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Composting of Rice Straw Using Different Inocula and Analysis of Compost Quality

Sneh Goyal and S.S. Sindhu

Department of Microbiology, CCS Haryana Agricultural University, Hisar-125004, India

Corresponding Author: Sneh Goyal, Department of Microbiology, CCS Haryana Agricultural University, Hisar-125004, India Tel: +91 1662 289292

ABSTRACT

Recycling of crop residues in agriculture through production of compost brings the much needed organic matter to the soils in tropical climates. The aim of the study was to monitor the chemical changes during composting of rice straw and analysis of maturity parameters of prepared compost. The unchopped paddy straw soaked in 0.1% urea solution was stacked in windrows. Composting was studied by using three different inocula i.e., cattle dung, biogas slurry and consortium of three fungi (*Aspergillus awamorii*, *Paecilomyces fusisporus* and *Trichoderma viride*). The level of moisture was maintained to 60% water holding capacity (WHC) by adding water at different intervals. At 90 days of composting, maximum 17.4% decrease in organic C was observed in the treatment containing consortium of three fungi and C:N ratio of compostable material decreased from 73.7 to 16.6. Cellulase activity increased from 88 (control untreated paddy straw) to 252 mg reducing sugar kg⁻¹ dry matter h⁻¹ at 30 days of composting by using fungal inoculum. Xylanase activity also varied from 9 to 111 mg reducing sugar kg⁻¹ dry matter h⁻¹. Total humic substances in finished product were 121 and 127 mg g⁻¹ compost with consortium of fungi and with cattle dung, respectively. Carbon dioxide evolution in finished product by using cattle dung and consortium of three fungi as inoculum was 188 and 174 mg 100 g⁻¹ compost, respectively. About 81 to 87% seeds of wheat and 78 to 86% seeds of mustard showed germination in compost water extract. This study showed that cattle dung and consortium of three fungi could be used for carrying out rice straw composting at farmer's field.

Key words: Composting, paddy straw, cattle dung, biogas slurry, consortium of fungi, compost quality

INTRODUCTION

Application of high input technologies and intensification of agriculture with the use of agrochemicals has resulted in manifold increase in production of farm commodities for feeding the surging population. Human, livestock and crops produce approximately 38 billions metric tons of organic waste worldwide each year and accumulation of wastes, particularly organic wastes, is becoming a serious hazard responsible for deterioration of environment (Dahiya *et al.*, 2007). The heavy mining of soil in intensive farming is causing decline in the productive capacity of agricultural lands (Tripathi *et al.*, 2006). Due to high rate of organic matter decomposition and repeated cultivation, most cultivated soils in the tropical climates have become poor in organic matter (Ghosh *et al.*, 2004). Crop residues are good sources of plant nutrients and are important

component for the stability of agricultural ecosystem. Therefore, sustaining crop productivity depends upon amendment of organic as well as mineral fertilizers. India produces more than 3,000 million tones of organic wastes annually which includes crop residues, animal shed wastes, rural and urban wastes, vegetable market wastes, forest and industrial wastes (Gupta *et al.*, 1998; Sharholy *et al.*, 2008). Recycling of organic wastes by the process of composting in agriculture brings in the much needed organic matter to the soils and improves the overall soil fertility and soil productivity (Tandon, 1995; Chukwuka and Omotayo, 2008; Ansari, 2011). Thus, composting is a process for appropriate disposal of waste and is also beneficial from ecological and economic point of view (Taiwo, 2011).

Rice (*Oryza sativa* L.) is a major crop grown worldwide with the annual productivity around 800 million metric tones that also generates large production of rice (paddy) straw. The management of rice residue through direct incorporation of straw in soil is associated with certain problems such as immobilization of plant nutrients particularly nitrogen and reduces germination of subsequent crops. Moreover, rice straw waste contains high C:N ratio about 80:1 and is rich in silica and lignin which make it difficult to be degraded (Kumar *et al.*, 2006). Therefore, farmers resort to *in situ* burning of a part of the crop residues that remain scattered in the field and is difficult to collect, all over the world (Jacobs *et al.*, 1997; Reinhardt *et al.*, 2001). The burning of crop residues is a great economic loss and burning is now being discouraged by the Governments. On the other hand, composting of rice straw arise as a safe alternative option which results in reusability of the nutrients contained in the residue (Banger *et al.*, 1989). Therefore, management of paddy straw through composting will avoid air pollution caused by residue burning and also prevent loss of plant nutrients and organic matter (Sidhu and Beri, 2008). However, the conventional method of composting takes longer time in the processing period and therefore, is not becoming popular among the farmers and waste management agencies.

Microorganisms in their natural habitats are crucial to the functioning of the world's ecosystems and they are major contributors to the biogeochemical cycles. Beneficial microorganisms in the soil are involved in decomposition of organic matter, in remediation of pollutants and in increased nutrient availability leading to improved soil fertility and crop productivity (Dileep and Dixit, 2005; Weyens *et al.*, 2009; Sindhu *et al.*, 2011). Similarly, organic farming practices in paddy fields showed the maximum microbial population counts and microbial biomass carbon followed by inorganically treated plot and control (Nakhro and Dkhar, 2010). Thus, proper management of the crop residues by utilizing microorganisms may result into availability of good quality manure and biofuels as well as protection of environment from pollution (Sharholy *et al.*, 2008; Ulusoy *et al.*, 2009).

During the present investigations, three different inocula i.e., biogas slurry, cattle dung and consortium of three lignocellulolytic fungi were evaluated for preparation of compost from rice straw. Changes in organic C, total N, C:N ratios, production of humic substances, cellulase and xylanase activities were determined during various stages of composting. The quality assessment of the finished compost extract was done by measuring germination index of wheat and mustard seeds and prepared compost did not show phytotoxic effect. The results indicated that rice straw could be effectively utilized in preparation of compost by inoculation with cattle dung or consortium of fungi as inocula.

MATERIALS AND METHODS

This study was carried out in the Department of Microbiology, CCS Haryana Agricultural University, Hisar on the straw obtained from rice crop during the months of October 2008 to December 2010.

Inoculum used for composting: Paddy straw was collected from the fields of Regional Rice Research Station, Kaul of CCS Haryana Agricultural University, Hisar, India. Cattle dung was collected from Animal Science Department and biogas slurry was collected from biogas plant of Department of Microbiology of the University. Organic carbon and total nitrogen contents of the three inocula were determined. The inoculum containing a fungal consortium of three fungi *Aspergillus awamorii*, *Paecilomyces fusisporous* and *Trichoderma viride*, isolated from our previous experiment was used as inoculum (Goyal *et al.*, 2005). Composting of unchopped paddy straw was carried out in windrows with following treatments:

- Paddy straw alone
- Paddy straw+Biogas slurry at 1%
- Paddy straw+Consortium of fungi at 1%
- Paddy straw+Cattle dung at 1%

Preparation of compost: The unchopped paddy straw was soaked in 0.1% urea solution for 3 min in a drum of 200 Litres capacity and then stacked in windrows (1 m height×1 m wide×2 m long). It was covered with thick polythene sheets to conserve moisture. The different inocula containing biogas slurry and cattle dung were added at 1.0% on dry weight basis to the urea solution. Charcoal based consortium of three fungi (100 g) containing 10^9 spores mL⁻¹ was suspended in 1000 Litre of urea solution. The level of moisture was maintained to 60% WHC by adding water at different intervals of composting. The material was allowed to decompose for three months and two turnings were given at 15 and 30 days of composting. Sampling was done after 0, 15, 30, 60 and 90 days.

Chemical analysis: The compost samples were dried and grounded to pass through 2 mm sieve for chemical analysis of carbon, nitrogen, phosphorus and potassium. Total organic C in the compost was measured by the method of Nelson and Sommers (1982) and total N was measured by Kjeldahl's digestion method (Bremner and Mulvaney, 1982). Total phosphorus content was determined by the method of John (1970). The potassium content in the digest was estimated on flame photometer by direct feeding. Total C in compost water extract was measured by the titration method (Kalembasa and Jenkinson, 1973). The cellulase and xylanase activities involved in the degradation of organic materials (Tiquia, 2002) were estimated by the method of Schinner and Von Mersi (1990) using carboxymethyl cellulose and birch wood xylan, respectively as substrates. Carbon dioxide evolution in finished product was determined by the method of Pramer and Schmidt (1964). Humic substances in compost were determined according to the method of Kononova (1961).

Seed germination: The germination index of wheat and mustard seeds was determined by taking 30 seeds of wheat and mustard on a sterile Petri plate containing a sterilized ordinary filter paper disc (El Hammadi *et al.*, 2007). Compost water extract was prepared by adding 10 g of finished compost in 90 mL of distilled water, shaken for 30 min and then filtered through Whatman no 1 filter paper. Eight mL of compost water extract from each treatment was added to the above plates and incubated in a BOD incubator at 30°C. The germination of seeds in each treatment was counted. The numbers of seeds germinated in sterilized distilled water were taken as control for calculation of germination percentage.

Statistical analysis: All chemical measurements were carried out in triplicate and LSD values at $p = 0.05$ were used to determine the significant differences between treatment means. Statistical analysis for determination of CD was done by using SPSS software programme (OPSTAT). Linear correlation coefficient between different compost maturity parameters was also determined.

RESULTS

Determination of organic C, total N and C:N ratio in paddy straw compost: Paddy straw contained 51.76% organic C, 0.65% nitrogen, 0.20% phosphorus, 0.30% potassium where as biogas slurry showed 44.0% organic C, 1.60% total N, 0.6 total P and 0.93 K. Cattle dung contained 48.14% organic C, 1.42% total N, 0.4% total P and 0.90% K. The initial C:N ratio of paddy straw, biogas slurry and cattle dung was found 80:1, 27:5 and 33:9, respectively.

The changes in C, N and C/N ratio were determined at different intervals of paddy straw composting (Table 1). Carbon content of the compostable material decreased from 52.3 (at 0 day) to 34.9% (at 90 days) in the treatment with inoculation of fungal cultures in the paddy straw. After 90 days of decomposition, lowest amount of organic C was found in paddy straw inoculated with consortium of fungi and cattle dung in comparison to uninoculated straw. Nitrogen content per unit of material increased from 0.70 to 2.17% that resulted in the decrease of C:N ratio of the compostable material. Inoculation of paddy straw with biogas slurry, consortium of fungi and cattle dung showed 66.6, 194.3 and 77.9% more N in comparison to uninoculated paddy straw after 90 days of composting. Thus, maximum increase in N content was observed by inoculation of fungal consortium followed by cattle dung application. However, in the beginning of the composting process, biogas slurry and cattle dung treatments showed more total N content than the consortium of three fungi which was due to presence of 1.6 and 1.4% N in biogas slurry and cattle dung, respectively.

The low C:N ratio is considered as one of the parameter for estimating the compost maturity and stability. In the treatment having fungal inoculum, the C:N ratio of compostable material decreased from 73.7 to 36.1 after 15 days of composting showing that microorganisms developed during the composting process decomposed the material efficiently. The microorganisms present in biogas slurry treatment lowered down C:N ratio from 50.9 to 34.0 and from 41.7 to 26.3 in cattle dung treatment after 15 days of composting. A non significant difference in C:N ratio was observed with cattle dung and consortium of three fungi than using biogas slurry as inoculum. After 90 days of composting, C:N ratio varied from 34.5 to 16.6 in different treatments. Thus, inoculation with consortium of fungi resulted in compostable material with lowest C:N ratio of 16.6 followed by cattle dung having C:N ratio of 17.0.

Table 1: Changes in organic carbon, total nitrogen and C:N ratio at different intervals of paddy straw composting

Treatments	Organic C (%)					Total N (%)					C:N ratio				
	0	15	30	60	90	0	15	30	60	90	0	15	30	60	90
	Days					Days					Days				
Paddy straw alone	51.7	48.2	45.5	42.5	39.7	0.70	0.86	0.88	0.92	1.15	73.90	56.0	51.7	46.2	34.50
Paddy straw+Biogas slurry	51.9	45.6	41.6	42.1	37.8	1.02	1.34	1.59	1.65	1.72	50.90	34.0	26.2	25.5	21.90
Paddy straw+Fungal culture	52.3	45.5	38.0	37.2	34.9	0.71	1.26	1.38	1.61	2.09	73.70	36.1	27.5	23.1	16.60
Paddy straw+Cattle dung	50.9	43.7	40.8	39.9	36.9	1.22	1.66	1.81	1.83	2.17	41.70	26.3	22.5	21.8	17.00
CD at 5%	1.2	1.4	2.1	2.4	2.1	0.05	0.07	0.02	0.06	0.04	4.21	3.12	4.11	2.13	1.24

Total nitrogen, phosphorus and potassium content of the compost: In the prepared compost, the total Nitrogen (N) content varied from 1.15 in paddy straw alone to 2.17% in paddy straw amended with cattle dung after 90 days of decomposition (Table 2). Maximum increase in total Phosphorus (P) content was found with fungal culture treatment followed by inoculation of cattle dung and it varied from 0.062 in paddy straw alone to 0.164 by inoculation of fungal consortium. The total potassium (K) content also varied from 0.134 to 0.169% and maximum increase in total K was observed by inoculation of the fungal consortium. Thus, amount of N, P and K contents were found more in compost prepared with consortium of fungi and cattle dung than the compost prepared from biogas slurry.

Cellulase and xylanase activities: Cellulases and xylanases are among the various hydrolytic enzymes which are involved in degradation of organic materials. Cellulase activity increased from 6 mg (in uninoculated paddy straw at 0 day) to 252 mg reducing sugar kg⁻¹ dry matter h⁻¹ in treatment having fungal inoculum at 30 days of composting (Table 3). Highest amount of cellulase activity was observed at 30 days of composting in all the treatments (except the treatment with fungal culture inoculum) and then declined at later stages of composting. Paddy straw inoculated with consortium of fungal cultures showed 65% higher cellulase activity in comparison to uninoculated paddy straw. On the other hand, addition of biogas slurry resulted in 48% increase whereas, only 13% increase in cellulase activity was observed with amendment of cattle dung at 30 days of composting. The results showed that these fungi used for inoculation were efficient in decomposing the lignocelluloses present in the paddy straw. After 90 days of decomposition, no significant difference in cellulase activity was observed in the treatments in which paddy straw was inoculated with consortium of fungi or amended with cattle dung. Xylanase activity also varied from 9 to 111 mg reducing sugar kg⁻¹ dry matter h⁻¹ (Table 3). The activity increased to maximum at 60 days and thereafter, it declined. Highest amount of xylanase activity was observed by using consortium of fungi and cattle dung as inoculum than the treatment amended with biogas slurry.

Table 2: Plant nutrient contents (N, P, K) of paddy straw compost after 90 days of paddy straw composting

Treatments	Total N (%)	Total P (%)	Total K (%)
Paddy straw alone	1.15	0.062	0.134
Paddy straw + Biogas slurry	1.72	0.148	0.138
Paddy straw + Fungal culture	2.09	0.164	0.169
Paddy straw + Cattle dung	2.17	0.159	0.146
CD at 5%	0.021	0.005	0.018

Table 3: Changes in cellulases and xylanases activity during paddy straw composting at different intervals

Treatments	Cellulase activity (mg reducing sugar kg ⁻¹ dry matter h ⁻¹)					Xylanase activity (mg reducing sugar kg ⁻¹ dry matter h ⁻¹)				
	0	15	30	60	90	0	15	30	60	90
Paddy straw alone	6	49	88	33	30	9	21	35	42	28
Paddy straw+Biogas slurry	14	76	131	84	68	11	30	64	89	72
Paddy straw+Fungal culture	18	123	252	492	112	18	61	99	111	86
Paddy straw+Cattle dung	52	176	218	166	109	22	58	82	102	78
CD at 5%	4	7	6	12	5	2	4	5	8	4

Humic acid and fulvic acid C content in the compost: During composting, the complex organic material lignin is polymerized into fulvic acid and humic acids due to the humification process. These humic substances become stable fraction of soil organic matter, provide energy for the growth of microorganisms and regulate the carbon cycle.

The amount of humic acid in the finished compost varied from 91 to 110 mg g⁻¹ of compost and fulvic acid from 3 to 23 mg g⁻¹ of compost (Table 4). Highest amount of humic substances were present in the prepared compost using cattle dung and consortium of fungi as inoculum. There was no significant difference in the amount of humic substances in these two kinds of composts. However, the compost prepared from paddy straw using biogas slurry as inoculum or paddy straw alone showed lower amount of humic substances. Thus, inoculation of paddy straw with fungal consortium and cattle dung showed 21.4 and 25.1% more total humic substances carbon in finished product in comparison to untreated control. The present studies showed that the total amount of humic substances generated by lignocellulolytic fungi and cattle dung were more than using biogas slurry as inoculum or to the uninoculated control.

Water soluble carbon and carbon dioxide evolution in finished compost: Changes in water soluble carbon in relation to total carbon content in the prepared compost varied from 2.69 to 5.92% by using different inocula (Table 4). The compost prepared from paddy straw alone and biogas slurry showed more amount of dissolved organic carbon than compost prepared from cattle dung and using consortium of fungi. Lesser amount of water soluble C (2.69%) was observed with the consortium of fungi inoculated paddy straw. However, biogas slurry and cattle dung inoculated paddy straw showed 4.01 and 2.74% water soluble C, respectively in comparison to uninoculated paddy straw (5.92%). The presence of more amount of water soluble carbon in compost prepared from paddy straw alone or by amendment of biogas slurry showed that these two composts were not stable.

Measurement of CO₂-C evolved from 90 days old compost obtained after inoculation of cattle dung and consortium of three fungi showed less amount of CO₂-C evolution than compost prepared with biogas slurry or without any inoculum (Table 4). The evolution of CO₂-C in four weeks varied from 174 to 333 mg 100 g⁻¹ compost. The three different inocula helped in the breakdown of complex organic matter present in paddy straw. In untreated paddy straw, CO₂-C evolution was 333 mg 100 g⁻¹ compost. The higher amount of CO₂ evolution suggested that material is not stabilized enough and needs further decomposition. During the present studies, the evolution of CO₂-C in 90 days old compost was less than above limit indicating that these composts were stabilized after the 90 days of decomposition.

Germination index of wheat and mustard: The application of unstable and immature compost in soil can lead to reduction of oxygen concentration, immobilization of important plant nutrients

Table 4: Humic and fulvic acid C in paddy straw compost after 90 days of composting

Treatments	Humic acid C (mg g ⁻¹ compost)	Fulvic acid C (mg g ⁻¹ compost)	Total humic substances C (mg g ⁻¹ compost)	Water soluble C as % of total C	CO ₂ -C evolution in 4 weeks (mg 100 g ⁻¹ compost)
Paddy straw alone	92	3	95	5.92	333
Paddy straw+Biogas slurry	91	23	114	4.01	194
Paddy straw+Fungal culture	107	14	121	2.69	174
Paddy straw+Cattle dung	110	17	127	2.74	188
CD at 5%	6.2	4.5	5.8	0.007	10.2

Table 5: Germination index of wheat and mustard seeds in compost water extract

Treatments	Wheat (%)	Mustard (%)
Paddy straw alone	69	68
Paddy straw+Biogas slurry	78	69
Paddy straw+Fungal culture	87	78
Paddy straw+Cattle dung	81	86
CD at 5%	5	4

Table 6: Correlation coefficient between compost maturity parameters

Parameters	C:N ratio	Humic substances	Fulvic substances	Water soluble C	CO ₂ -C evolved	% germination wheat	% germination mustard
Humic substances	0.999*						
Fulvic substances	0.999*	1.000*					
Water soluble C	0.987NS	0.982NS	0.978NS				
CO ₂ -C evolved	0.987NS	0.981NS	0.977NS	1.000**			
% germination wheat	0.512NS	0.484NS	0.468NS	0.641NS	0.644NS		
% germination mustard	0.488NS	0.459NS	0.444NS	0.620NS	0.623NS	1.000*	

Correlation coefficient at 0.05% level, * and ** : Level of correlation with each other, NS : Non significant correlation

and may result in inhibition of seed germination due to its phytotoxic effect. To find out the phytotoxic effect of the compost prepared by using different inocula, per cent germination of wheat and mustard seeds were tested under laboratory conditions. Germination of seeds in sterilized water was used as control. Compost prepared without any inoculum showed only 69 to 68% seed germination of wheat and mustard, respectively (Table 5). Whereas, the paddy straw compost prepared by inoculation of biogas slurry, cattle dung and consortium of three fungi showed higher percent germination of seeds which varied from 78 to 87% in wheat and 79 to 86% in mustard. Thus, compost prepared without any inoculum was not fully mature and therefore, it inhibited germination of seeds. The poor quality of compost resulting in the inhibition of seeds is also supported by the amount of CO₂-C evolved, water soluble C and humic substances present in the paddy straw compost prepared without any inoculum.

Correlation coefficient: Correlation coefficient among various parameters was determined which could be used as indicator of compost maturity and stability (Table 6). Some parameters were positively correlated with each other in this study. For example, there was statistically significant positive correlation between C:N ratio and humic substances, water soluble C and CO₂ evolution. Whereas, no significant correlation was observed among water soluble C, humic substances, CO₂ evolution and germination index of wheat and mustard. However, there was no single parameter that can be used to determine compost quality and maturity.

DISCUSSION

Rice is a major crop grown worldwide and generates large production of straw annually. Paddy straw contains 51.76% organic C, 0.65% nitrogen, 0.20% phosphorus, 0.30% potassium and has high C:N ratio. It is also rich in silica and lignin which makes it difficult to be degraded (Kumar *et al.*, 2006). The composting of rice straw results in reusability of the nutrients contained in the residue and also avoids air pollution caused by residue burning (Dileep and Dixit, 2005; Sidhu and Beri, 2008).

During decomposition of paddy straw, carbon content of the compostable material decreased from 52.3 to 34.9% in the different treatments (Table 1). Maximum 17.4% decrease in organic C was observed in the treatment containing consortium of three fungi, whereas only 14.0% decrease in organic C was observed with cattle dung at 90 days of composting. The lowering of carbon contents during the process of composting is due to the intense microbial activity of the microbiota present in the compostable material or that has been inoculated as inoculum. During composting, there is a degradation of complex organic matter into simple ones with the evolution of CO₂ gas and energy (Adani *et al.*, 1997). Vuorinen and Saharinen (1997) have also reported that approximately 11-27% of the total C is lost during initial stage of active composting and about 62-66% during the whole composting time.

In the beginning of the composting process, biogas slurry and cattle dung treatments showed more total N content than the consortium of three fungi which was due to presence of 1.6 and 1.4% N in the inocula consisting of biogas slurry and cattle dung, respectively. At 90 days of composting, increase in N content was found more by inoculation of fungal consortium (194.3%) followed by cattle dung application (77.9%) whereas, inoculation of paddy straw with biogas slurry showed only 66.6% more N in comparison to uninoculated paddy straw. Thus, maximum decrease in C:N ratio of compostable material from 73.7 to 16.6 was observed with consortium of fungi. In different treatments, C:N ratio varied from 34.5 to 16.6 after 90 days of composting. The C:N ratio of compostable material inoculated with consortium of fungi (16.6) and cattle dung (17.0) was lowest in comparison to uninoculated paddy straw or paddy straw inoculated with biogas slurry. Gaind *et al.* (2005) also reported that composting of wheat straw by inoculation of fungi along with application of 1% urea resulted into an end product with C:N ratio of 10:7 within three months in pits. Similarly, Brito *et al.* (2008) also observed a decline in the C:N ratio at the end of composting from 36 to a value of 14, by the addition of solid fraction of cattle slurry. Compost production from sugar cane organic waste was performed using *Trichoderma* fungi with different levels of urea and pH (Torkashvand *et al.*, 2008) and it was observed that C:N ratio reduced below 30 in 5 weeks and below 20 in 10 weeks after composting.

Maximum increase in total N content in the prepared compost was observed by amendment with cattle dung after 90 days of decomposition whereas maximum increase in total P content was found with fungal culture treatment followed by inoculation of cattle dung (Table 2). Similarly, maximum increase in total K was observed by inoculation of the fungal consortium and it varied from 0.134 to 0.169%. A non significant difference in the N, P and K content was observed in paddy straw compost prepared by using consortium of fungi and cattle dung. Similarly, Saludes *et al.* (2008) also reported that the total N, P and K concentrations of the dairy cattle manure/wallboard compost mixture did not change significantly after 28 days of composting. Application of 250 t ha⁻¹ of fresh organic amendments in nutrient depleted soil of South-Western Nigeria was found to increase the soil N, P, K, Ca, Mg, Cu, Zn, Mn and Fe (Chukwuka and Omotayo, 2008). Moreover, the compost prepared from the uprooted *Parthenium* (before flowering) was found to contribute 1.58, 0.33 and 1.64% of total N, P and K, respectively and also provided Fe, Mn, Zn and Cu micronutrients (Kishor *et al.*, 2010).

The compost prepared by using fungal consortium as inoculum showed maximum cellulase activity at 30 days of composting and it increased from 88 mg (control untreated paddy straw) to 252 mg reducing sugar kg⁻¹ dry matter h⁻¹ in fungal inoculated compostable material (Table 3). Xylanase activity varied from 9 to 111 mg reducing sugar kg⁻¹ dry matter h⁻¹ and highest amount

of xylanase activity was observed by using consortium of fungi and cattle dung as inoculum. Addition of consortium of fungal cultures, biogas slurry and cattle dung resulted in 65, 48 and 13% higher cellulase activity at 30 days of composting. Similarly, maximum cellulase activity was observed at 30 days during composting of organic waste (Goyal *et al.*, 2005) and using bark of pine and eucalyptus (Cunha-Queda *et al.*, 2002).

Paddy straw is recalcitrant and contains high amount of silica. Due to the humification process carried out by lignocellulolytic fungi, lignin present in the paddy straw is decomposed into fulvic acid and humic acids which become stable fraction of soil organic matter (Crawford and Crawford, 1980; Huang *et al.*, 2008). These humic substances act as permanent source of energy for the growth of microorganisms and regulate the carbon cycle (Veeken *et al.*, 2000). In the finished compost, amount of humic acid varied from 91 to 110 mg g⁻¹ of compost and fulvic acid from 3 to 23 mg g⁻¹ of compost (Table 4). The inoculation of paddy straw with fungal consortium and cattle dung showed 21.4 and 25.1% more total humic substances carbon in finished product in comparison to untreated control. Different composting strategies have been reported to have impact on the degree of humification during composting process (Alburquerque *et al.*, 2009). Lopez *et al.* (2006) evaluated the degradation of lignin in the mixtures of horticultural plant residues having different C:N ratios by the inoculation of different lignocellulolytic fungi namely *Coriolus versicolor*, *Phanerochaete flavido-alba* and *Trichoderma koningii*. Inoculation with these three fungi enhanced the formation of humic substances by degradation of lignin.

Lesser amount of water soluble C (2.69%) was observed in the compost prepared with inoculation of consortium of fungi (Table 4). However, biogas slurry and cattle dung inoculated paddy straw showed 4.01 and 2.74% water soluble C, respectively in comparison to uninoculated paddy straw (5.92%). Said-Pullicino *et al.* (2007) reported that increase of value greater than unity in the ratio of hydrophobic to hydrophilic carbon, is an indicator of stabilized compost. Castaldi *et al.* (2005) also reported that water-soluble organic C concentration rapidly increased to a maximum at day 18 and declined thereafter during 122 days of composting. Garcia *et al.* (1992) found that water soluble carbon content prepared from municipal waste reached from 0.41 to 1.19 of total organic C in 90 days. On the other hand, these values ranged from 2.69 to 5.92% in the present studies. Moreover, the evolution of CO₂-C in four weeks incubation varied from 174 to 333 mg 100 g⁻¹ compost (Table 4). Inoculation of cattle dung and consortium of three fungi showed less amount of CO₂-C evolution than compost prepared with biogas slurry or without any inoculum. It has been suggested that good quality compost should have carbon dioxide evolution less than 500 mg 100 g⁻¹ of total organic C (Garcia *et al.*, 1992). The evolution of CO₂-C in 90 days old compost was less than above limit during the present studies, indicating that these composts were stabilized after the 90 days of decomposition (Bernal *et al.*, 1998).

Stability of compost is very important before its application into field and it should not have phytotoxic effect (Hue and Liu, 1995; El Hammadi *et al.*, 2007). The paddy straw compost prepared by use of different inocula showed 78 to 87% germination of seeds in wheat and 79 to 86% germination in mustard, as compared to 69 to 68% seed germination of wheat and mustard with the compost prepared without any inoculum (Table 5). Cunha-Queda *et al.* (2002) also tested the stability and maturity of compost by measuring the phytotoxicity towards germination of *Lipidum sativum* seeds. Evaluation of compost maturity prepared from poultry droppings, neem cake, castor cake, jatropha cake and grass clippings by inoculation of different fungal consortium showed that mixture of wheat straw, poultry dropping and jatropha cake had the lowest C:N ratio of 10:1 and

showed germination index exceeding 80% in 60 days of decomposition (Gaind *et al.*, 2009). Similarly, wheat straw-poultry dropping mixture inoculated with fungal consortium and grass clippings resulted in compost with C:N ratio of 13.5 and showed germination index of 59.66%. Al-Turki (2010) analyzed 14 commercially produced composts in Saudi Arabia and their germination index indicated that 64% of examined samples were below 80%, indicating that these composts could exhibit phytotoxicity.

In this study, a statistically significant positive correlation was observed between C:N ratio and humic substances, water soluble C and CO₂ evolution (Table 6). Similarly, Zmora-Nahum *et al.* (2005) reported a highly positive correlation between C:N ratio and dissolve organic carbon during estimation of compost maturity. Goyal *et al.* (2005) also observed that there was statistically significant correlation between C:N ratio and CO₂ evolution, water soluble C and humic substances. On the other hand, no significant correlation was observed among water soluble C, humic substances, CO₂ evolution and germination index of wheat and mustard.

CONCLUSION

The present study showed that good quality compost could be prepared from paddy straw within three months by using consortium of three fungi as inoculum. Maximum 17.4% decrease in organic C and in C:N ratio of compostable material from 73.7 to 16.6 was observed with consortium of fungi at 90 days of composting. Cellulase activity increased in fungal inoculated compostable material at 30 days of composting whereas highest amount of xylanase activity was observed by using consortium of fungi and cattle dung as inoculum. Total humic substances in finished product were 121 and 127 mg g⁻¹ compost with consortium of three fungi and with cattle dung, respectively. The resulting compost product is stable and mature and does not show any phytotoxic effect on seed germination of wheat and mustard. Thus, composting of rice straw resulted in reusability of the nutrients contained in the residue and this process will avoid air pollution caused by residue burning as well as loss of plant nutrients.

REFERENCES

- Adani, F., P.L. Genevini, F. Gasper and G. Zorzi, 1997. Organic Matter Evolution Index (OMEI) as a measure of compost efficiency. *Compost Sci. Util.*, 5: 53-62.
- Al-Turki, A.I., 2010. Quality assessment of commercially produced composts in Saudi Arabia market. *Int. J. Agric. Res.*, 5: 70-79.
- Albuquerque, J.A., J. Gonzalvez, G. Tortosa, G.A. Baddi and J. Cegara, 2009. Evaluation of alperujo composting based on organic matter degradation, humification and compost quality. *Biodegradation*, 20: 257-270.
- Ansari, A.A., 2011. Worm powered environmental biotechnology in organic waste management. *Int. J. Soil Sci.*, 6: 25-30.
- Banger, K.C., S. Shankar, K.K. Kapoor, K. Kukreja and M.M. Mishra, 1989. Preparation of nitrogen and phosphorus enriched paddy straw compost and its effect on yield and nutrient uptake by wheat. *Biol. Fertil. Soils*, 8: 339-342.
- Bernal, M.P., M.A. Sanchez-Monedero, C. Paredes and A. Roig, 1998. Carbon mineralization from organic wastes at different composting stages during their incubation with soil. *Agric. Ecosyst. Environ.*, 69: 175-189.
- Bremner, J.M. and C.S. Mulvaney, 1982. Nitrogen Total. In: *Methods of Soil Analysis*. American Society Agronomy, Madison, WI., USA., pp: 595-624.

- Brito, L.M., J. Coutinho and S.R. Smith, 2008. Methods to improve the composting process of the solid fraction of dairy cattle slurry. *Bioresour. Technol.*, 99: 8955-8960.
- Castaldi, P., G. Alberti, R. Merella and P. Melis, 2005. Study of the organic matter evolution during municipal solid waste composting aimed at identifying suitable parameters for the evaluation of compost maturity. *Waste Manage.*, 25: 209-213.
- Chukwuka, K.S. and O.E. Omotayo, 2008. Effects of tithonia green manure and water hyacinth compost application on nutrient depleted soil in South-Western Nigeria. *Int. J. Soil Sci.*, 3: 69-74.
- Crawford, D.L. and R.L. Crawford, 1980. Microbial degradation of lignin. *Enzyme Microbiol. Technol.*, 2: 11-22.
- Cunha-Queda, A.C., H.M. Ribeiro, A. Ramos and F. Cabral, 2002. Study of biochemical and microbiological parameters during composting of pine and eucalyptus bark. *Bioresour. Technol.*, 98: 3213-3220.
- Dahiya, B.S., R.B. Srivastava and J. Singh, 2007. Impact of Intensive Agriculture on Environment. In: *Environmental Pollution and Global Health*, Saharan, R.P. and P.K. Sareen (Eds). EMSI, BARC, Mumbai, India, pp: 3-16.
- Dileep, K. and A.K. Dixit, 2005. Residue management practices using fly ash and various crop residues for productivity of rice (*Oryza sativa*)-wheat (*Triticum aestivum*) cropping system under limited moisture conditions. *Indian J. Agron.*, 50: 249-252.
- El Hammadi, M.A., M. Trabelsi and B. Hanchi, 2007. Phytotoxicity of Tunisian municipal and textile sludges compared to the produced composts. *Asian J. Agric. Res.*, 1: 86-91.
- Gaind, S., A.K. Pandey and Lata, 2005. Biodegradation study of crop residues as affected by exogenous inorganic nitrogen and fungal inoculants. *J. Basic Microbiol.*, 45: 301-311.
- Gaind, S., L. Nain and V.B. Patel, 2009. Quality evaluation of co-composted wheat straw, poultry droppings and oil seed cakes. *Biodegradation*, 20: 307-317.
- Garcia, C., T. Hernandez, F. Costa and M. Ayuso, 1992. Evaluation of the maturity of municipal waste compost using simple chemical parameters. *Commun. Soil Sci. Plant Anal.*, 23: 1501-1512.
- Ghosh, P.K., P. Ramesh, K.K. Bandyopadhyay, A.K. Tripathi, K.M. Hati, A.K. Misra and C.L. Acharya, 2004. Comparative effectiveness of cattle manure, poultry manure, phosphocompost and fertilizer-NPK on three cropping systems in vertisols of semi-arid tropics. Crop yield and system performance. *Bioresour. Technol.*, 95: 77-83.
- Goyal, S., S.K. Dhull and K.K. Kapoor, 2005. Chemical and biological changes during composting of different organic wastes and assessment of compost maturity. *Bioresour. Technol.*, 96: 1584-1591.
- Gupta, S., K. Mohan, R. Prasad, S. Gupta and A. Kansal, 1998. Solid waste management in India: Option and opportunities. *Resour. Conserv. Recycl.*, 24: 137-154.
- Huang, H.L., G.M. Zeng, L. Tang, H.Y. Yu, H.M. Xi, Z.M. Chen and G.H. Huang, 2008. Effect of biodelignification of rice straw on humification and humus quality by *Phanerochaete chrysosporium* and *Streptomyces badius*. *Int. Biodeter. Biodeg.*, 61: 331-336.
- Hue, N.V. and J. Liu, 1995. Predicting compost stability. *Compost Sci. Util.*, 3: 8-15.
- Jacobs, J., R. Kreutzer and D. Smith, 1997. Rice burning and asthma hospitalizations in Butte County, California, 1983-1992. *Environ. Health Perspect.*, 105: 980-985.
- John, M.K., 1970. Colorimetric determination of phosphorus in soil and plant materials with ascorbic acid. *Soil Sci.*, 109: 214-220.

- Kalembasa, S.J. and D.S. Jenkinson, 1973. A comparative study of titrimetric and gravimetric methods for the determination of organic carbon in soil. *J. Sci. Food Agric.*, 24: 1085-1090.
- Kishor, P., B.R. Maurya and A.K. Ghosh, 2010. Use of uprooted *Parthenium* before flowering as compost: A way to reduce its hazards worldwide. *Int. J. Soil Sci.*, 5: 73-81.
- Kononova, M.M., 1961. *Soil Organic Matter*. Pergamon Press, Oxford.
- Kumar, A., S. Gaiind and L. Nain, 2006. Evaluation of thermophilic fungal consortium for paddy straw composting. *Biodegradation*, 19: 395-402.
- Lopez, M.J., M.D.C. Vargas-Garcia, F. Suarez-Estrella and J. Moreno, 2006. Biodelignification and humification of horticultural plant residues by fungi. *Int. Biodeter. Biodeg.*, 57: 24-30.
- Nakhro, N. and M.S. Dkhar, 2010. Impact of organic and inorganic fertilizers on microbial populations and biomass carbon in paddy field soil. *J. Agron.*, 9: 102-110.
- Nelson, D.W. and L.E. Sommers, 1982. Total Carbon, Organic Carbon and Organic Matter. In: *Methods of Soil Analysis. Part 2: Chemical and Microbiological Properties*, Wiscosin, A.L. (Ed.). 2nd Edn., ASA and SSSA, Madison, WI., pp: 539-579.
- Pramer, C. and A. Schmidt, 1964. Organic Matter. In: *Methods of Soil Analysis, Part 2*, Black, C.A. (Ed.). American Society of Agronomy, Madison, USA., pp: 1395-1397.
- Reinhardt, T.E., R.D. Ottmar and C. Castilla, 2001. Smoke impacts from agricultural burning in a rural Brazilian town. *J. Air Waste Manag. Assoc.*, 51: 443-450.
- Said-Pullicino, D., K. Kaiser, G. Guggenberger and G. Gigliotti, 2007. Changes in the chemical composition of water-extractable organic matter during composting: Distribution between stable and labile organic matter pools. *Chemosphere*, 66: 2166-2176.
- Saludes, R.B., K. Iwabuchi, F. Miyatake, Y. Abe and Y. Honda, 2008. Characterization of dairy cattle manure/wallboard paper compost mixture. *Bioresour. Technol.*, 99: 7285-7290.
- Schinner, F. and W. Von Mersi, 1990. Xylanase, CM cellulase and invertase activity in soil an improved method. *Soil Biol. Biochem.*, 22: 511-515.
- Sharholy, M., K. Ahmad, G. Mahmood and R.C. Trivedi, 2008. Municipal solid waste management in Indian cities-A review. *Waste Manag.*, 28: 459-467.
- Sidhu, B.S. and V. Beri, 2008. Rice residue management: Farmer's perspective. *Indian J. Air Pollut. Control*, 8: 61-67.
- Sindhu, S.S., S. Goyal and D.K. Malik, 2011. Soil flora and their significance. In: *Modern Concepts of Vegetable Production*, Rana, M.K. (Ed.). Biotech Books, Daryagani, New Delhi, India, pp: 386-429.
- Taiwo, A.M., 2011. Composting as a sustainable waste management technique in developing countries. *J. Environ. Sci. Technol.*, 4: 93-102.
- Tandon, H.L.S., 1995. *Recycling of Crop, Animal, Human and Industrial Wastes in Agriculture. Fertilizer Development and consultation Organization*, New Delhi, pp: 148.
- Tiquia, S.M., 2002. Evaluation of enzyme activities during manure composting. *J. Applied Microbiol.*, 92: 764-775.
- Torkashvand, A.M., S. Radmehr and H. Nadian, 2008. Investigation of compost production from cane organic wastes with the different treatment of urea and pH by using *Trichoderma* fungi. *Biotechnology*, 7: 739-744.
- Tripathi, R.P., S. Peeyush and S. Surendra, 2006. Soil physical response to multi-year rice-wheat production in India. *Int. J. Soil Sci.*, 1: 91-107.
- Ulusoy, Y., A.H. Ulukardesler, H. Unal and K. Alibas, 2009. Analysis of biogas production in Turkey utilising three different materials and two scenarios. *Afr. J. Agric. Res.*, 4: 996-1003.

- Veeken, A., K. Nierop, V. De Wilde and B. Hamelers, 2000. Characterization of NaOH-extracted humic acids during composting of a biowaste. *Bioresour. Technol.*, 72: 33-41.
- Vuorinen, A.H. and M.H. Saharinen, 1997. Evaluation of microbiological and chemical parameters during manure and straw co-composting in a drum composting system. *Agric. Ecosyst. Environ.*, 66: 19-29.
- Weyens, N., D. van der Lelie, S. Taghavi, L. Newman and J. Vangronsveld, 2009. Exploiting plant-microbe partnerships to improve biomass production and remediation. *Trends Biotechnol.*, 27: 591-598.
- Zmora-Nahum, S., O. Markovitch, J. Tarchitzky and Y. Chen, 2005. Dissolved organic carbon (DOC) as a parameter of compost quality. *Soil Biol. Biochem.*, 37: 2109-2116.