Impact of Microbial Decomposers Spray on *in situ* Degradation of Paddy Straw Stubble Left in the Field after Paddy Harvesting in Punjab

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Effects of microbial decomposer application were studied relative to *in situ* decomposition of paddy straw in the rice-wheat system using both paddy straw incorporation (*i.e.* mechanical mixing of leftover straw and stubble using rotavator) and retention (*i.e.* leftover straw and stubble without mechanical mixing) methods. An experiment was conducted on paddy straw degradation during 2020-2021 and 2021-22 using microbial consortium (decomposer) at four locations in Punjab, India using three different treatments. Lignin content, C/N ratio, and tensile strength after 30 days of incorporation and retention of paddy straw were recorded. Microbial treatment along with incorporation improved decomposition parameters from 32.0 to 32.6% (C/N ratio) and 47.5 to 36.6% (lignin), whereas a major share – 28.6 (C/N ratio) and 36.6 (lignin) per cent of decomposition was achieved by soil incorporation as such. Wheat grain yield with and without microbial decomposer was similar across sowing methods (incorporation vs retention) in all locations. Similar observations were recorded in 2021-22 also at the same site of PAU, Ludhiana. Microbial agents responsible for the degradation of straw are present in sufficient quantity in the soil and incorporation of paddy straw in the soil by incorporation using a rotavator can enhance the paddy straw decomposition.

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INTRODUCTION

Rice crop (*Oryza sativa* L.) generates straw in quantities as much as 23% of its total weight, and this is usually burnt to clear the fields for the next crop, *i.e*., wheat (*Triticum aestivum* L.) in the rice-wheat system. The amount of straw burning in different states of India has already been highlighted (Jain *et al.* 2014), and open-field straw burning contributes up to 0.05% of the total greenhouse gas emissions (Gadde *et al.* 2009; Abdurrahman *et al.* 2020). However, after drying, the low moisture content and high bulk and energy density of straw make it a suitable substrate for pelleting but breakage and attrition further contribute to environmental challenges (Ilic *et al.* 2018). As is well known, paddy straw is rich in different types of nutrients. It contains 0.5 to 0.8% N, 0.16 to 0.27% P_2O_5, 1.4 to 2.0% K_2O, 0.05 to 0.10% S, and 4 to 7% Si on dry weight basis; thus, if it is allowed to degrade *in-situ*, this can lead to improved soil health (Dobermann and Fairhurst 2002). Besides NPK, straw residue contains Zn, Fe, and Mg that can enrich the soil. Burning paddy straw wastes substantial valuable natural resources and puts great pressure on the soil ecosystem in the rice-wheat rotation system. It has been proposed that returning 1,500 to 4,500 kg ha^{-1} of rice straw and 2,250 to 6,750 kg ha^{-1} of wheat straw to the field helps increase the organic carbon content and quality of the soil and promotes annual yield (Jin *et al.* 2020).

Various other methods have been investigated to screen the degradation of paddy straw in an environment-friendly way instead of burning it. By carrying out the *in situ* degradation the organic matter content per hectare can be increased with a simultaneous increase in nitrogen content, phosphoric anhydride, and potassium oxide. The slow rate of hydrolysis accompanied by substrate and temperature specificity of fungi and enzymes, however, reduces the overall fascination of microbial degradation by intrinsic microflora of soil.

Biological pretreatment involves the use of lignocellulolytic microorganisms or enzymes. It is favored over the other pretreatment methods because it is more eco-friendly and does not generate any kind of toxic waste. Decomposition of residues is a microbial process, and it requires proper environmental conditions to function efficiently. If a microbial nutrient enrichment solution or suspension along with proper irrigation is applied to rice straw, the native microflora present on the straw and in the soil is stimulated to increase in numbers which, in turn, can accelerate its biodegradation (Sharma *et al.* 2014). Because the rice straw has an almost impermeable epidermis, mechanical breaking through the epidermis to allow moisture and nutrient penetration are essential for microbial decay from inside the hollow straw to the outside (Pinckard and Gill 1990).

As degradation of the straw proceeds, its physical strength decreases upon decomposition and returns to the soil in the form of humus. To mitigate open-field burning and to enhance the recycling of organic waste, there will be a need to look for an alternative that includes *in-situ* degradation of paddy straw for sustainable agriculture (Shrivastava *et al.* 2018).

Soil microbes essentially decompose the leftover straw. Further, any of the factors that can potentially affect soil microbial species, abundance, and their activity also affect the decomposition of returned straw. These decomposers (microbial agents made up of of many bacteria, molds, yeast, and bacillus) can accelerate straw degradation by secreting extracellular enzymes, and they can induce the fibrosis of the microporous structure of the added straw (Arora *et al.* 2002; Geisseler and Horwath 2008; Wiedermann *et al.* 2017). They decompose cellulose, hemicellulose, and lignin present in the straw into simple organic compounds to release CO_2, thereby accelerating straw decomposition.

Strong intra- and inter-species cooperation (such as synergy, syntrophy, and/or symbiosis) is strictly required for sufficient straw decomposition (Jimenez *et al.* 2016). The aim of this work was to find out whether the intrinsic flora of soil is sufficient to do the decomposition of incorporated straw or whether the additional microbial application facilitates or hastens the process.

EXPERIMENTAL

Earlier studies carried out during 2015-2019 using different microbial formulations as individual as well as consortium cultures tried mainly in retention studies led to the selection of a consortium named PAU decomposer. This consortium contains two fungal (*Aspergillus* and *Trichoderma* sp.) and six bacterial inoculants (*Bacillus*, *Delftia*, *Pseudomonas*, *Lysinibacillus fusiformis*, *Arthrobacter nicotianae* and *Paenibacillus ehimensis*) that outperformed other microbiota in previous studies (Katyal *et al*. 2022). An experiment was conducted on paddy straw degradation during 2020-2021 using a microbial consortium developed by Punjab Agricultural University, Ludhiana (PAU Decomposer) along with another consortium developed by Indian Agricultural Research Institute, Pusa Campus, New Delhi (PUSA Decomposer). The experiment was conducted at four locations *i.e.* at PAU Ludhiana, Krishi Vigyan Kendra - Kheri (Sangrur), Regional Research Station - Kapurthala, Regional Research Station - Gurdaspur. Two different methods of rice straw management *i.e.* 1. Incorporation (after harvesting of paddy (rice) whatever straw was left in the field was mechanically mixed in the soil by Rotavator) and 2. Retention (straw is left as such in the field not mechanically mixed in soil) was used. The experimental design included two plots *i.e.* one with incorporation and the other with retention and three different treatments in each sub-plot:

1. Control (without microbial decomposer spray)
2. Application of PAU Decomposer @ 15 L diluted to 200 L for spray on one acre
3. Application of PUSA Decomposer @ 10 L diluted to 200 L for spray on one acre (as standard operating procedure given by the manufacturer is to use 25L per hectare)

A liquid suspension of the microbial consortium was sprayed after harvesting the paddy. The wheat crop was sown using two different methods, *i.e.*, with Happy Seeder (Retention) and with Conventional drill after incorporation of straw with rotavator after 30 days of application of PAU decomposer in the plots of size 8 m x 5 m in triplicate with split plot design. At the other three locations, sowing of wheat was done after 7 to 15 days of spraying with decomposers. The observations were recorded on lignin content, C/N ratio, and tensile strength after 30 days of incorporation, and the grain yield of wheat was recorded after harvesting. To confirm the result of the 2020-21 trials, another field trial was conducted at two different locations within PAU, Ludhiana during 2021-22. In this trial also same three treatments were repeated in incorporation and retention modes.

Determination of Lignin Content of Paddy Straw

Proximate analysis of paddy straw was carried out using a Van Soest scheme for fibre analysis (Van Soest 1963). For measuring neutral detergent fibre (NDF) and acid detergent fibre (ADF), the dried sample was homogenously ground to powder, and 0.5 g of it was reflexed with 50 mL of neutral detergent solution and acid detergent solution, respectively. Then, the contents were kept at 80 °C for 1 h followed by filtration using a G-1 crucible. The residue was then washed with hot distilled water followed by acetone and was kept in a hot air oven till the constant weight was achieved. Thus, hemicellulose content was calculated from the difference between NDF and ADF. Similarly, from the difference between ADF and 72% H_2SO_4 treated residues, cellulose content was calculated. For estimation of acid detergent lignin (ADL), crucibles containing 72% H_2SO_4 treated residue were ignited in the muffle furnace at 600 °C for 3 h.

Analysis of C/N Ratio

Straw samples were analyzed for the C: N ratio using a CHNS Elemental analyzer (model Vario EL III) at the Department of Soil Science, Punjab Agricultural University, Ludhiana.

Tensile Strength

The tensile strength of paddy straw was measured using a double-column texture analyser (Stable Micro Systems, Model: TA.TXT Plus, UK) and expressed in Newtons. For measurement of tensile strength, paddy straw samples were segregated into three categories *viz*. i) hard stubble, ii) hard straw, and iii) crumbled straw in triplicates and held with tensile grip set at 50mm separation gap. The straw was stretched at a crosshead speed of 5 mm/s and the tensile strength was determined from the force-time graph.

Grain Yield

Grain yield (quintal per hectare) was calculated after manual threshing of harvested crops from each net plot size of 7m X 5m. The grains were weighed, their weight was converted into q $ha^{-1,}$ and grain weights were corrected according to the safe moisture content (12%).

Statistical Analysis

To study the effect of different methods *i.e.* incorporation *versus* retention and different treatments (unsprayed, sprayed with PAU decomposer, and sprayed with PUSA decomposer) on percent decrease in lignin, C/N ratio, and tensile strength, the sowing method was considered as factor A and treatments were considered as factor B. Two factorial CD were calculated w.r,t factor A, factor B, and interaction of these factors using an online statistical tool WASP version 2.0.

RESULTS AND DISCUSSION

Effect of Different Treatments on Lignin Content of Paddy Straw

Lignin is the most recalcitrant component of straw, and a plethora of microbial enzymes can be helpful in its degradation. A decrease in lignin content is directly related to the degree of straw degradation and is the first step to expose the cellulosic fiber for the action of cellulases and hemicellulases. In the present study, degradation of straw was studied with respect to the decrease in lignin content of straw after 30 days of microbial application. The observations on changes in lignin content after incorporation and retention are presented in Table 1.

There was a decrease in lignin content in control as well as in decomposer treatments. At PAU, Ludhiana's initial value of lignin was 16.5%, which decreased to 7.7, 5.4, and 9.1% after 30 days in control, PAU decomposer, and Pusa decomposer, respectively. This clearly shows that the addition of decomposers did not invariably surpass control for lignin degradation. The degradation percent in control (without microbial spray) was quite high because of the enzymatic activity of intrinsic microflora of soil. Further, the addition of extraneous microbial formulations such as PAU decomposer showed numerically high degradation percent, but this was not reflected in other decomposer applications. This can be due to altered microbial diversity in the soil on the application of extraneous microbes. In the soil, a variety of microbes co-exist in a balanced way so that each can get its nutrients and in turn release their metabolic end products in the soil itself. Any alteration in microbial diversity can influence the soil health and in turn affect its fertility. A small increase in lignin degradation cannot justify the extra step involved for multiplying and spray of decomposer formulations. Taking into account the interaction of factor A and factor B, there was significant difference in lignin degradation percentage in incorporation as compared to retention trials. Incorporation of paddy straw in the field after microbial spray resulted in better degradation as revealed by higher lignin reduction percent in the former (48.1%) as compared to the latter (32.4%). Earlier studies carried out in the authors' laboratory also revealed a small degradation in retention trials during consecutive two years *i.e.* 2018-19 and 2019-20 (Katyal *et al.* 2022).

Effect of Microbial Decomposer Application on C/N Ratio

Initially straw has a very high C/N ratio, but the degradation of straw or its composting can lead to a decrease in this ratio, thereby making its nutrients available to the soil. Periodic change in C/N ratio was analyzed to study the effect of microbial decomposer application, and results are presented in Table 1. The initial C/N ratio of straw depends on its variety, on an average the C/N ratio of paddy straw obtained from different varieties varies from 60:1 to 80:1. Crop straw represents a major source of carbon (C) in agroecosystems (Nakamura *et al.* 2003). Its decomposition involves the mineralization and transformation of photosynthesis products into stable soil organic matter, which plays the main role in resource recycling and soil nutrient transformation (Lal 2004). During the microbial decomposition, bacteria predominate at the early stages degrading the less recalcitrant components (cellulose, hemicelluloses, oligosaccharides, and organic acids), while actinomycetes and fungi are highly abundant in the later stages for degradation of recalcitrant components like lignin (Cusack *et al.* 2011; Marschner *et al.* 2011). However, enzyme activities and microbial community structure that are engaged in straw decomposition vary with various environmental factors such as temperature, soil moisture, and nutrient availability (Zhou *et al.* 2016). This is the main reason for the variable decrease in the C/N ratio at different locations. Studies have demonstrated that the C decomposition rate is affected by the biochemical composition of straw, such as contents of C, N, cellulose, and lignin, as well as the ratios of C/N and lignin/N (Raiesi 2006). With the progression of paddy straw decomposition, organic carbon content decreased due to the loss of carbon in the form of CO_2, and nitrogen content increased due to the concentration effect which resulted in a decreased C: N ratio. Lee *et al.* (2002) also reported an increase in total nitrogen concentration during the progression of composting, where the loss of volatile solids (organic matter) exceeds the loss of NH_3.

At PAU Ludhiana, the initial value for the C/N ratio recorded was 61.6 and after 30 days it was decreased to 24.0, 21.3, and 21.9, respectively, and at Sangrur, the initial value was 81.9 decreased to 66.3, 63.7 and 65.1 respectively for control, PAU decomposer and PUSA decomposer after 30 days in incorporation treatments. Similar was the case at RRS Kapurthala, where the initial C/N value was 85.6 that reduced to 77.8, 69.5, and 71.2, respectively. The initial value of the C/N ratio at RRS Gurdaspur was 70.1 and after 30 days decreased to 51.0, 50.7, and 52.4, respectively in retention treatments.

From these results, it is clear that the application of decomposers did not help to decrease the C/N ratio as compared to control. Further, the window between incorporation and sowing plays a significant role in reducing the C/N ratio. At Ludhiana sowing was done after 30 days of incorporation and resulted in a better reduction in C/N ratio as compared to outstations where wheat was sown after 7 to 15 days of incorporation. Here also no significant difference was observed in unsprayed and decomposer-sprayed fields, as the difference in the mean values of treated plots was less than 5.27. Considering the interaction between the two factors, the difference in C/N of the incorporation trial (32.52) and retention trial (29.63) was non-significant. Similarly, there was no significant difference in the C/N ratio with or without microbial spray. From these findings, we can suggest that the intrinsic microflora present in the soil plays an important role in decreasing the C/N ratio while the addition of extraneous microbes does not significantly contribute to further reducing its value.

Effect of Microbial Decomposer Application on Tensile Strength

Tensile strength results exhibited brittleness of straw and periodic change in tensile strength both in control and treated plots, as shown in Table 1. Tensile strength is the most important parameter for ease of use of conventional drill machines for sowing operations when straw is retained in the field. The initial value of tensile strength at PAU Ludhiana was recorded as 26.5 N. After 30 days the value was decreased to 4.3, 8.9, and 8.2 N, respectively, for control, PAU decomposer, and PUSA decomposer. The mean value of the percent decrease in tensile strength in incorporation plots was 72.3, which was significantly higher than retention (49.9) plots, highlighting the importance of mixing straw in soil to decrease its tensile strength. Comparing the average reduction value of tensile strength in unsprayed and sprayed fields, the difference was found to be non-significant.

To validate the results of multilocational trials conducted in 2020-21, similar treatments were tried in 2021-22 using the sowing method (Incorporation/retention) as factor A and three microbial inoculation treatments (unsprayed, PAU decomposer, PUSA decomposer) as factor B. The trials were carried out at two different locations within PAU Ludhiana, and results are presented in Table 2. The mean value of factor A during incorporation revealed a 54.6% reduction in lignin as compared to the 28.5% reduction reported in retention. Similarly, a significant reduction in C/N ratio (58.2%) and tensile strength (73.6%) was observed in the incorporation trial with respect to their corresponding values of 47.5% and 56.2% in the retention trial. The present findings again highlight the importance of straw incorporation to improve its *in-situ* degradation as compared to retention. While comparing the mean values of factor B, non-significant difference was observed in unsprayed and sprayed plots.

Effect of Different Treatments on Grain Yield of Wheat

In Punjab, harvesting of paddy is mostly followed by sowing of wheat. In the present study also, the sowing of wheat was done on both control and microbial decomposer sprayed plots by using the conventional drill procedure for the incorporation treatments and Happy Seeder for retention treatments. The grain yield of wheat from different treatments of experiments conducted during 2020-21 and 2021-22 at different locations was recorded and is presented in Tables 3 and 4.

In 2020-21, spraying of PAU decomposer and PUSA decomposer was done in September 2020, and sowing of wheat variety PBW 725 was done on 3rd Nov 2020. A similar experiment was conducted at Regional Research Station, Kapurthala by spraying both the decomposers on 28th Oct 2020 and sowing of wheat variety PBW 677 on 13th Nov 2020 after 15 days of decomposer spray. At RRS Gurdaspur also both the decomposers were sprayed on 28th Oct 2020 and sowing of wheat variety PBW 725 was done on 5th Nov 2020 after 8 days.

Table 1. Percent Decrease in Lignin, C/N ratio, and Tensile Strength using Microbial Decomposers in Incorporation and Retention Trials (2020-21)

Sowing Method	Parameter											
	Lignin (%)				C/N ratio				Tensile strength (Newtons)			
	Initial value	Unsprayed	PAU Decomposer	PUSA Decomposer	Initial value	Unsprayed	PAU Decomposer	PUSA Decomposer	Initial value	Unsprayed	PAU Decomposer	PUSA Decomposer
	PAU, Ludhiana											
#Incorporation	16.5	7.7 *(53.4)	5.4 (67.3)	9.1 (44.9)	61.6	24.0 (61.1)	21.3 (65.4)	21.9 (64.5)	26.5	4.3 (83.8)	8.9 (66.4)	8.2 (69.1)
^Retention		13.8 (16.4)	8.4 (49.1)	12.8 (22.4)		29.6 (51.7)	28.4 (53.7)	29.1 (52.8)		17.62 (33.61)	22.6 (14.7)	20.6 (22.26)
	KVK Sangrur											
Incorporation	17.8	12.2 (31.5)	9.9 (44.4)	12.8 (28.1)	81.9	66.3 (19.1)	63.7 (22.2)	65.1 (20.5)	30.9	10.3 (66.7)	6.7 (78.3)	9.3 (69.9)
Retention		11.5 (35.1)	12.3 (30.8)	12.5 (29.8)		62.8 (23.3)	63.8 (22.1)	53.1 (35.1)		11.3 (63.47)	18.8 (39.09)	10.8 (64.99)
	RRS Kapurthala											
Incorporation	17.2	8.5 (50.6)	8.0 (53.5)	8.4 (51.2)	85.6	77.8 (9.1)	69.5 (18.8)	71.2 (16.8)	32.1	6.9 (78.5)	6.5 (79.8)	9.2 (71.3)
Retention		12.6 (26.8)	10.3 (39.9)	11.6 (32.8)		73.8 (13.8)	72.3 (15.6)	74.3 (13.2)		12.3 (61.71)	13.8 (56.91)	15.8 (50.72)
	RRS Gurdaspur											
Incorporation	16.9	9.6 (43.2)	7.3 (56.8)	8.1 (52.1)	70.1	49.5 (29.4)	48.9 (30.2)	46.9 (33.1)	34.3	10.3 (70.0)	13.0 (62.1)	9.8 (71.4)
Retention		10.9 (35.7)	15.0 (38.4)	11.5 (31.8)		51.0 (21.4)	50.7 (27.7)	52.4 (25.2)		12.81 (62.71)	12.35 (64.06)	12.34 (64.06)

Two Factorial CD w.r.t Percent Decrease in Individual Component						
Factor A	Mean value	CD (5%)	Mean value	CD (5%)	Mean value	CD (5%)
Incorporation	48.08	7.16	32.52	4.30	72.27	10.93
Retention	32.42		29.63		49.86	
Factor B						
Unsprayed	36.59	8.77	28.61	5.27	65.06	13.38
PAU Decomposer	47.53		31.96		57.68	
PUSA Decomposer	36.64		32.65		60.46	
Factor A X Factor B		12.40		7.46		18.92

*Figures in parenthesis indicate percent decrease w.r.t initial value #mixing straw in soil by rotavator before spray ^Spray on surface straw without mixing

Table 2. Percent Decrease in Lignin, C/N Ratio, and Tensile Strength using Microbial Decomposers in Incorporation and Retention Trials (2021-22)

Sowing Method	Treatments											
	Lignin (%)				C/N ratio				Tensile strength (Newtons)			
	Initial value	Unsprayed	PAU Decomposer	PUSA Decomposer	Initial value	Unsprayed	PAU Decomposer	PUSA Decomposer	Initial value	Unsprayed	PAU Decomposer	PUSA Decomposer
Location 1												
Incorporation	24.2	10.9 *(54.96)	10.6 (56.2)	11.1 (54.1)	84.0	33.8 (59.8)	29.2 (65.2)	30.1 (64.2)	32.1	6.9 (78.5)	6.5 (79.7)	9.2 (71.4)
Retention		17.7 (26.8)	14.5 (40.1)	16.3 (32.6)		47.2 (43.8)	45.7 (45.6)	39.3 (53.2)		12.3 (61.7)	13.8 (56.9)	15.8 (50.8)
Location 2												
Incorporation	20.5	9.9 (51.8)	8.8 (57.0)	9.6 (53.3)	81.3	39.1 (51.9)	33.6 (58.6)	31.1 (61.8)	31.4	8.6 (72.6)	7.4 (76.4)	11.4 (63.2)
Retention		14.6 (28.8)	16.3 (20.7)	15.9 (22.2)		45.4 (44.2)	43.7 (46.3)	39.1 (51.9)		12.6 (59.8)	13.2 (58.2)	15.7 (49.5)

Two Factorial CD w.r.t Percent Decrease in Individual Component						
Factor A	Mean value	CD (5%)	Mean value	CD (5%)	Mean value	CD (5%)
Incorporation	54.56	8.65	58.23	4.10	73.63	3.57
Retention	28.53		47.50		56.15	
Factor B		10.60		5.03		4.37
Unsprayed	40.59		49.92		68.15	
PAU Decomposer	43.50		50.90		67.80	
PUSA Decomposer	40.55		57.77		58.72	
Factor A X Factor B		14.99		7.11		6.18

*Figures in parenthesis indicate percent decrease w.r.t initial value [#]mixing straw in soil by rotavator before spray ^Spray on surface straw without mixing

Similarly at Krishi Vigyan Kendra, Kheri, spraying of both the decomposers was done on 29th Oct 2020 followed by sowing of wheat variety DBW 187 on 4th Nov 2020 after 7 days of spraying. The effect of the sowing method and microbial decomposer application on grain yield was insignificant. Small location-specific variations in the yield can be due to the different wheat varieties and the physicochemical composition of the soil.

Considering the result of the 2020-21 trial, the next year's trial was laid in the PAU campus on the field used in the previous year and the physicochemical degradation of paddy straw was evaluated after 30 days and the effect of microbial spray and sowing method on wheat yield has been demonstrated in Table 4 that indicate insignificant effect of microbial decomposer application on yield. It also indicated no significant effect of the sowing method on grain yield.

Table 3. Comparative Grain Yield of Wheat as Affected by Microbial Decomposers in Multi-locational Trials (2020-21)

Treatment	**Grain Yield (q ha^{-1})**
Location	
Ludhiana	52.8
Sangrur	52.6
Kapurthala	42.4
Gurdaspur	51.8
CD (p=0.05)	1.1
Sowing method	
Incorporation	49.0
Retention	50.6
CD (p=0.05)	NS
Microbial decomposer application	
Unsprayed	48.9
PAU Decomposer	49.6
PUSA Decomposer	49.8
CD (p=0.05)	NS
Interaction (AxB, AxC, BxC, AxBxC)	NS

Table 4. Comparative Grain Yield of Wheat as Affected by Microbial Decomposers at PAU, Ludhiana (2021-22)

Treatment	**Grain yield (q ha^{-1})**		
	Incorporation	Retention	**Mean**
Unsprayed	53.7	55.3	**54.5**
PAU Decomposer	55.1	53.6	**54.4**
PUSA Decomposer	54.5	53.4	**53.9**
Mean	**54.4**	**54.1**	
CD (p=0.05)	**Sowing method: NS**	**Decomposer: NS**	**Interaction: NS**

CONCLUSIONS

1. Soil management interventions at the field scale appear more important in affecting the role of the plant as well as microbial-mediated carbon input. The soil organic carbon acts as the substrate for microbial activity thereby enhancing the microbial activity in soil. In the present study, soil texture and soil organic carbon content in different locations were responsible for variable lignin decomposition, C:N ratio, and tensile strength reduction.

2. From a long-term perspective, straw incorporation is a beneficial practice to alleviate soil degradation, maintain soil fertility, and promote crop yields in intensive agricultural systems (Sun *et al.* 2013). However, straw returning in a short period always increases soil N immobilization and mineralization, thereby causing N deficiency and yield decline (Ladha *et al.* 2004). Thus, simultaneous N fertilizer application with straw return has been widely suggested and accepted.
3. The management of crop residues has become an important aspect of sustaining long-term fertility in cropping systems. Incorporation of crop residues can change soil microbial processes, which affect nutrient availability and crop yield (Chen *et al.* 2014). Thus, evaluation of the straw decomposition pattern and the microbial communities associated with its decomposition under the application of different N fertilizer rates could provide insights into the scientific management of crop residues (Guo *et al.* 2018).
4. Though the application of microbial decomposers for paddy straw degradation has been suggested by several workers, the present work reveals that the intrinsic microflora present in the soil can contribute to *in situ* paddy straw degradation only when paddy straw is mixed in soil and a significant window period (time interval between microbial spray and sowing of next crop) is given.

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Conflicts of Interest

None of the authors have any competing financial and non-financial conflicts of interest.

REFERENCES CITED

Abdurrahman, M. I., Chaki, S., and Saini, G. (2020). "Stubble burning: Effects on health and environment, regulations and management practices," *Environ. Adv.* 2, article 100011. DOI: 10.1016/j.envadv.2020.100011

Arora, D. S., Chander M., and Gill, P. (2002). "Involvement of lignin peroxidase, manganese peroxidase and laccase in degradation and selective ligninolysis of wheat straw," *Int. Biodeterior. Biodegrad.* 50, 115-120. DOI: 10.1016/S0964-8305(02)00064-1

Chen, L., Zhang, J., Zhao, B., Yan, P., Zhou, G., and Xin, X. (2014). "Effects of straw amendment and moisture on microbial communities in Chinese fluvo-aquic soil," *J. Soils. Sediments* 14, 1829-1840. DOI: 10.1007/s11368-014-0924-2

Cusack, D. F., Silver W. L., Torn, M. S., Burton, S. D., and Firestone, M. K. (2011). "Changes in microbial community characteristics and soil organic matter with

nitrogen additions in two tropical forests," *Ecolog.* 92, 621-632. DOI: 10.1890/10-0459.1
Dobermann, A., and Fairhurst, T. H. (2002). "Rice straw management," *Better. Crops. Int.* 16, 7-11.
Gadde, B., Christoph, M. C., and Wassmann, R. (2009). "Rice straw as a renewable energy source in India, Thailand, and the Philippines: Overall potential and limitations for energy contribution and greenhouse gas mitigation," *Biomass. Bioenergy* 33, 1532-1546. DOI: 10.1016/J.BIOMBIOE.2009.07.018
Geisseler, D., and Horwath, W. R. (2008). "Regulation of extracellular protease activity in soil in response to different sources and concentrations of nitrogen and carbon," *Soil. Biol. Biochem.* 40, 3040-3048. DOI: 10.1016/j.soilbio.2008.09.001
Guo, T., Zhang, Q., Ai, C., Liang, G., He, P., and Zhou, W. (2018). "Nitrogen enrichment regulates straw decomposition and its associated microbial community in a double-rice cropping system," *Sci. Rep* 8, article 1847. DOI: 10.1038/s41598-018-20293-5
Ilic, D., Williams, K., Farnish, R., Webb, E., and Liu, G. (2018). "On the challenges facing the handling of solid biomass feedstocks," *Biofuel. Bioprod. Biorefin.* 12, 187-202. DOI: 10.1002/bbb.1851
Jain, N., Bhatia, A., and Pathak, H. (2014). "Emission of air pollutants from crop residue burning in India," *Aerosol. Air. Qual. Res* 14, 422-430. DOI: 10.4209/aaqr.2013.01.0031
Jimenez, D. J., de Lima Brossi, M. J., Schückel, J., Kračun, S. K., Willats, W. G., and van Elsas, J. D. (2016). "Characterization of three plant biomass-degrading microbial consortia by metagenomics- and metasecretomics-based approaches," *Appl. Microbiol. Biot* 100, 10463-10477. DOI: 10.1007/s00253-016-7713-3
Jin, Z., Shah, T., Zhang, L., Liu, H., Peng, S., and Nie, L. (2020). "Effect of straw returning on soil organic carbon in rice–wheat rotation system: A review," *Food. Energy. Secur* 9, article e200. DOI: 10.1002/fes3.200
Katyal, P., Bhardwaj, R., Sharma, S., Kaur, J., Pathania, N., Vyas, P., Kapoor, S., and Kocher, G.S. (2022). "Microbial decomposer assisted *in situ* degradation of surface retained paddy straw," *Int. J. Recycl. Org. Waste. Agric*. DOI: 10.30486/IJROWA.2022.1935169.1292
Ladha, J. K., Khind, C. S., Gupta, R. K., Meelu, O. P., and Pasuquin, E. (2004). "Long-term effects of organic inputs on yield and soil fertility in the rice-wheat rotation," *Soil. Sci. Soc. Am. J.* 68, 845-853. DOI: 10.2136/sssaj2004.8450
Lal, R. (2004). "Soil carbon sequestration impacts on global climate change and food security," *Science* 304, 1623-1627. DOI: 10.1126/science.1097396
Lee, B. I., Kim, P. J., and Chang, W. K. (2002). "Evaluation of stability of compost prepared with Korean food waste," *Soil Sci. Plant Nutr.* 48, 1-8. DOI: 10.1080/00380768.2002.10409164
Marschner, P., Umar, S., and Baumann, K. (2011). "The microbial community composition changes rapidly in the early stages of decomposition of wheat residue," *Soil Biol. Biochem.* 43, 445-451. DOI: 10.1016/j.soilbio.2010.11.015
Nakamura, A., Tun, C. C., Asakawa, S., and Kimura, M. (2003). "Microbial community responsible for the decomposition of rice straw in a paddy field: Estimation by phospholipid fatty acid analysis," *Biol. Fertil. Soils* 38, 288-295. DOI: 10.1080/00380768.2004.10408598
Pinckard, J. A., and Gill, P. E. (1990). "Method for accelerating the biodegradation of crop residues following grain harvest," US Patent 5005345.

Raiesi, F. (2006). "Carbon and N mineralization as affected by soil cultivation and crop residue in a calcareous wetland ecosystem in Central Iran," *Agric. Ecosyst. Environ* 112, 13-20. DOI: 10.1016/j.agee.2005.07.002

Sharma, A., Sharma, R., Arora, A., Shah, R., Singh, A., Pranaw, K., and Nain, L. (2014). "Insights into rapid composting of paddy straw augmented with efficient microorganism consortium," *Int. J. Recycl. Org. Waste Agric* 3, article 54. DOI: 10.1007/s40093-014-0054-2

Shrivastava, S., Verma, S. K., Patra, A. K., Manna, M. C., and Arya, V. (2018). "Explore of ligno-cellulolytic microbial consortia on paddy straw decomposition in vertisol," *Int. J. Chem. Stud* 6, 2393-2398.

Sun, B., Wang, X., Wang, F., Jiang, Y. and Zhang, X. (2013). "Assessing the relative effects of geographic location and soil type on microbial communities associated with straw decomposition," *Appl. Environ. Microbiol* 79, 3327-3335. DOI: 10.1128/AEM.00083-13

Van Soest, P. J. (1963). "The use of detergents in the analysis of fibrous feeds: A rapid method for the determination of fiber and lignin," *Off. Agric. Chem* 46, and 829.

Wiedermann, M. M., Kane, E., Potvin, L. and Lilleskov, E. (2017). "Interactive plant functional group and water table effects on decomposition and extracellular enzyme activity in *Sphagnum* peatlands," *Soil Biol. Biochem* 108. DOI: 10.1016/ j.soilbio. 2017.01.008

Zhou, G. X., Zhang, J. B., Chen, L., Zhang, C. Z. and Yu, Z. H. (2016). "Temperature and straw quality regulate the microbial phospholipid fatty acid composition associated with straw decomposition," *Pedosphere* 26, 386-398. DOI: 10.1016/S1002-0160(15)60051-0

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