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Co-composting of physic nut (*Jatropha curcas*) deoiled cake with rice straw and different animal dung

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ABSTRACT

To address the dispensing of this growing volume, a study on utilization of jatropha (*Jatropha curcas*) deoiled cake through compost production was carried out. The deoiled cake was composted with rice straw, four different animal dung (cow dung, buffalo dung, horse dung and goat dung) and hen droppings in different proportions followed by assessment, and comparison of biochemical characteristics among finished composts. Nutrient content in finished compost was within the desired level whereas metals such as copper, lead and nickel were much below the maximum allowable concentrations. Although a few finished material contained phorbol ester (0.12 mg/g), but it was far below the original level found in the deoiled cake. Such a study indicates that a huge volume of jatropha deoiled cake can be eliminated through composting.

1. Introduction

Biodiesel feedstock markets worldwide are in transition from increasingly expensive first generation feedstock of soy, rapeseed and palm oil to alternative, lower cost, non-food feedstock. For example, China recently set aside an area the size of England to produce physic nut i.e. jatropha and other non-food plants for biodiesel. *Jatropha curcas*, the non-food biodiesel crop, grown in southern Asia and Africa was cited as one of the best candidates for future biodiesel production (Goldman Sachs, 2010). In Brazil and Africa, there are significant programs underway dedicated to producing non-food crops of jatropha and castor for biodiesel (Emerging market online, 2008).

India with the geographical area of around 316.65 million hectares, has 63.85 million hectares (20.16% of the total geographical area) classified as wasteland (Ministry of Rural Development and National Remote Sensing Centre, 2010). The National Policy on Biofuels released by India promotes the use of wasteland for growing non-edible oilseeds such that a blending of 20% can be achieved by 2017 (Ministry of New and Renewable Energy, 2009). Although the land area and biodiesel requirement for the country is huge, in the first phase – the demonstration phase, the Government of India proposed to cover 0.4 million hectares under jatropha plantations in 26 states (TERI, 2005). These plantations would generate 0.68 million tons of deoiled cake (at the rate of 65% oil recovery with 3 tons/ha oil yield), which is quite a significant amount. Jatropha deoiled cake cannot be used as animal feed because of its toxic properties. It has been reported to possess phorbol esters, a potential toxic compound to animals. Toxicity of *J. curcas* seeds has been studied extensively in different animals like goat, sheep, mice, rats and fish. Decrease in glucose level, lack of appetite, diarrhea, dehydration and other hemorrhagic effects in different organs were the common observations when animals were fed on phorbol ester containing feed (Adam, 1974; Adam and Magzoub, 1975; Makkar and Becker, 1999). However, deoiled cake from jatropha seed is valuable as organic manure due to its high nitrogen content, which is similar to that of seed cake from castor bean and chicken manure. The nitrogen content in deoiled cake varies depending on the source and up to 6.48% was reported in literature (GTZ, 1995). Tender branches and leaves are used as a soil amendment for coconut trees. All plant parts can be used as a green manure. Extracts from different parts of *J. curcas* show molluscicidal and insecticidal properties. The seed oil, extracts of jatropha seeds, and phorbol esters from the oil have been used to control various pests (Wiesenhutter, 2003). Thus, there is a need for further exploration and assessment through investigation for the utilization of the biopesticidal and manurial property of deoiled cake. This will open up the possibilities of the use and application of the seed cake after the oil extraction, as a carrier for bio-fertilizers which are otherwise applied after mixing (diluting) with inert carriers or organic manures like farmyard manure, cow dung or vermicompost. Considering all those aspects, the study was undertaken to produce composts from co-composting of deoiled jatropha seed cake with different animal dung and agricultural residue, rice straw.

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Composting is a bio-oxidative process involving mineralization of organic matter to carbon dioxide, ammonia, water and partial humification leading to a stabilized final product free of phytotoxicity and pathogens. In other words, composting represents a strategy of organic waste treatment that is fully compatible with sustainable agriculture (Adbrecht et al., 2011a,b). Whereas, co-composting means composting of several types of residual matters altogether such as municipal solid wastes and sewage sludge (Fourti et al., 2010); bio-solids and spent active clays (Ho et al., 2010); olive solid residue and olive mill waste water (Zorpas and Costa, 2010).

Besides production of compost, other aims of the study included evaluation of finished compost in terms of nutritional values and phytotoxicity, and to recommend best co-composting combination. The outcome of the study would provide specific information on application suitability of jatropha deoiled cake as manure in agriculture through co-composting with other organic waste.

2. Methods

2.1. Composting method

A composting experiment was conducted at TERI GRAM, Gual Pahari, Gurgaon, India to study the biochemical changes during composting of deoiled cake and animal dung. Mini compost pits, each with a dimension of 0.9 m length × 0.9 m width × 0.9 m height were designed. The floor of the compost pit was made up of concrete slabs to prevent seepage of leachates and subsequent moisture and nutrient loss. Rice straw and animal dung was procured from local farmers, and deoiled cake from the expeller units at Jodhpur. Due to low C:N ratio (Table 1) and high compactness of deoiled cake, a mixture of jatropha deoiled cake and rice straw comprising 1 part of deoiled cake and 9 parts of rice straw (w/w) was used as a principal feedstock, which had a C/N ratio of 37.4.

Table 1
Physico-chemical properties of jatropha deoiled cake ($n = 3$, Mean ± SE).

Parameters	Values
pH	6.28 ± 0.02
EC (dSm^{-1})	9.14 ± 0.03
C/N	10.2 ± 0.10
Total nitrogen (%)	2.93 ± 0.06
Total phosphorus (ppm)	9623 ± 109
Total potassium (ppm)	8563 ± 157

Table 2
Description of mixed substrate used for composting ($n = 3$).

Treatment	Description
T1	JRSM* : Buffalo dung = 20:1
T2	JRSM : Buffalo dung = 10:1
T3	JRSM : Buffalo dung = 5:1
T4	JRSM : Cow dung = 20:1
T5	JRSM : Cow dung = 10:1
T6	JRSM : Cow dung = 5:1
T7	JRSM : Goat dung = 20:1
T8	JRSM : Goat dung = 10:1
T9	JRSM : Goat dung = 5:1
T10	JRSM : Hen droppings = 20:1
T11	JRSM : Hen droppings = 10:1
T12	JRSM : Hen droppings = 5:1
T13	JRSM : Horse dung = 20:1
T14	JRSM : Horse dung = 10:1
T15	JRSM : Horse dung = 5:1

* JRSM = a 1:9 mixture of jatropha deoiled cake and rice straw.

A total of 15 compost recipes (each in replicates of three) comprising various ratios of deoiled cake-rice straw mixture and animal dung (only excretions) were formulated in as per Table 2. Berkley rapid composting method (Raabe, 2001) was followed for composting the feedstock. Jatropha deoiled cake was mixed thoroughly with rice straw and different dung/dropping in desired ratios to give the different treatments and filled in individual concrete pits with 80% moisture at the beginning. The heaps were periodically turned for aeration and water was added whenever required to maintain the moisture content 50–60%. To compensate the large quantity of moisture that can evaporate during composting, to control temperature, and as moisture content diminishes the rate of decomposition decreases, then rewetting should be required in order to maintain the optimum moisture content for the microbial activity (Bernal et al., 2009).

2.2. Biochemical analysis

After twenty-one days, the various compost were collected from the respective pit, air dried and sieved prior to biochemical analysis. The pH and electrical conductivity (EC) were measured in a 1:2.5 solution of dry compost and water. Organic carbon (OC) was determined by colorimetric method at 660 nm (Datta et al., 1962). To determine total P and K, the compost material was first digested with a mixture of nitric acid and perchloric acid (9:4). Phosphorus in the digestate was estimated through formation of vanado-molybdo-phosphoric–heteropoly complex followed by absorbance measurement at 420 nm (Gupta, 2004). Whereas, potassium was measured in the digestate using flame photometer (Singh et al., 2007). Dry compost was processed (H_2SO_4 digestion followed by distillation with NaOH) in Kel Plus Nitrogen estimation system (Classic DX, Pelican Equipments) prior to determination of total nitrogen. Total nitrogen was estimated through titration of the distillate collected from the Kel Plus distillation unit against 0.1 (N) H_2SO_4. C/N ratio was determined after individual estimation of C and N in dry compost using CHNS/O Analyser (2400, Series II, Perkin Elmer). Nitrate nitrogen in the dry compost was measured following aerobic incubation method and ammoniacal nitrogen by anaerobic incubation method (Keeney and Bremner, 1966). Available metal (iron, copper, nickel, manganese and lead) in different compost was measured by estimating metal concentration in diethylene triamine pentaacetic acid (DTPA) extract (Lindsay and Norvell, 1978) of dried compost using Atomic Absorption Spectrophotometer (AAS, SOLAAR, TJA Solutions, UK). Total metal content was also determined by di-acid digestion (nitric: perchloric acid, 9:4) of compost followed by AAS analysis of the digestate (Gupta, 2004).

2.3. Phytotoxicity test

2.3.1. Germination percentage

Phytotoxicity of finished compost was assessed in terms of seed germination percentage of 4 different plant species namely mustard (*Brassica juncea*), sorghum (*Sorghum vulgare*), vigna (*Vigna mungo*) and wheat (*Triticum aestivum*) following modified OECD method (OECD, 1984). Different composts were mixed with control soil (pH ∼ 6) in a ratio of 1:1 and the EC of the resulting mixture was maintained below 50mS/m. 50 seeds from each of the 4 species were sowed in plastic pots containing both control and treated soil (3 replicates per plant per soil-compost mixture) with high moisture content and covered the seeds with the respective mixture. The pots were maintained inside a poly-green house at temperature 20–25 °C, humidity 60–70%, light intensity 5000–6000 lux, length of day time 14 h (sunlight was the only source of light). The germination percentage was calculated using the formula,

$$\% \text{ germination} = (\text{No. of germinated seeds}/\text{No. of seeds sowed}) \times 100.$$

2.3.2. Phorbol ester

The composts were further tested for quantification of phorbol esters (Makkar et al., 1997). Sample preparation for estimation was done by extracting 1.0 g of compost with 10 ml of methanol followed by centrifugation (5 min at 19,098×g) and filtration through 0.22 μ syringe filter. HPLC analysis was carried out on Prominence HPLC (Shimadzu, Japan). The reversed phase chromatrography column (Luna C18) was procured from Phenomenex (USA); 250 × 4.6 mm, octadecyl group, particle size 5 micron. As mobile phase a mixture of acetonitrile and water in the ratio of 80:20 (v/v) was used at a flow rate of 1 ml/min. The detector (Photo Diode Array) wavelength was set on 280 nm and 20 μl of sample solution was injected for analysis.

2.4. Statistical analysis

The data for each physicochemical parameters and phytotoxicity test were analyzed using SPSS (SPSS Inc., version 10.0). One-way analysis of variance (ANOVA) was carried out to compare the means of different treatments where significant *F* value was obtained, difference between individual means were tested using Duncan's multiple range test (DMRT) at 0.05 significance level.

3. Results and discussion

The variation in physico-chemical properties in various finished compost are presented in Table 3 and heavy metal content in Tables 4 and 5.

During composting, temperature of the pit material was found to increase gradually at the initial phase reaching a maximum of around 70 °C, and then decreased to ambient temperature (Fig. 1). Due to variability in starting material, the time required to attain maximum temperature also differed slightly. Moisture content of the experimental pit varied widely during composting (Fig. 2). The main factor responsible for moisture variation is metabolic production of heat, which is a function of aeration rate, agitation, and bulking agent used (Ho et al., 2010).

All the 15 composts had alkaline pH ranging from 8.80 to 9.35 and it may be due to the formation of NH_4^+ during proteolysis and when oxygen is not limiting, organic acid production will be low but ammonia emission will be high, hence pH of the compost rises (Sharma et al., 2009). Electrical conductivity measures the amount of soluble salts in the compost and in the case of fresh compost the values may be in the acceptable range from 3 to 10, and higher and these values determine the application whether

Table 4
Comparison of available Cu, Fe, Mn, Pb and Ni* content among different compost (*n* = 3, Mean ± SE).

Treatment	Cu (ppm)	Fe (ppm)	Mn (ppm)	Pb (ppm)
T1	5.0 ± 0.5[ef]	8.2 ± 0.3[def]	108.2 ± 7.8[fg]	4.3 ± 0.2[cde]
T2	4.9 ± 0.2[ef]	9.1 ± 1.3[de]	131.7 ± 4.8[cd]	3.7 ± 0.4[e]
T3	5.1 ± 0.5[ef]	12.8 ± 1.0[d]	107.1 ± 2.9[fg]	4.4 ± 0.5[cde]
T4	4.2 ± 0.3[f]	5.1 ± 0.5[ef]	99.7 ± 3.5[g]	4.0 ± 0.5[de]
T5	4.4 ± 0.2[ef]	6.2 ± 0.8[ef]	111.5 ± 7.2[efg]	4.2 ± 0.5[cde]
T6	4.7 ± 0.0[ef]	8.4 ± 0.7[def]	109.0 ± 2.1[efg]	4.5 ± 0.4[cde]
T7	11.5 ± 1.1[b]	29.5 ± 1.0[c]	157.2 ± 5.0[a]	8.7 ± 0.3[a]
T8	5.1 ± 0.2[ef]	42.5 ± 4.0[b]	151.3 ± 2.2[ab]	5.2 ± 0.4[cd]
T9	5.2 ± 0.5[ef]	55.8 ± 3.8[a]	155.9 ± 5.3[ab]	2.6 ± 0.3[f]
T10	5.9 ± 0.4[e]	3.4 ± 0.5[f]	126.1 ± 3.8[cde]	5.3 ± 0.3[cd]
T11	9.6 ± 0.3[cd]	5.4 ± 0.4[ef]	110.2 ± 7.0[efg]	5.0 ± 0.1[cde]
T12	13.6 ± 0.5[a]	5.3 ± 0.7[ef]	119.6 ± 3.7[def]	5.4 ± 0.6[c]
T13	8.5 ± 0.8[d]	4.5 ± 0.6[ef]	139.8 ± 4.8[bc]	6.7 ± 0.2[b]
T14	10.2 ± 0.4[bc]	9.4 ± 0.3[de]	109.7 ± 9.4[efg]	8.0 ± 0.5[a]
T15	9.6 ± 0.6[cd]	12.3 ± 0.4[d]	109.0 ± 4.4[efg]	5.3 ± 0.4[c]

*Ni was below detection limit.
Different letters in the same column indicate significant differences at $p < 0.05$ according to Duncan's multiple range test.

Table 5
Comparison of total Cu, Fe, Mn, Pb and Ni*,+ content among different compost (*n* = 3, Mean ± SE).

Treatment	Cu (ppm)+	Fe (ppm)	Mn (ppm)	Pb (ppm)+
T1	21.8 ± 1.7[ef]	815 ± 28[de]	429 ± 21[cde]	22.7 ± 1.8[a]
T2	19.7 ± 1.7[fg]	910 ± 132[de]	402 ± 13[def]	20.2 ± 0.8[abc]
T3	19.3 ± 1.6[fg]	1213 ± 122[d]	378 ± 13[efg]	20.4 ± 0.5[abc]
T4	16.0 ± 1.6[g]	473 ± 29[ef]	355 ± 9[fg]	21.5 ± 0.2[abc]
T5	19.0 ± 1.5[fg]	586 ± 49[ef]	352 ± 8[fg]	19.3 ± 0.6[abc]
T6	18.6 ± 0.8[fg]	815 ± 43[de]	329 ± 14[g]	17.4 ± 0.8[bc]
T7	22.4 ± 1.7[def]	2951 ± 96[c]	580 ± 32[a]	18.9 ± 3.6[abc]
T8	26.5 ± 0.2[de]	4254 ± 392[b]	514 ± 3[b]	16.5 ± 0.6[c]
T9	27.1 ± 0.8[cd]	5585 ± 381[a]	485 ± 36[bc]	17.5 ± 1.8[bc]
T10	31.1 ± 2.1[bc]	282 ± 27[f]	493 ± 24[b]	21.6 ± 0.8[ab]
T11	33.8 ± 1.0[ab]	538 ± 42[ef]	484 ± 8[bc]	21.7 ± 0.1[ab]
T12	37.3 ± 1.2[a]	555 ± 48[ef]	456 ± 21[bcd]	22.9 ± 1.1[a]
T13	26.2 ± 1.8[de]	487 ± 44[ef]	458 ± 15[bcd]	21.9 ± 1.8[ab]
T14	36.4 ± 2.6[a]	963 ± 52[de]	374 ± 14[efg]	21.8 ± 2.4[ab]
T15	20.0 ± 0.5[fg]	1228 ± 39[d]	378 ± 13[efg]	18.8 ± 0.8[abc]

Different letters in the same column indicate significant differences at $p < 0.05$ according to Duncan's multiple range test.
*Ni was below detection limit.
+Maximum acceptable limit in compost: Cu: 500 ppm, Ni: 500 ppm, Pb: 100 ppm (The Municipal Solid Waste) (Management and Handling) Rules, 1999.

Table 3
Comparison of pH, EC, OC, C/N, available N, total P, K among different compost (*n* = 3, Mean ± SE).

Treatment	pH	EC (dSm^{-1})	OC (%)	C/N	N (%)	P (ppm)	K (ppm)
T1	9.02 ± 0.03[abc]	6.62 ± 0.4[ab]	1.11 ± 0.04[cde]	30.1 ± 0.6[ab]	0.082 ± 0.001[b]	11,123 ± 14[f]	12,243 ± 86[bc]
T2	9.04 ± 0.06[abc]	5.76 ± 0.1[bc]	1.08 ± 0.03[de]	27.7 ± 0.5[b]	0.075 ± 0.001[c]	12,413 ± 65[d]	12,530 ± 64[bc]
T3	8.99 ± 0.02[abc]	5.36 ± 0.1[bcd]	1.17 ± 0.09[cde]	28.2 ± 0.2[b]	0.067 ± 0.000[d]	11,819 ± 131[e]	10,353 ± 93[d]
T4	9.00 ± 0.02[abc]	6.25 ± 0.5[abc]	1.14 ± 0.08[cde]	32.5 ± 2.2[a]	0.067 ± 0.000[d]	11,048 ± 29[fg]	12,537 ± 175[bc]
T5	8.91 ± 0.05[bc]	5.75 ± 0.3[bc]	1.32 ± 0.08[abc]	31.7 ± 1.3[a]	0.067 ± 0.000[d]	10,721 ± 25[g]	11,850 ± 49[c]
T6	8.92 ± 0.08[bc]	5.06 ± 1.2[cd]	1.06 ± 0.17[e]	28.7 ± 1.0[b]	0.067 ± 0.000[d]	11,358 ± 80[f]	12,390 ± 86[bc]
T7	9.07 ± 0.02[abc]	4.22 ± 0.6[de]	1.46 ± 0.03[a]	11.2 ± 0.4[e]	0.015 ± 0.002[g]	12,371 ± 135[d]	8163 ± 58[e]
T8	9.35 ± 0.32[a]	4.25 ± 0.08[de]	1.44 ± 0.03[a]	12.0 ± 0.5[de]	0.013 ± 0.003[g]	11,241 ± 102[f]	7857 ± 148[e]
T9	8.86 ± 0.03[bc]	3.36 ± 0.2[e]	1.41 ± 0.05[ab]	11.3 ± 0.6[e]	0.019 ± 0.002[f]	11,165 ± 125[f]	7863 ± 121[e]
T10	8.80 ± 0.25[c]	7.34 ± 0.2[a]	1.29 ± 0.03[abcd]	13.8 ± 0.2[de]	0.082 ± 0.002[b]	17,128 ± 80.7[c]	12,760 ± 350[b]
T11	8.87 ± 0.08[bc]	5.98 ± 0.4[abc]	1.23 ± 0.07[bcde]	13.3 ± 0.3[de]	0.093 ± 0.000[a]	24,632 ± 323[a]	12,740 ± 586[b]
T12	8.81 ± 0.08[c]	6.31 ± 0.3[abc]	1.12 ± 0.07[cde]	14.7 ± 0.5[d]	0.095 ± 0.000[a]	23,125 ± 161[b]	14,790 ± 407[a]
T13	9.21 ± 0.03[ab]	5.43 ± 0.1[bcd]	1.19 ± 0.04[cde]	13.2 ± 0.5[de]	0.070 ± 0.002[d]	9230 ± 30[h]	10,583 ± 233[d]
T14	9.20 ± 0.03[ab]	4.05 ± 0.2[de]	1.18 ± 0.04[cde]	13.4 ± 0.4[de]	0.067 ± 0.000[d]	9130 ± 80[h]	8543 ± 87[e]
T15	8.99 ± 0.04[abc]	3.42 ± 0.4[e]	1.19 ± 0.02[cde]	19.0 ± 0.5[c]	0.055 ± 0.001[e]	7237 ± 135[i]	7033 ± 258[f]

Different letters in the same column indicate significant differences at $p < 0.05$ according to Duncan's multiple range test.

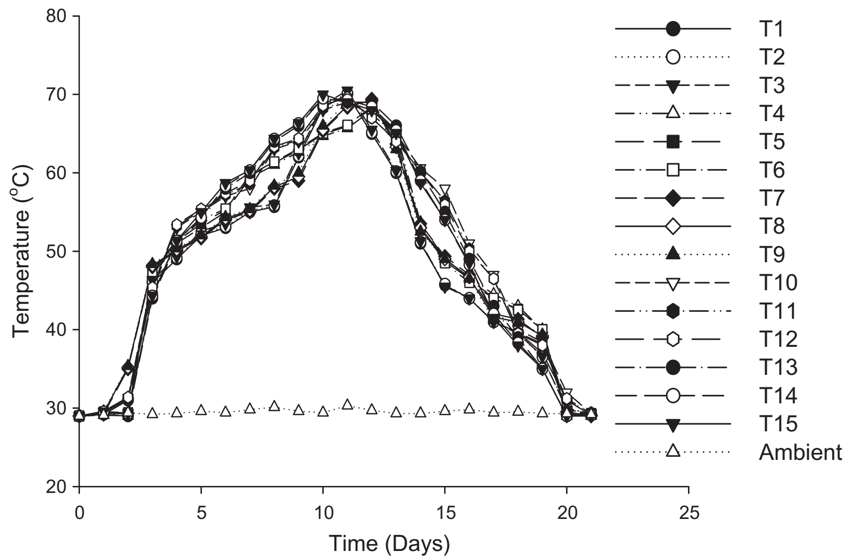

Fig. 1. Variation in temperature during composting.

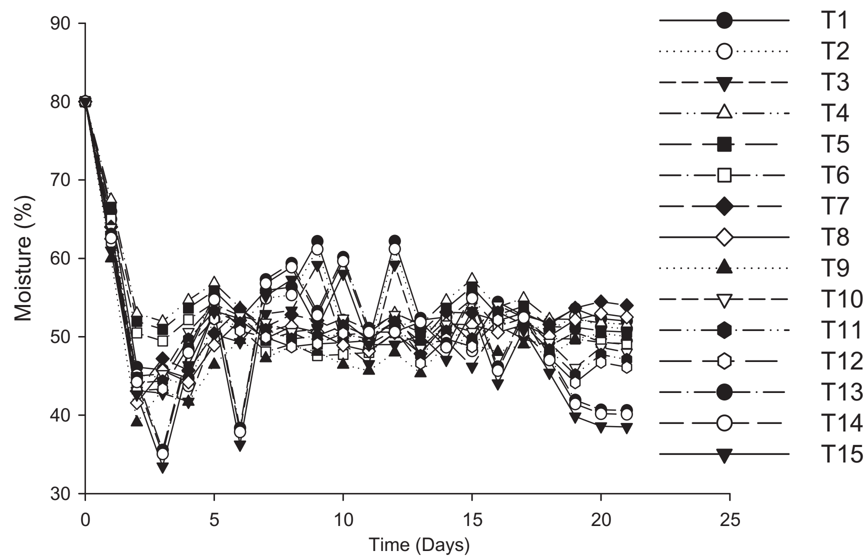

Fig. 2. Variation in moisture content during composting.

the compost is to be diluted or applied as such. Low values of EC indicate the lack of available minerals, while higher than that will inhibit biological activities (Woods End Research Laboratory, 2005). EC values in all the 15 composts were within the desired value. Compost T8 and T10 showed significantly higher ($p < 0.05$) pH and EC, respectively, when compared with other treatments. Loss of organic matter due to microbial degradation and the higher concentration of soluble salts might be the reason for high EC values in finished compost (Kumar et al., 2007).

Organic carbon (OC) varied from 1.06–1.46%, having significantly higher values ($p < 0.05$) in compost containing goat dung (T7–T9). Poor decomposition (microbial utilization of organic matter) might be the reason for high OC content in compost comprising of goat dung. The pellet like structure of goat dung may not allow thorough homogenization with the rest of the JRSM which ultimately affects the decomposition.

Compost containing buffalo and cow dung (T1–T6) showed significantly higher ($p < 0.05$) C:N ratio and those were nearly about 30 (32.5–27.7), characteristic of good quality compost. However, C/N ratio cannot be used as an absolute indicator of compost quality because of the large variability in raw materials and often gives a misleading indication of maturity. Also, it may not reflect a material which is sufficiently decomposed (Hirai et al., 1983; Ko et al., 2008).

Nitrogen, phosphorous and potassium are the nutrients which are utilised in the greatest quantities by plants. Knowledge of the nutrient content of compost is important because the nutrient content can vary widely and also because it allows facility operators to determine an appropriate end use for the compost (Zethner et al., 2000). In general, nutrients are organically bound within compost and are slowly released over a period of time as a result of microbial activity. This ensures a continuous supply of nutrients to the plant (US Composting Council, 2003). The available N in the compost varied from 0.013% to 0.095%, whereas, total P and K were in the range 7128–24,632 ppm and 7237–14,790 ppm, respectively. Compost containing buffalo dung, cow dung and hen droppings showed significantly higher ($p < 0.05$) available N indicating proper microbial degradation of feedstock materials. Both,

Table 6
Maturity indices (NH_4-N/NO_3-N) and germination test with different composts ($n = 3$, Mean ± SE).

Treatment	NH_4-N/NO_3-N	Seed germination (%)			
		Wheat	Sorghum	Mustard	Vigna
T1	0.385 ± 0.05^{abcd}	86.7 ± 4.9^{abc}	67.0 ± 3.5^{abcd}	64.0 ± 1.5^{e}	50.3 ± 4.3^{bc}
T2	0.619 ± 0.14^{abc}	93.3 ± 3.3^{ab}	72.7 ± 4.3^{ab}	85.3 ± 3.3^{abcd}	57.3 ± 4.1^{abc}
T3	0.353 ± 0.07^{bcd}	94.0 ± 1.0^{ab}	77.7 ± 5.8^{a}	78.0 ± 4.6^{d}	63.7 ± 3.4^{ab}
T4	0.417 ± 0.21^{abcd}	70.7 ± 6.4^{d}	57.0 ± 2.1^{cde}	81.7 ± 3.9^{bcd}	56.0 ± 6.1^{abc}
T5	0.271 ± 0.03^{d}	98.7 ± 1.3^{a}	72.0 ± 2.3^{ab}	85.3 ± 0.9^{abcd}	53.7 ± 8.3^{abc}
T6	0.434 ± 0.07^{abcd}	93.7 ± 1.7^{ab}	68.0 ± 1.2^{abcd}	84.3 ± 3.5^{abcd}	67.0 ± 4.2^{a}
T7	0.589 ± 0.06^{abcd}	84.7 ± 2.7^{abc}	65.0 ± 7.4^{abcd}	54.3 ± 2.4^{ef}	48.0 ± 3.2^{c}
T8	0.553 ± 0.11^{abcd}	93.3 ± 2.0^{ab}	56.0 ± 2.1^{de}	95.0 ± 0.6^{a}	57.0 ± 6.0^{abc}
T9	0.574 ± 0.05^{abcd}	95.7 ± 1.5^{ab}	60.3 ± 3.3^{bcde}	87.3 ± 6.2^{abcd}	49.7 ± 1.2^{bc}
T10	0.485 ± 0.16^{abcd}	75.7 ± 6.4^{cd}	60.0 ± 4.7^{bcde}	82.7 ± 2.7^{bcd}	33.0 ± 1.5^{d}
T11	0.323 ± 0.04^{cd}	83.3 ± 7.5^{bcd}	62.7 ± 4.1^{bcde}	46.7 ± 4.3^{f}	46.0 ± 2.9^{c}
T12	0.287 ± 0.05^{d}	86.7 ± 7.3^{abc}	51.7 ± 6.4^{e}	10.7 ± 2.3^{g}	9.3 ± 2.9^{e}
T13	0.488 ± 0.06^{abcd}	91.3 ± 5.8^{ab}	72.0 ± 2.3^{ab}	58.0 ± 3.1^{e}	54.7 ± 5.2^{abc}
T14	0.667 ± 0^{ab}	96.3 ± 1.9^{ab}	69.7 ± 2.7^{abc}	91.0 ± 3.8^{ab}	58.0 ± 5.0^{abc}
T15	0.679 ± 0.09^{a}	95.0 ± 3.2^{ab}	77.3 ± 1.9^{a}	89.7 ± 3.7^{abc}	67.7 ± 3.7^{a}
Control		95.7 ± 0.7^{ab}	73.0 ± 1.5^{ab}	79.0 ± 3.6^{cd}	63.7 ± 3.9^{ab}

Different letters in the same column indicate significant differences at $p < 0.05$ according to Duncan's multiple range test.

total phosphorus and potassium content in compost containing hen droppings were found significantly higher ($p < 0.05$) than others.

Presence of heavy metal in the finished compost constitutes a very important problem from an agricultural and environmental point of view. Hence, it should be mandatory to check the concentration and phytotroxicity effect of metals in compost. Concentrations of available Cu, Mn, Fe, and Pb in all the composts were very low and Ni was below the detection limit. The variability in metal concentration in different compost may be due to differences in availability of metals in feedstocks, inhomogeneity in compost preparation, mixing of feedstock and also sample collection processes (Ko et al., 2008). Regarding total metal also, those were below the maximum acceptable limit (Cu: 500 ppm, Ni: 500 ppm, Pb: 100 ppm) defined for safe application of compost by Ministry of Environment & Forests (MoEF), Government of India, in the Municipal Solid Wastes (Management & Handling) Rules, 1999. However, during aerobic composting heavy metals in feedstock undergo complexation in organic fraction and due to strong binding with compost matrix their solubility and bioavailability become limited (Smith, 2009).

The presence of phorbol ester, a toxic bioactive diterpene derivative in jatropha deoiled cake deters people from using this nitrogen and phosphorus rich cake as animal feedstock. Hence, presence of this ester in compost from jatropha deoiled cake is also an important concern from agricultural and environmental point of view. As jatropha deoiled cake was the only possible source for phorbol ester, feedstock having higher percentage of jatropha cake (JRSM:dung = 20:1) showed presence of the same (0.12 mg/g) in the finished compost. In the remaining treatments, it was below the detection limit due to a dilution effect. However, in nontoxic variety of jatropha, phorbol ester content in kernel was reported up to 0.11 mg/g (Makkar et al., 1997). Absence or presence of phorbol ester in very low level in compost reduces the possibility of accumulation or magnification of the same in plants grown on compost treated soil.

Compost maturity can also be evaluated in terms of a ratio of NH_4-N and NO_3-N. When the NH_4-N concentration decreases and NO_3-N appears in the composting material it is considered ready to be applied as compost. According to California Compost Quality council (CCQC, 2001) compost having NH_4-N/NO_3-N ratio lower than 0.5 can be considered as very mature, 0.5–3.0 as mature, and greater than 3 as immature compost. In the present study, NH_4-N/NO_3-N ratio varied from 0.263–0.667, and could be considered as mature (Table 6) and suitable for agronomic use.

Germination test are commonly used for assessment of phytotoxicity of compost as it may contain various compounds such as heavy metals, ammonia and/or low molecular weight organic compounds that may reduce seed germination and also inhibit root development (Tam and Tiquia, 1994; Ko et al., 2008). The percentage germination of mustard, sorghum, vigna, and wheat are presented in Table 6. The germination of all the four plants (mustard, sorghum, vigna, wheat) varied widely among composts. Wheat and mustard showed good response in terms of percentage germination in all the compost as compared to sorghum and vigna. Average germination percentage of wheat, sorghum, vigna and mustard were 89.3%, 65.9%, 51.4% and 72.9%, respectively. Low germination of sorghum and vigna might be due to poor seed quality and response. More than 90% germination of wheat was found in 9 treatments (T2-T3, T5-T6, T8-T9, T13-T15) while 2 (T8 and T14) with mustard (and more than 80% in 7 treatments). Sorghum and vigna showed less than 80% seed germination in all 15 different composts. As observed, germination percentage was affected by the type and quality of seed used, thus result of germination should be interpreted with caution (Bernal et al., 1998; Tang et al., 2006). Overall, compost from horse dung supported better germination than others. The average germination percentage in compost containing horse dung were 94.2%, 73%, 60.1%, 79.5% with wheat, sorghum, vigna and mustard, respectively.

4. Conclusion

The results obtained pointed out that co-composting of deoiled jatropha seed cake with rice straw and animal dung (in desired ratios) could be feasible and a viable method in co-recycling both agricultural and industrial residues in large quantities. More over the nutritional benefit of jatropha deoiled cake is best utilized in this manner as it cannot be used as animal feed due to presence of phorbol ester. However, the applicability and potential of such compost as soil amendment should be assessed effectively through field trials followed by validation prior to recommendation.

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