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Impact of *in situ* rice straw incorporation on soil nutrient dynamics and carbon cycling

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Abstract
This study investigates the impact of *in situ* rice straw incorporation on soil nutrient dynamics during the 2021-22 *kharif* season in Sindewahi, Maharashtra. Using a Factorial Randomized Block Design, two microbial treatments-PDKV decomposer and Resident Isolates-were tested along with three nutrient management levels. The data revealed that during decomposition of in situ incorporated rice straw total N, total P and total K were increased. The data of the present experiment revealed that the total C were gradually decreased in the rice straw treated with PDKV decomposer and resident isolates. Whereas total, P, and K were slightly increased in soil in situ incorporated with rice straw and treated with PDKV decomposer and resident isolates indicating progressive increase/decrease in the elemental composition. The magnitude of decrease in the total C was 0.057% during decomposition of crop residue in soil. Among total N, P and K, the magnitude of increase was higher in case of total K which was 0.00082% during decomposition.

Keywords: Rice straw, microbial inoculants, nutrient cycling, carbon dynamics, PDKV decomposer, sustainable agriculture

Introduction

Rice (*Oryza sativa)* is a staple crop cultivated widely across the globe, particularly in Asian countries, where it forms the primary source of food and livelihood for millions of people. However, rice cultivation generates substantial quantities of rice straw as a byproduct, which poses a significant challenge in terms of its management. Traditional methods of straw disposal, such as open-field burning, contribute to severe environmental problems, including greenhouse gas emissions, loss of soil nutrients, and air pollution (Hindoriya and Suryawanshi, 2023) [1]. Sustainable rice straw management strategies are, therefore, essential for mitigating these environmental impacts while enhancing soil health (Meshram and Pinjari, 2023) [5].

Incorporating rice straw into the soil as an organic amendment is a viable alternative that improves soil fertility, organic carbon levels, and microbial activity (Hu *et al.,* 2024; Zhou *et al.,* 2024) [12]. This practice, however, requires effective decomposition of the straw to release nutrients in forms available for crop uptake. The decomposition of rice straw is a complex process involving microbial breakdown of organic materials, with rates influenced by microbial activity, environmental conditions, and nutrient amendments (Rallos *et al.,* 2023) [7]. The addition of microbial inoculants and nutrient enhancers, such as nitrogen fertilizers and phosphate, can accelerate this process by promoting microbial proliferation and enzymatic activity (Kumar *et al.*, 2024). Despite the growing interest in *in situ* rice straw incorporation, the effectiveness of different microbial inoculants and nutrient management practices in enhancing nutrient cycling and soil quality requires further investigation. This study aims to evaluate the effects of two microbial consortia-PDKV decomposer and Resident Isolates-on rice straw decomposition and their impact on soil chemical properties, including nitrogen, phosphorus, potassium. Additionally, the study examines the role of nutrient management practices, including varying levels of recommended fertilizer dose (RDF) and Azolla incorporation, in optimizing nutrient availability and soil health during rice cultivation (Kumar *et al*., 2024; Meshram and Pinjari, 2023; Zhou *et al*., 2024) [5, 4, 12].

These insights are critical for developing sustainable rice production practices that maximize productivity while minimizing environmental impacts.

Materials and Methods

Experimental Design

The experiment was conducted at the Agricultural Research Station, Sindewahi, Maharashtra (20°15'N, 79°40'E), during the 2021-22 *kharif* season. The soil was classified as Inceptisols, and rice was grown under a Factorial Randomized Block Design with four replications. The study involved two treatments: PDKV decomposer (D_1) and Resident Isolates (D_2), along with three nutrient management levels: 75% RDN, 100% RDF, and 75% RDN + Azolla @ 2 t ha^{-1} one week after transplanting of rice. Fertilizers were applied at 100:50:50 kg N, P_2O_5, K ha^{-1}. Rice straw was chopped to 15 cm lengths and uniformly distributed across plots in January. The PDKV decomposer (1 L $tone^{-1}$) and Resident Isolates (1 L $tonne^{-1}$) were applied, supplemented with a 1% urea solution, 7.5 kg single super phosphate (SSP)/tonne, and a jaggery-besan mixture dissolved in water. The treated straw was incorporated into the soil using a rotavator, ensuring thorough mixing to a depth of 30–35 cm. Soil samples were collected at 30, 60, 90, and 120 days to analyze nutrient changes. Total carbon was assessed using the Walkley-Black method, total nitrogen via Micro-Kjeldahl digestion (Jackson, 1973) [3], total phosphorus using the Vanadomolybdate method (Jackson, 1973) [3], and total potassium by hydrofluoric and perchloric acid digestion (Pratt, 1982) [6].

Results and Discussion

A significant reduction in Total Carbon (%) was observed over 120 days across treatments (Table 1, Fig. 4.1). The mean Total Carbon content decreased from 25.36% at 30 days to 20.36% at 120 days. The rapid decline during the first 60 days, from 25.36% to 23.38%, reflects the decomposition of labile carbon compounds, consistent with findings by Silva *et al.* (2022) [9]. The slower reduction from 60 to 120 days suggests the breakdown of recalcitrant materials such as lignin.

Total Nitrogen (%) showed a steady increase over 120 days, with mean values rising from 0.71% at 30 days to 0.74% at 120 days. This increase highlights the effectiveness of microbial inoculants in nitrogen mineralization and cycling, supporting findings by Sharma *et al.* (2021) [8]. The consistent nitrogen enhancement over time indicates active microbial processes promoting nitrogen release from organic matter.

Total Phosphorus (%) also exhibited a progressive increase over time. Mean phosphorus levels rose from 0.27% at 30 days to 0.34% at 120 days. This trend underscores the efficiency of microbial activity in organic phosphorus mineralization. The results are in line with the observations of Wang *et al.* (2021) [10], which highlight the pivotal role of microbial inoculants in mobilizing phosphorus for plant availability.

Total Potassium (%) followed a similar trend of steady increase, with mean values increasing from 1.18% at 30 days to 1.23% at 120 days. This gradual release of potassium indicates efficient microbial degradation of water-soluble and exchangeable potassium fractions. The findings corroborate the work of Wang *et al.* (2022) [12], emphasizing the microbial contribution to potassium release during organic matter decomposition.

Overall, the observed changes in carbon, nitrogen, phosphorus, and potassium align with microbial decomposition dynamics. The use of both PDKV decomposer (D_1) and Resident Isolates (D_2) effectively facilitated nutrient mineralization and organic matter turnover, improving soil nutrient availability over time.

Table 1: Changes in Total Carbon, Total Nitrogen, Total Phosphorus, and Total Potassium during decomposition of rice straw over 120 days under different treatments.

	Total C (%)					LSD ($p<0.05$)
	Treatments	**30**	**60**	**90**	**120**	**Stages**
	***In situ* rice straw incorporation**					
D_1	PDKV decomposer	24.67	23.72	20.77	19.84	SIG
D_2	Resident Isolates	26.04	23.03	21.96	20.87	SIG
	Mean	25.36	23.38	21.37	20.36	SIG
	Total N (%)					
	Treatments	**30**	**60**	**90**	**120**	
	***In situ* rice straw incorporation**					
D_1	PDKV decomposer	0.70	0.71	0.72	0.74	SIG
D_2	Resident Isolates	0.72	0.73	0.74	0.74	SIG
	Mean	0.71	0.72	0.73	0.74	SIG
	Total P (%)					
	Treatments	**30**	**60**	**90**	**120**	
	***In situ* rice straw incorporation**					
D_1	PDKV decomposer	0.27	0.30	0.33	0.34	SIG
D_2	Resident Isolates	0.27	0.30	0.31	0.33	SIG
	Mean	0.27	0.3	0.32	0.34	SIG
	Total K (%)					
	Treatments	**30**	**60**	**90**	**120**	
	***In situ* rice straw incorporation**					
D_1	PDKV decomposer	1.18	1.20	1.23	1.27	SIG
D_2	Resident Isolates	1.18	1.21	1.22	1.24	SIG
	Mean	1.18	1.21	1.23	1.26	SIG

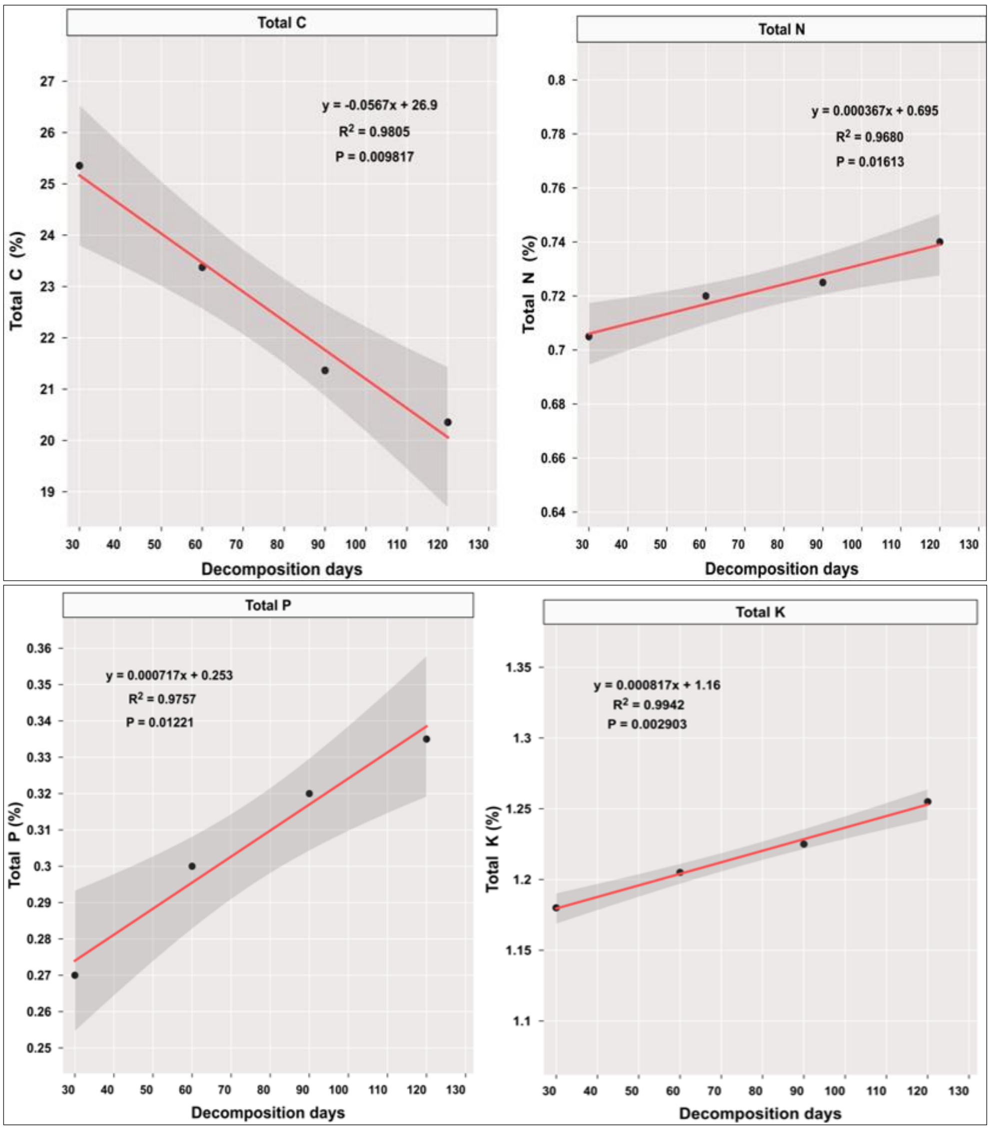

Fig 1: Changes in Total Carbon, Total Nitrogen, Total Phosphorus, and Total Potassium (%) over 120 days after rice straw incorporation under PDKV decomposer (D_1) and Resident Isolates (D_2).

Conclusion

The findings of this study revealed the transformative potential of *in situ* rice straw incorporation, particularly through the application of microbial inoculants, in advancing soil nutrient dynamics and carbon cycling. The PDKV decomposer exhibited superior efficacy in enhancing nutrient availability, as evidenced by a more pronounced reduction in total carbon and significant increases in soil nitrogen, phosphorus, and potassium levels. These results underscore the value of integrating targeted microbial strategies to optimize nutrient turnover, support agro ecosystem sustainability, and bolster soil fertility. Such innovations align with the principles of sustainable intensification, offering a robust framework for addressing the dual challenges of productivity and environmental stewardship in modern agriculture.

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