-8524(94)00125-K

Bernal MP, Paredes C, Mondero MA, Cegarra J (1998) Maturity and stability parameters of composts prepared with a wide range of organic wastes. Bioresour Technol 63:91–99. doi:10.1016/S0960-8524(97)00084-9

Canarutto S, Petruzzelli G, Lubrano L, Vigna-Guidi G (1991) How composting affects heavy metal content. Biocycle 32:48–50

Casida LE, Klein DA, Santoro T (1964) Soil dehydrogenase activity. Soil Sci 98:371–376. doi:10.1097/00010694-196412000-00004

Dickman SR, Bray RH (1940) Colorimetric determination of phosphorus. Ind Eng Chem Anal Ed 12:665–668. doi: 10.1021/ac50151a013

Edwards CA, Bohlen PJ (1996) Biology and ecology of earthworms, 3rd edn. Chapman and Hall, London

Gaind S, Gaur AC (1990) Influence of temperature on the efficiency of phosphate solubilising microorganisms. Indian J Microbiol 30:305–310

Gaind S, Nain L (2007) Chemical and biological properties of wheat soil in response to paddy straw incorporation and its biodegradation by fungal inoculants. Biodegradation 18(4):495–503

Gaind S, Nain L, Goyal D (2006a) Trace element characterization for quality evaluation of compost from amended paddy straw inoculated with fungal consortium. Indian J Microbiol 46:127–132

Gaind S, Pandey AK, Nain L (2006b) Microbial biomass, P nutrition and enzyme activities of wheat soil in response to phosphorus enriched organic and inorganic manures. J Environ Sci Health Part B Pestic Food Contam Agric Wastes 41B(2):177–187

Gaur AC, Sadasivam KV, Mathur RS, Magu SP (1982) Role of mesophilic fungi in composting. Agric Wastes 4:453–460

Golueke CG (1981) Principle of biological resource recovery. Biocycle 22:36–40

Grossl PR, Inskeep WP (1991) Precipitation of dicalcium phosphate dihydrate in the presence of organic acid. Soil Sci Soc Am J 55:670–675

Hirai MF, Chanyasak V, Kubolta H (1983) A standard measurement for compost maturity. Biocycle 24:54–56

Iglesias-Jimenez E, Perez Garcia G (1992) Determination of maturity indices for city refuse composts. Agric Ecosyst Environ 38:331–343

Jackson ML (1973) Soil chemical analysis. Prentice Hall of India Pvt.Ltd., New Delhi, 660 pp

Kononova MM (1966) Soil organic matter, its nature, its role in soil formation and soil fertility. Pergamon, Oxford, 325 pp

Kuwatsuka S, Shindo H (1973) Behavior of phenolic substances in decaying process of plants. I. Identification and quantitative determination of phenolic acids in rice straw and its decayed product by gas chromatography. Soil Sci Plant Nutr 19:219–227

Lindsay WL, Norvell WA (1978) Development of DTPA test for zinc, iron, manganese and copper. Soil Sci Soc Am J 42:421–428

Nair MG (2006) Technology convergence for the next green revolution. In: 36th Lal Bahadur Shastri Memorial Lecture at IARI, New Delhi, India, 8 Feb

Narang RS, Virmani SM (2001) Rice wheat cropping systems of Indo-Gangetic Plain of India. Consortium paper series 11. Rice wheat consortium for Indogangetic Plains, New Delhi, India, pp 1–37

Navarro AF, Cegarra J, Roig A, Garcia D (1993) Relationships between organic matter and carbon content of organic wastes. Bioresour Technol 44:203–207

Oliveira ND, Felix SP, Da Matta RA, Machado OL (2007) Chemical treatment to inactivation of castor cake's allergen. In: International union of biochemistry and molecular biology held at Salvador da Bahia in Brazil, 21–25 May 2007

Panse VG, Sukhatme PV (1978) Statistical methods for agriculture workers. ICAR, New Delhi, 358 pp

Raviv M, Medina S, Shamir Y (1999) Cocomposting—a method, to improve results of poultry manure composting. Compost Sci Util 7:6–16

Tiquia SM (2005) Microbiological parameters as indicator of compost maturity. J Appl Microbiol 99:816–828

Veeken A, Nierop K, de Wilde V, Hamelers B (2000) Characterization of NaOH extracted humic acids during composting of biowaste. Bioresour Technol 72:33–41

Walkley A, Black IA (1934) An examination of Degtareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci 27:29–38

WERL (2000) Compost quality in America, technical document. Woods End Research Laboratory Inc, USA, pp 30–42

Westerman PW, Bicudo JR (2005) Management consideration for organic waste use in agriculture. Bioresour Technol 96(2):215–221

Wood WA, Bhat KM (1988) Methods for measuring cellulose activities. Methods Enzymol 160:87–112

Zucconi F, Forte M, Monaco A, Bertoldi M (1981) Biological evaluation of compost maturity. Biocycle 22(4):27–29