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EX-SITU PADDY STRAW MANAGEMENT USING PARTIALLY AERATED STATIC PIT COMPOSTING APPROACH

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ABSTRACT

Aeration is a critical factor for composting which provides oxygen, controls temperature, and removes excess moisture for the biological processes. An experiment was conducted to study the effect of partially aerated static pile approach for ex-situ composting of paddy straw on physical, chemical, C/N ratio and microbial properties of the compost at 60 and 150 days. The pits containing paddy straw mixture were equipped with perforated horizontal and vertical pipes for aeration and water supply. The pits were covered with different materials such as plastic sheets, farmyard manure (FYM), soil, rugs, paddy straw, and 'without cover' to retain the moisture during composting. Covering with FYM, soil, and paddy straw resulted in higher degradation in terms of C/N ratio and higher nutrient content of compost. The use of FYM as cover during composting resulted in the highest values for N(1.9%),P(0.63%), K(2.4%), micronutrients [Fe(202ppm), Zn(288ppm), Mn(1626ppm) and Cu(514ppm)], bacteria, fungi, and actinomycetes count (8.86, 5.54 and 6.94 log CFU/gm, respectively) and highest degradation with C/N ratio of 17.0 after 150 days. It was concluded that partial aeration is an economic option to reduce period of composting from 9 to 5 months with FYM. This practice ensures an opportunity for farmers for ex-situ composting of paddy straw as an alternative to burning.

Keywords: C/N ratio, Micronutrients, Paddy straw compost, Partially aerated.

Enormous crop residues are generated from different crops, among which paddy straw accounts for 106-159 million tonnes (MT). Some crop residues are used as animal feed; however, due to the recalcitrant nature of paddy straw, it is not utilized as animal feed. Punjab alone accounts for the production of 18.7 MT of paddy straw annually; among this, 80% of paddy straw is burnt in the fields by farmers, which results in environmental pollution, loss of biodiversity, and nutrients. Paddy straw is a local material that can potentially be turned into organic fertilizer. Although it is available in abundance, however, it is not fully utilized (Zhao *et al.,* 2014). Composting is an attractive form for the recycling of paddy residues where residues can be converted into high-value manure of better quality (Singh *et al.,* 2014). During the process of composting, there is a succession of microorganisms, and these microbes bring about physical, chemical, and biological changes during different stages of composting (Aslam *et al.,* 2008; Ryckeboer *et al.,* 2003). The process of composting is entirely dependent on particle size, C: N ratio, and nutrient content of the raw material used. Apart from these, other factors which add to the progression of composting are moisture, O_2 concentration, and temperature (Richard *et al.,* 2002; Petric *et al.,* 2015). Throughout the composting process, different microbial communities follow succession according to the nutritional and environmental conditions prevailing at each phase (Vargas-García *et al.,* 2010). Composting is done either aerobically or anaerobically by mixing and piling together organic materials (Mishra *et al.,* 2003). An optimum aeration is a prerequisite for successful composting, as low aeration may result in the anaerobic conditions, while a high aeration rate might result in excessive cooling, thereby preventing thermophilic conditions (Barthod *et al.,* 2018). The aeration can be enhanced either by mechanical turning (Chowdhury *et al.,* 2014) or aeration through pipes (Ogunwande and Osunade, 2011). Many composting technologies, including anaerobic and aerated static pile, are available; however, they require several days, e.g., nearly 90 days for aerobic, and 5-10 months for anaerobic for complete decomposition of paddy straw. At present, there are no viable methods that can decompose paddy straw within a short window of time. Therefore, for expediting the decomposition of paddy straw, there is a dire need to adopt innovative approaches along with the routine decomposition processes. The present study, therefore, aimed at determining the effect of FYM, microbial cultures, compost covers, and perforated horizontal and vertical pipes in hastening the composting process and improving nutrient quality.

MATERIALS AND METHODS

Experimental setup

An experiment on composting of paddy straw

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was conducted at Research farms of PAU, Ludhiana, from January 2018 to June 2018. The experiment was conducted in pits with a dimension of 4×2×1.5 meters, and the pits were filled with water to maintain moisture (Fig.1). In the treatments, six alternate layers of paddy straw and FYM in a ratio of 1:1 (dry weight basis) were used (Fig. 2a). Paddy straw in each treatment was treated with the microbial consortium (*Bacillus megaterium*, *B. subtilis*, *B. species,* and *Streptomyces griseus*) and urea (0.3%). In the treatment T4, glyphosate was added @ 0.1% on a dry weight basis. Waste pipes (4 inch) and drills are usually available with the farmers to economize the process. Holes were pierced in the pipes with drill or using a hot rod. In each of the pits, horizontal (4 m) and vertical (2m) pipes with holes (0.5 inch) were inserted in the middle of the pit (Fig. 2b), and moisture was maintained by watering the pipes at an interval of 15 days. The pits were covered with different materials such as plastic sheets, FYM, soil, rugs, paddy straw, and uncovered. Samplings were done after 60 and 150 days from the start of the experiment and analyzed for pH, EC, nitrogen (N), phosphorus (P) and potassium (K), micronutrient content, and microbial count.

Physical, chemical and microbiological analysis

The temperature was measured from five different locations of the pit using a digital thermometer at 1, 3, 5, 7, 10, 20, 30, 40, 50, 60, 100, and 150 days. The moisture content was determined gravimetrically by drying samples at 105°C using a hot air oven for 24 h (Tiquia and Tam, 1998). It was calculated using the following formula

Moisture (%)= [(Initial weight-final weight)/Initial weight] *100

For determining moisture content, samplings were done randomly from 3-4 different locations at 15, 30, 60, 90, 120, and 150 days. For chemical (60 and 150 days) and microbiological (150 days) analysis, random sampling of compost was done from 3-4 different locations of the compost pits. Sample were pooled and divided into two parts. One part was air-dried, followed by oven drying at 60°C, sieved (2 mm mesh), and analyzed for pH, EC, N, P, K, and micronutrients (Zn, Cu, Fe, and Mn) content. The pH was measured in the water extracted sample (1:10 w/v) using a glass electrode pH meter (Sanchez-Monedero *et al.,* 2001). Electrical conductivity was measured with 1:5 w/v compost water extracts using EC meter (Thompson *et al.,* 2002). Total nitrogen was determined by digesting the compost with concentrated H_2SO_4 and catalyst mix, and the N was estimated by the Kjeldahl method (Westerman, 1990). Total P, K, and micronutrients contents were determined in diacid mixture (HNO_3: $HClO_4$, 4:1) digests using the ammonium molybdate method for P (Nelson and Sommers, 1996) and flame photometry for K (Westerman, 1990). The total C was determined by combustion using the method of Schollenberger (1945). After appropriate dilution with double distilled water, the micronutrient content of the digested materials was estimated by using atomic absorption spectrophotometer (AAS). The other part of compost sample was used immediately or stored at 4°C for microbiological analysis using three different media *viz.*, Nutrient agar (total bacterial count), Rose Bengal agar (Fungi), and Kenknight medium (Actinomycetes). Serial dilution spread plating technique was used for the enumeration of microorganisms (Wollum, 1982). The microbial population was expressed as log colony forming units/gm of moist compost.

RESULTS AND DISCUSSION

Temperature and moisture

Optimum temperature and moisture conditions are necessary for the decomposition of crop residues. The highest temperatures were observed on the 7th day, and after that, a decreasing trend was observed up to 150 days (Fig. 3a). By the end of the composting at the 100 and 150 days, saturation in the temperature values was observed. In the present study, higher temperature ranged from 45-65°C in T2, T3, and T4 treatments. This could be due to proper covering of compost with porous materials, which might have facilitated in retaining moisture, aeration thereby maintaining proper temperature and resulting in the thermophilic phase with microbial proliferation. Several studies showed that temperature had a strong effect on the rate of decomposition; a slower rate of decomposition was observed at low temperatures, and it increased with higher temperatures (Singh *et al.,* 2010; Nielsen *et al.,* 2007). The moisture content in the compost was maintained to 55-60% by watering regularly and covering the compost. The moisture content varied from 54-65% at 15th days, 50-71 % at 30 days, 52-68 at 60 days, 53-69% at 90 days, 51-65% at 120 days and 50-61% at 150 days (Fig. 3b). The variation in moisture was found to be non-significant at 15 days; however, a significant variation was observed at 30, 60, 90, 120 and 150 days. For the majority of the sampling, highest moisture content was retained in T1, which could be due to less evaporation of water whereas, the lowest moisture content was observed in T6. This could be due to the non-covering of the compost pit with the cover, which might have resulted in the loss of moisture. This could be due to the covering of compost pits with different raw materials, and their aeration was maintained by using vertical and horizontal pipes in the composting pits. In the present study, the design of the experimental setup helped in maintaining both moisture and aeration

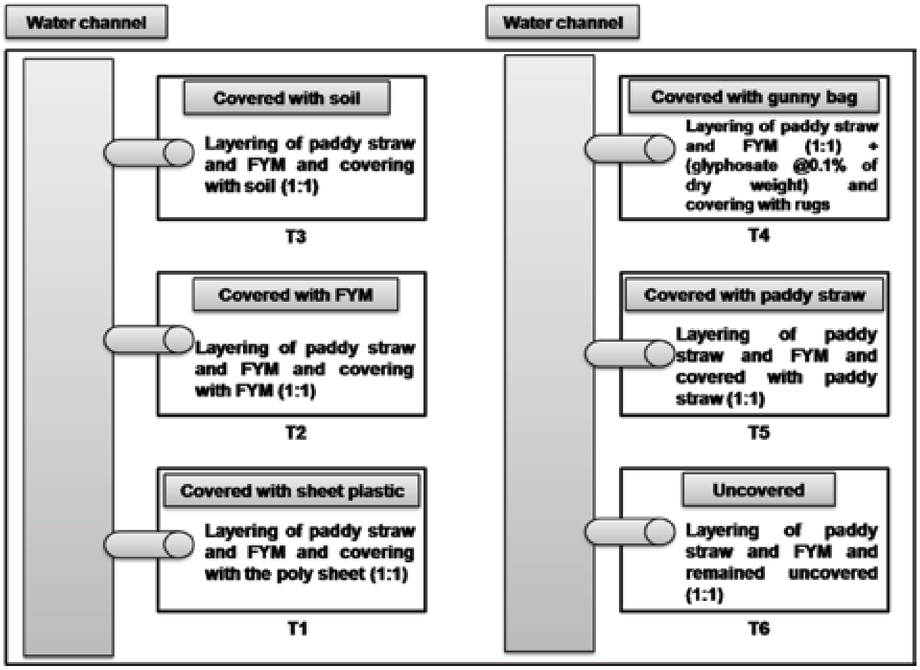


Fig. 1. Experimental setup and structure of composting pits.

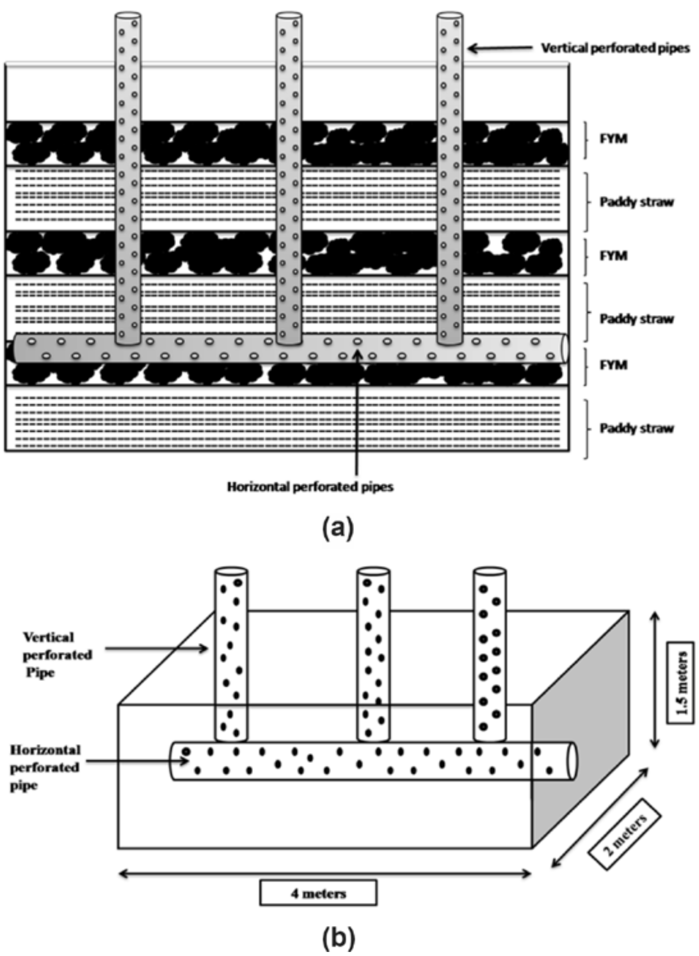
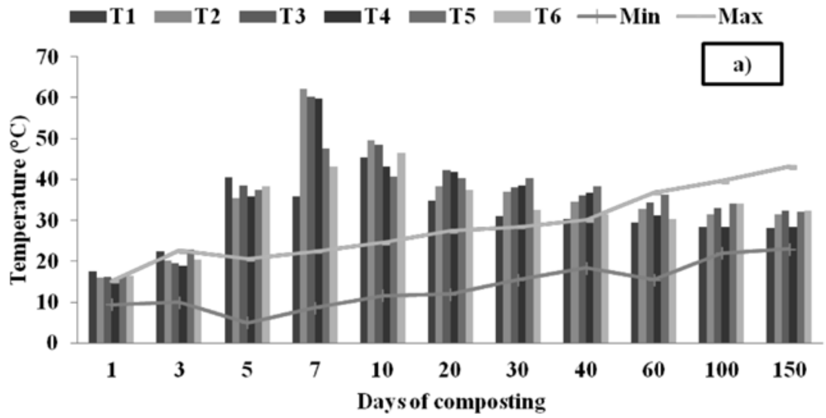


Fig. 2. a) Layering of FYM and paddy straw in pit b) Dimensions and arrangement of vertical and horizontal pipes in the pit.



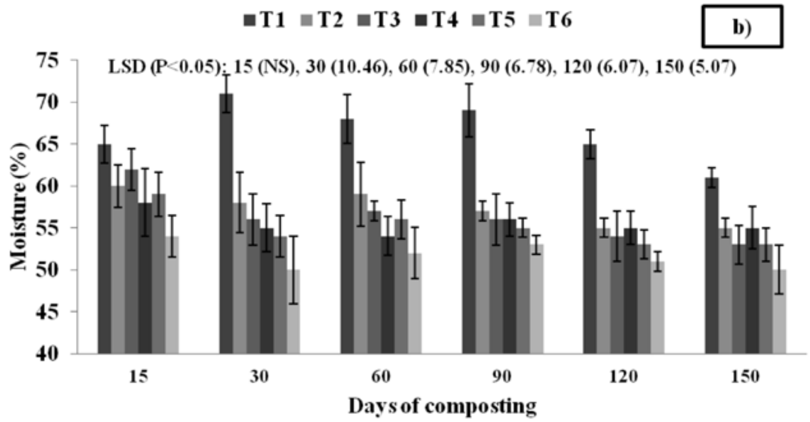


Fig. 3 a) Variation in temperature of the pit during composting (Min and max shows outside temperature) b) Moisture (%) at different sampling days.

during composting of paddy straw. The uncovered pit and the one covered with rugs retained less moisture as compared to the rest of the treatments. Carrying out composting in big pits without using perforated pipes results in a limited supply of oxygen within the pit, thereby creating anaerobic conditions which enhances the time required for degradation of materials. Normally the process of anaerobic composting takes 7-9 months. Secondly, inserting pipes also ensured proper moisture throughout the composting pile, which otherwise is not able to seep in after 30cm. The moisture content and aeration during composting plays an important role which enhances microbial activity and degradation rate. According to Richard *et al.* (2002), the optimal moisture required for organic matter degradation should be within 50–70%. Optimal moisture content coupled with aeration through horizontal and pipes resulted in partially aerated conditions, which helped in decreasing the compost maturation time (Iqbal *et al.,* 2015).

pH and EC

The pH of the compost plays an important role in the composting process. During the process of composting, pH generally varies from 3 to 11 (Bertoldi *et al.,* 1984; Jusoh *et al.,* 2013). The pH of the samples ranged from 7.4-7.9 at 60 and 7.4 to 7.8 at the 150 days of samplings (Fig. 4a). The lowest values of pH were recorded in T4 at both the 60 and 150 days. This could be due to supplementing the paddy straw with glyphosate, which results in an acidification reaction (Boraha *et al.,* 2016a, b). The pH in T1 was also low at 60 days, which might be due to covering the pit with a plastic sheet, which creates an anaerobic environment and production of acidic by-products. EC is mainly due to the decomposition of organic matter, which releases mineral salts (Ogunwande and Osunade, 2011) and the concentration effect due to net loss of dry mass (Sanchez-Monedero *et al.,* 2001; Silva *et al.,* 2009). EC of the samples varied from 2.4 -3.1 dS m^{-1} and 2.4 to 3.0 dS m^{-1} at 60 and 150 days (Fig. 4b), respectively. The increase in the EC is mainly due to the decomposition of organic matter, which releases mineral salts (Ogunwande and Osunade, 2011) and the concentration effect due to net loss of dry mass (Silva *et al.*, 2009). The results obtained in the present study are in congruence with the results obtained by Ogunwande and Osunade (2011), who also reported an increase in the EC of the compost with time.

Table 1. Chemical parameters of compost after 60 and 150 days

Treatment	Macronutrients (%)						Micronutrients (ppm)			
	N		P		K		Zn	Cu	Fe	Mn
Days	60	150	60	150	60	150	150	150	150	150
T1	1.1±0.13	1.2±0.10	0.34±0.01	0.40±0.02	1.4±0.22	1.5±0.12	144±5.20	182±4.04	1526±5.13	306±5.29
T2	1.1±0.15	1.9±0.12	0.39±0.02	0.63±0.01	2.1±0.31	2.4±0.12	202±6.25	288±5.03	1626±6.35	514±6.08
T3	1.2±0.15	1.6±0.12	0.32±0.02	0.47±0.02	1.0±0.18	2.1±0.15	177±6.11	192±6.66	1976±9.54	476±7.57
T4	0.9 ±0.17	1.1±0.17	0.28±0.03	0.37±0.02	1.8 ±0.18	2.3±0.27	152±4.36	290±7.64	1218±6.66	302±5.78
T5	1.1±0.12	1.3±0.06	0.46±0.02	0.40±0.01	1.9±0.23	2.2±0.30	190±3.21	378±4.04	1566±6.81	420±7.64
T6	0.9±0.06	1.2±0.15	0.38±0.01	0.47±0.03	2.1±0.29	2.2±0.12	184±3.79	324±3.46	1272±4.58	316±5.51
LSD (P<0.05)	0.38	0.39	0.64	0.52	0.47	NS	16.36	17.82	22.61	16.70

*Initial status
Macro nutrients
Paddy straw : N(0.45%), P(0.56%), K(1.25%)
FYM : N(0.74%), P(0.32%), K(0.95%)
Micronutrient content (ppm)
Paddy straw : Zn(30 ppm), Cu(3 ppm), Fe(350 ppm), Mn(310 ppm)
FYM : Zn(106 ppm), Cu(24 ppm), Fe(956 ppm), Mn(70 ppm)

Macro- and micro-nutrients

During the process of composting, microbial transformations of critical plant nutrients such as N, P, and K take place (Bernal *et al.,* 2009; Maeda *et al.,* 2013). These microbial transformations occur via the action of microbial enzymes which results in hydrolysis of complex macromolecules present in organic waste (Delgado *et al.,* 2004). The N content of the compost ranged from 0.9 to 1.2 % at 60 days and 1.1 to 1.9 % at 150 days, with the highest value of 1.9 % in T2 covered with FYM (Table 1). Similar values of N content (2.17%) were reported by Goyal and Sindhu (2011) for paddy straw compost. Higher N content at the end of the composting period could be attributed to the reduction of N by microbes and its build-up in microbial cells, followed by their death and recycling (Polprasert, 1996). Other workers state that the increase in N could be due to the loss of carbon during composting, and N becomes concentrated during composting (Vuorinen and Saharinen, 1997). The P content ranged from 0.28 to 0.46 % at 60 days and 0.40 to 0.63 % at 150 days, with the highest value of 0.63 % in T2. Similar results have been obtained by various workers (Vourinen and Saharinen, 1997; Sommer, 2001; Iyengar and Bhave, 2005; Tai and He, 2007; Jusoh *et al.,* 2013). The increase in P content could be attributed to the loss of carbon as carbon dioxide emissions. K is usually known to leach out quickly (Polprasert, 1996); however, in the present study, an increase in K content was observed. The K content of the samples ranged from 1.0 to 2.1 % at 60 days and 1.5 to 2.4 % at 150 days. This could be due to the property of paddy straw to absorb moisture and maintain its structural integrity and porosity, which might have resulted in retaining of K in the compost (Yengar and Bhave, 2005; Jusoh *et al.,* 2013). Rice plants uptake K in larger amounts compared to N and P so, by composting paddy straw, these natural reserves can be recycled for subsequent use in next season (Sarkar, 2017). A variation in N, P and carbon content was also obtained by Karanja *et al.* (2019) while co-composting paddy straw with chicken and donkey manure. In the present study, the use of FYM also helped in improving the quality of compost in terms of nutrients.

Application of glyphosate @ 0.1% resulted in lower values of N, P, K, and micronutrients, which could be attributed to the lower pH, which might have resulted in lower microbial activity, degradation and nutrient content of the compost. A variation was observed in the micronutrient content of compost, which ranged from 144 to 202 ppm for Zn, 182-378 ppm for Cu, 1218 to 1976 ppm for Fe, and 306 to 514 ppm for Mn (Table 1). The increasein the micronutrients content of paddy straw compost could be due to the addition of organic manures and increased microbial activity during paddy straw composting (Kausarab *et al.,* 2014).

C/N ratio

The degradation of crop residues is mainly dependent on the C/N ratio of the raw materials used for composting. For the best composting, an ideal C/N ratio must be achieved, where C serves as an energy source, and N helps in protein production. The initial C/N ratio of paddy straw was 88 (0.45% N and 39.8% C), and FYM was 29.3 (0.74% N and 21.7 % C). The addition of raw material with a high C/N to the material with a low C/N ratio results in a balance of C/N ratio, thereby resulting in fast degradation. At 30 days, the total N in the compost samples ranged from 0.7-0.9 % (Fig. 5a), Total C from 34.8-37.6 % (Fig. 5b), and C/N ratio varied from 39.2 to 50.9 (Fig. 5c). Highest C/N

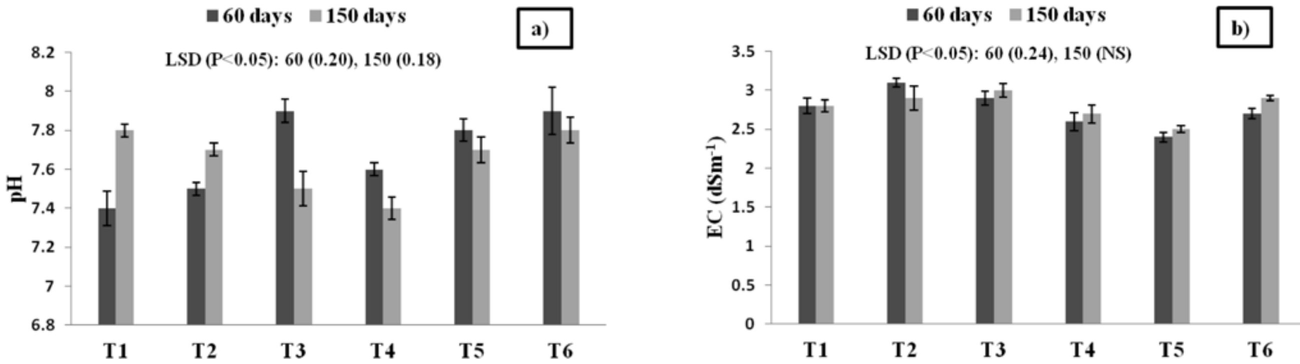


Fig. 4. Variation in a) pH and b) EC of compost samples at 60 and 150 days.

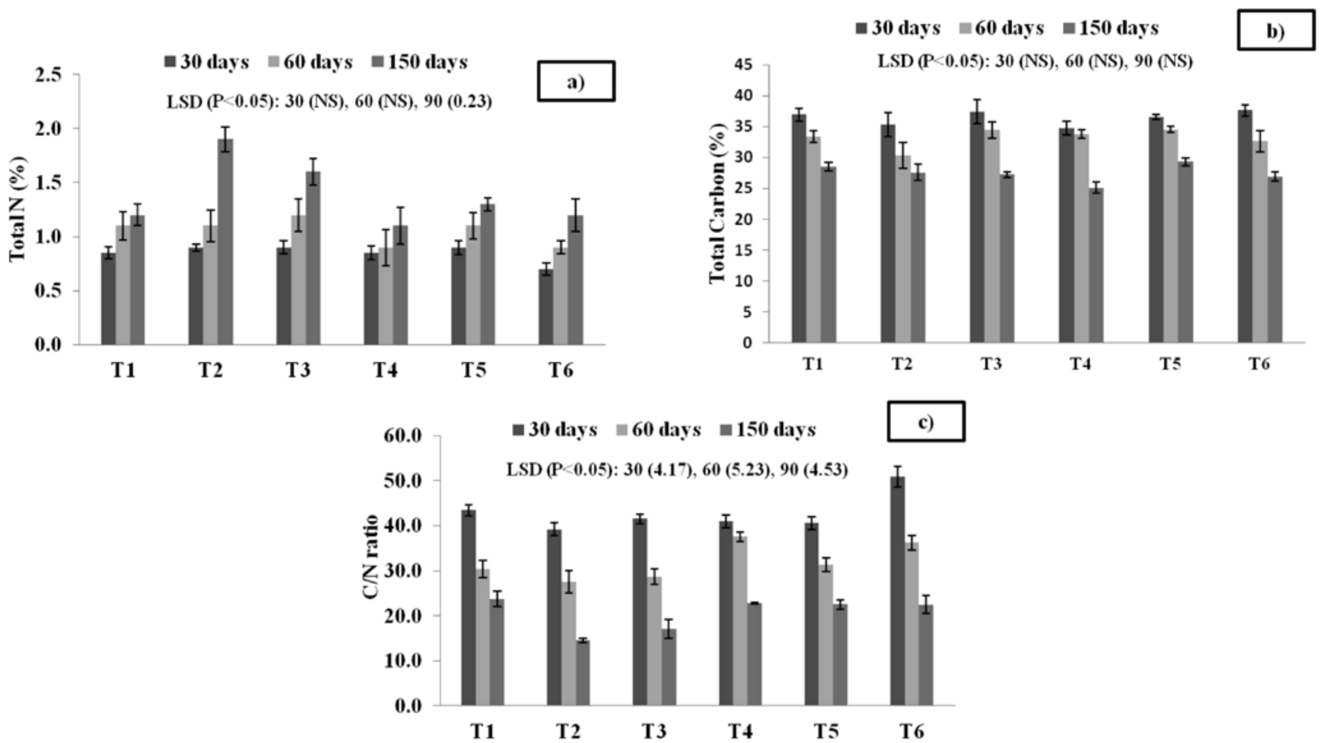


Fig. 5. a) Total nitrogen content (%), b) Total carbon, and c) C/N ratio of compost at different sampling days.

ratio was observed in the T6, which is mainly attributed to low total N. After 60 days, a further increase in N content was observed, which ranged from 0.9 to 1.1 %; the increase in N could be attributed to increased microbial activity. Further, a reduction in the C content was observed, which ranged from 34.5 to 30.3 % and the C/N ratio varied from 27.5 to 36.2. The highest decrease in C/N ratio was observed in T2, which was covered with FYM, which might have accelerated the composting process by the leaching of nutrients down to the pit and might have facilitated microbial proliferation. During maturity, the degradation of recalcitrant forms of carbon takes place at 150 days. A further reduction in total carbon and C/N ratio was observed, which ranged from 25.1 to 29.3 % and 17-25.8, respectively. Total nitrogen content at 150 days was found to be statistically significant. This could be due to more microbial activity. The increase in N content at 30 and 60 days was found to be non-significant. The total C content in the compost was found to be statistically non-significant at 30, 60, and 150 days. This could be attributed to the inherent capability of different organisms to use carbon as a raw material. However, the C/N ratio in all the samplings at 30, 60, and 150 days were found to be statistically significant, which could be due to a variation in N content, which might have resulted in a higher C/N ratio. The increase in N content could be attributed to anabolism of cell structure, enzymes, hormones and

Table 2. Microbiological parameters of the final compost product.

Treatment	Total microbial count	Fungi	Actinomycetes
	(log CFU/g of moist compost)		
T1	8.74±0.082	5.39±0.040	6.82±0.047
T2	8.86±0.046	5.54±0.076	6.94±0.078
T3	8.82±0.064	5.47±0.089	6.89±0.040
T4	8.62±0.068	5.16±0.081	6.76±0.081
T5	8.74±0.061	5.46±0.046	6.77±0.070
T6	8.78±0.072	5.34±0.040	6.79±0.049
LSD (P<0.05%)	0.19	0.15	0.20

*Initial Microbiological parameters (log CFU/g)
Paddy straw: Total microbial count: 8.39, Fungi: 4.84; Actinomycetes: 6.10
FYM: Total microbial count: 9.02, Fungi: 5.69; Actinomycetes: 6.57

decrease in C content could be due to the loss of C as CO_2. These results are in agreement with the studies of several researchers who also reported a decrease in C/N ratio with the passage of time (Kumar *et al.,* 2008; Sharma and Arora, 2011; Shukla *et al.,* 2016). Lestari *et al.* (2020) reported that the C/N ratio of rice straw composting at 50%, 100%, and 150% moisture content was 35.6; 29.7, and 29.2, respectively.

Microbial diversity

The process of composting proceeds with the succession of different groups of bacteria, fungi, and actinomycetes that can degrade even the more recalcitrant compounds in wastes (Karnchanawong and Nissaikla, 2014). The population of different groups of microbes obtained during composting was determined at 150 days (Table 2). The total microbial count ranged from 8.62-8.86 log CFU/gm of moist compost with an initial count of 8.39 and 9.02 log CFU/gm in paddy straw and FYM, respectively. The results obtained are in agreement with those obtained by Vuorinen and Saharinen (1997), where count ranged from 1.2 to 2.1×10^8 CFU/g. Fungi are considered as major players of decomposition, and their count ranged from 5.16 to 5.54 log CFU/g of moist compost. The results obtained in the present study are in congruence with the results obtained by Vuorinen and Saharinen (1997), who reported a variation in the mold population from 3.76-9.35×10^5 CFU/gm. Actinomycetes play an important role in the maturation of composts, and their population ranged from 6.77 to 6.94 log CFU/g of moist compost. Umsakul *et al.* (2010) also reported a variation of 3.5 to 5.5 log CFU/g at 11 weeks. The results obtained in the present study show higher values of actinomycetes count as compared to other workers (Devi *et al.,* 2012), which could be due to the presence of higher actinomycetes at the maturity of the compost. In a study made by Sahoo *et al.* (2019), a variation in microbial diversity of bacteria, fungi and actinomycetes was observed during different stages of composting using different types of straws. Chang *et al.* (2021) reported the abundance of genera *Staphylococcus, Bacillus* and *Thermobifida* during mesophilic, and *Aspergillus* during thermophilic stage of composting. Treatment T4 was supplemented with glyphosate, which resulted in lower values of total microbial count, fungi, and actinomycetes. The lower microbial counts in the treatment could be attributed to the adverse effect of glyphosate on microbial diversity during composting. However, some workers have reported better decomposition of rice stubble through acidification with the application of glyphosate facilitated effective inoculation of microorganisms (Borah *et al.,* 2016a, Borah *et al.,* 2016b). In all the treatments, maximum count was obtained from the pit covered with FYM. FYM contains nutrients in the form of readily available substrates, which also helps to narrow down the C:N ratio for better degradation. Higher microbial counts in this treatment could be due to the addition of FYM and microbial formulations, which might have facilitated better microbial activity during composting.

To conclude, on-farm composting contributes substantially in solving the problem of management of paddy straw and concomitantly provides the farmer with a self-supply of quality compost for improving agricultural productivity. In the present study, well-decomposed compost was prepared within 150 days. The use of horizontal and vertical pipes for partial aeration and maintaining moisture content in the pit helped in better microbial activity and rapid degradation. Among all the treatments, the pit covered with FYM resulted in the highest values of macro (N, P, and K) and micronutrients (Fe, Mn, Cu and Zn), reduction in C/N ratio, and microbial count. So to avoid the delay in the composting process and reduce the manual operations of aerobic composting, an intermediate cost-effective approach can be adopted for composting of paddy straw. The quality compost so prepared can be used for the subsequent rice crop, other *Kharif* crops, or kitchen garden by the farmers and the unnecessary burden of paddy straw burning can be reduced from the environment.

Authors' contribution

Conceptualization of research work and designing of experiments (N, SS); Execution of field/lab experiments and data collection (N, SS); Analysis of data and interpretation (N, SS); Preparation of manuscript (N, SS)

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