Original Research Article

Impact of Crop Residue Management on Soil Health in Rice- Wheat Cropping System in Southern Bihar

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ABSTRACT

The study investigates the effects of paddy straw bale management on soil health and the productivity of a rice-wheat cropping system in Southern Bihar. Conducted from 2021 to 2023, the experiment involved four treatments: control (FP), tillage + recommended dose of fertilizer (RDF), zero tillage (ZT) + mulching, and burning + ZT (RDF). Soil samples and crop yields were analyzed to evaluate physico-chemical properties, microbial activities, and economic viability. Results revealed that ZT + mulching significantly enhanced soil properties, including organic carbon, nutrient availability (NPK), and microbial activity, compared to other treatments. Grain and straw yields were highest under ZT + mulching for both rice (80.01 and 84.25 q/ha) and wheat (53.4 and 57.35 q/ha), with improved plant height, panicle density, and grain quality. Economic analysis indicated the highest benefit-cost ratio under ZT + mulching (3.18 for rice and 2.92 for wheat). This sustainable practice demonstrated its potential to mitigate residue burning's negative impacts, enhance soil health, and boost productivity, offering a viable strategy for long-term agricultural sustainability in the region.

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Keywords: Crop Residue Management, Soil Health, Zero tillage, Mulching,

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INTRODUCTION

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Wheat (*Triticum aestivum*) is one of India's most important staple crops, critical to ensuring food security. It is the second most widely cultivated cereal in the country, next only to rice. India contributes about 14% of global wheat production, ranking second globally after China. Major wheat-producing states include Uttar Pradesh, Punjab, Haryana, Madhya Pradesh, Rajasthan, and Bihar, with wheat cultivation covering approximately 30 million hectares annually, predominantly in the Rabi season. The Indo-Gangetic Plain, spanning Punjab, Haryana, Uttar Pradesh, and Bihar, forms the heartland of wheat cultivation due to its fertile soils, favorable climate, and extensive irrigation infrastructure. In this region, Bihar plays a significant role, with over 2.2 million hectares of its area dedicated to wheat farming annually. Despite its contributions, Bihar's wheat productivity averages 2.4–2.6 tons per hectare, which is below the national average of 3.4 tons per hectare and significantly lower than states like Punjab and Haryana, where yields exceed 4.5 tons per hectare. Lower wheat yields compared to wheat with no rice straw incorporated (Yadvinder-Singh, *et al.,* 1988; Toor and Beri, 1991). Wheat production in Bihar, particularly in northern districts like Rohtas, is influenced by multiple factors, including climate, soil health, and crop residue management, especially of paddy straw. One critical practice that has affected soil health and wheat productivity is stubble burning, which has adverse environmental and agronomic consequences. Exploring sustainable alternatives for managing paddy straw is essential for enhancing wheat production and preserving soil health in the region.

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However, the incorporation of paddy straw may result in immobilization of the fertilizer-N and a reduction in the N supply for plants. Nitrogen immobilized in crop residue rematerializes later in the season. However, soil was amended with rice straw and incubated under moist aerobic conditions. During the first nine days, soil and fertilizer-N were rapidly immobilized, followed by N mineralization (Toor and Beri, 1991). Keeping the above facts in view, the present investigation was to evaluate the Impact of Paddy Straw Bale Management on Soil Health and Wheat Productivity.

MATERIALS AND METHODS

The field study was conducted by Krishi Vigyan Kendra (KVK), Rohtas on farmers' fields over three consecutive years, from Rabi 2021 to 2023, in selected 5 villages under Climate Resilient Agriculture Project with 10 replications. The experiment aimed to evaluate the impact of various paddy straw bale management techniques on wheat productivity and soil health. The experiment was laid out in RBD with ten replications and four treatments viz.T1:-Control (FP) : 200: 60: 10, T2: Tillage + (RDF), T3: ZT (RDF) + Mulching, T4: Burning + ZT (RDF). In control plots (T1) the conventional method followed by local farmers, In T2 conventional tillage practices, where the soil is plowed before planting for loosen the soil, remove weeds, and incorporate crop residues into the soil. In T_3 planting crops without plowing the soil, zero tillage helps maintain soil structure, reduce soil erosion, conserve moisture, and increase the microbial activity in the soil. After zero tillage mulching practice of applying a layer of paddy crop residues on the soil surface to retain moisture, reduce soil erosion, suppress weed growth, and improve soil fertility.   In T_4 treatment, the paddy crop residue is burned by farmers before planting is used for wheat crop after that zero tillage machine is used before planting the wheat.

The soil samples were collected from different plots in each year before sowing and after the harvesting of crops. The soil samples were analyzed using standard methods for different soil properties. Organic carbon content was determined by the Walkley and Black method, available nitrogen with alkaline $KMNO_4$ method, available phosphorous with Olsen's method and available potash with Flamphotometrically method. The pH and ECe were measured in soil suspension (1:2.5) using electrode and microbial activities and biomass determined by chloroform fumigation extraction method.

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The recommended dose of NPK was applied through urea, DAP and muriate of potash, respectively. The wheat variety HD 2967 was taken as a test crop. Then follow the normal package of practices for irrigation and insect pest management throughout the cultivation process after sown in the month of November since 2022. Wheat was harvested in March, and grains were manually separated after threshing. The grains were sun-dried to a moisture content of 14% before recording their weight. Straw yield was calculated by subtracting grain weight from the total biological yield for each net plot. Harvest index of each plot was calculated with the help of following formula:

Harvest index (%) = Grain yield (q ha^{-1})/Total biological yield (qha-1) ×100

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The data collected on different parameters under the experiment were statistically analyzed to obtain the level of significance using the computer MSTAT package program developed by Russell.

RESULTS AND DISCUSSION

The study investigated the effects of different paddy straw bale management practices on soil physico-chemical properties, microbial and enzymatic activities, and crop growth and yield in a rice-wheat system. The results demonstrated significant variations among the treatments, emphasizing the impact of sustainable residue management practices.

Soil Physico-Chemical Properties

Soil texture remained loam across all treatments, with no significant changes observed. However, the treatments influenced soil particle size distribution. Sand content was reduced in ZT (RDF) + Mulching and Burning + ZT (RDF), while silt and clay fractions increased slightly, indicating potential improvement in soil structure.

It is clear from Table 1 and fig 1 that Bulk density, an indicator of soil compaction, was significantly reduced under ZT (RDF) + Mulching (1.48 mg m^{-3}) compared to other treatments, promoting better root penetration and aeration. The infiltration rate was highest under ZT (RDF) + Mulching (0.36 cm h^{-1}), suggesting improved water movement through the soil profile. Aggregate stability, crucial for soil erosion resistance and water retention, peaked at 14% under ZT (RDF) + Mulching, reflecting enhanced soil structure. This result conformity by Sharma and Bali (1998), Sidhu,and Beri (1989). Table 1 and fig 4 clear that nutrient availability was significantly influenced by residue management. ZT (RDF) + Mulching recorded the highest levels of available nitrogen (205 kg ha^{-1}), phosphorus (29.24 kg ha^{-1}), and potassium (204 kg ha^{-1}), highlighting its role in improving soil fertility (Gaskin *et al.* 2007, Deka *et al.* 2018, Hung *et al*. 2019). Organic carbon (table 1, fig 2) content was slightly elevated (0.44%) under this treatment, further supporting soil health. Paudel *et al*.(2014) also found the CA in rice-wheat system can help directly in building–up of soil organic carbon and improve the fertility status of soil.

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Microbial and Enzymatic Activities

Soil microbial activity (table 1, fig 3), as indicated by bacterial and fungal populations, was significantly enhanced under ZT (RDF) + Mulching. Bacterial counts were highest at 34.55 x 106^66, and fungal populations peaked at 111.72 x 10^3. Enzymatic activities followed a similar trend, with phosphatase activity reaching 176 mg p-NP $g^{-1}h^{-1}$and dehydrogenase activity at 66 mg TPFg^{-1} 24 h^{-1} under ZT (RDF) + Mulching. These improvements suggest a favorable environment for microbial proliferation and soil biochemical processes, driven by the addition of organic matter and reduced soil disturbance (Ahlawa *et al.* 2024).

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Growth, Yield Attributes, and Yield of Rice

Plant Height

The tallest rice plants (112 cm) were observed under the ZT (RDF) + Mulching treatment, significantly surpassing the control (101 cm) and residue-burning treatments (96 cm). This increase can be attributed to improved soil conditions, including better moisture retention and nutrient availability facilitated by mulching (Yadav *et al.* 2015, Yadav *et al.* 2020).

Panicle Number and Weight

ZT (RDF) + Mulching resulted in the highest panicle density (266 m^{-2} and panicle weight (3.15 g), demonstrating its superiority in fostering robust crop growth. These parameters were lowest under residue burning, indicating that burning might hinder optimal crop development (Singh *et al.* 2019).

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Grain Quality

Filled grains per panicle were significantly higher under ZT (RDF) + Mulching (135), reflecting enhanced grain filling due to better soil fertility and moisture conditions. Similarly, the 1000-grain weight peaked under ZT (RDF) + Mulching (22.28 g), highlighting the role of mulching in improving grain quality (Singh *et al.* 2019,).

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Grain and Straw Yield

ZT (RDF) + Mulching recorded the highest grain (80.01 qt ha^{-1} and straw (84.25 qt ha^{-1}) yields, far exceeding the control (58.51 and 60.49 qt ha^{-1}, respectively) and residue-burning treatments. The improved yields can be attributed to better nutrient cycling and soil health under mulching. This result conformity with Singh *et al* 2019, Malik & Yadav 2019).

Harvest Index and Economic Viability

The harvest index (HI) was consistent across treatments (0.49 for most), indicating balanced biomass allocation. The benefit-cost (B:C) ratio was highest under ZT (RDF) + Mulching (3.18), making it the most economically viable option. The control (2.39) and burning (2.32) had significantly lower B:C ratios, demonstrating the inefficiency of these practices (Kamboj *et al.*2013).

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Conclusion and Implications

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ZT (RDF) + Mulching for rice and residue incorporation for wheat emerged as the most effective residue management strategies. These practices improved growth, yield attributes, and yield, while also enhancing economic returns. Adopting these sustainable practices can mitigate the negative environmental impacts of residue burning, improve soil health, and ensure long-term agricultural sustainability.

Table 1: Impact of Paddy Straw Bale Management on Soil Physico-chemical properties.

Indicators	Initial (Nov 2021)	Crop residue management practices				CD (p=0.05)
		Control (FP)	Tillage + (RDF)	ZT (RDF) + Mulching	Burning + ZT (RDF)	
Texture	Loam	Loam	Loam	Loam	Loam	Loam
Sand	45	45	45	42	41	0.02
Silt	32.8	32.00	32.05	35.64	36.25	0.01
Clay	21.20	23.00	22.95	22.36	22.75	0.03
Bulk density (mg m^{-3})	1.58	1.59	1.57	1.48	1.59	0.02
Infiltration rate (cm h^{-1})	0.33	0.30	0.30	0.36	0.25	0.01
Aggregate stability (%)	9	9	10	14	12	0.04
pH (1:2.5)	6.5	6.4	6.5	6.6	6.5	NS
EC (d Sm^{-1})	0.22	0.21	0.22	0.24	0.21	0.01
OC (%)	0.42	0.42	0.42	0.44	0.41	0.11
Avail N ($Kgha^{-1}$)	172	181	185	205	171	1.80
Avail P ($Kgha^{-1}$)	24.25	24.95	25.64	29.24	21.55	0.31
Avail K ($Kgha^{-1}$)	182	188	201	204	145	0.91

Table: 2. Impact of Paddy Straw Bale Management on soil microbial and enzymatic activities

Indicators	Initial (Nov 2021)	Crop residue management practices				CD (p=0.05)
		Control (FP)	Tillage + (RDF)	ZT (RDF) + Mulching	Burning + ZT (RDF)	
Bacteria (x 10^6)	15.64	14.22	22.47	34.55	3.08	3.24
Fungi (x 10^3)	44.24	55.24	72.25	111.72	10.87	10.15
Phosphatase activity (mg p-NP $g^{-1}h^{-1}$)	118	124	132	176	79	2.05
Dehydrogenase activity (mg $TPFg^{-1}$ 24 h^{-1})	25	31	48	66	28	1.32

Table: 3. Impact of Paddy Straw Bale Management on growth, yield attributes and yield of rice

Indicators	Crop residue management practices				CD (p=0.05)
	Control (FP)	Tillage + (RDF)	ZT (RDF) + Mulching	Burning + ZT (RDF)	
Plant Height (cm)	101	106	112	96	2.05
Panicle (numbers m^{-2})	218	264	266	212	12.25
Panicle weight (g)	2.95	3.13	3.15	2.92	0.04
Filled grain (numbers $panicle^{-1}$)	125	132	135	122	1.02
1000 grain weight (g)	21.47	22.27	22.28	21.42	0.07
Grain yield (qt ha^{-1})	58.51	77.61	80.01	55.40	1.03
Straw yield (qt ha^{-1})	60.49	80.25	84.25	60.25	2.32
Harvest Index	0.49	0.49	0.49	0.48	-
Benefit : Cost ratio	2.39	3.14	3.18	2.32	-

Table: 4. Impact of Paddy Straw Bale Management on growth, yield attributes and yield of wheat

Indicators	Crop residue management practices				CD (p=0.05)
	Control (FP)	Tillage + (RDF)	ZT (RDF) + Mulching	Burning + ZT (RDF)	
Plant Height (cm)	88	96	102	85	2.5
Panicle (numbers m^{-2})	612	680	705	602	18.24
1000 grain weight (g)	41.04	41.12	41.14	41.01	0.04
Grain yield (qt ha^{-1})	46.2	51.4	53.4	45.4	1.24
Straw yield (qt ha^{-1})	51.84	54.22	57.35	51.09	1.87
Harvest Index	0.47	0.49	0.48	0.47	-
Benefit : Cost ratio	2.7	2.86	2.92	2.15	-

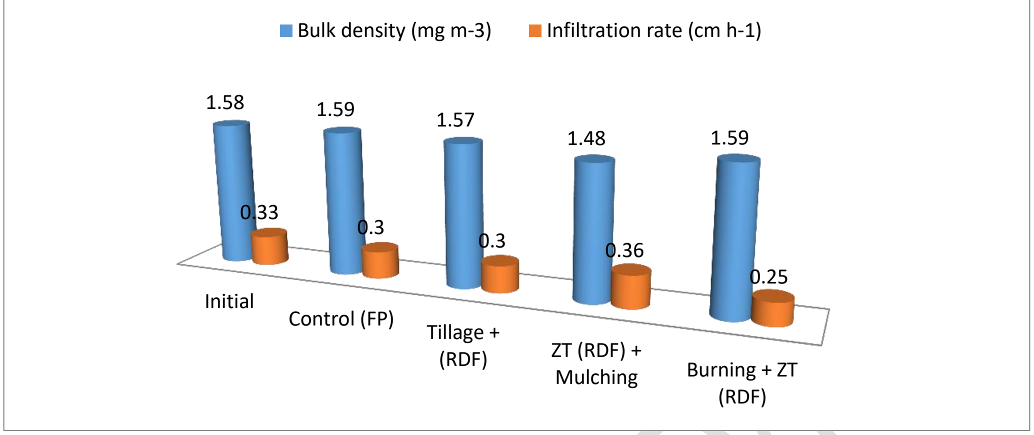

Fig 1. Effect of different treatment on Physical properties of soil

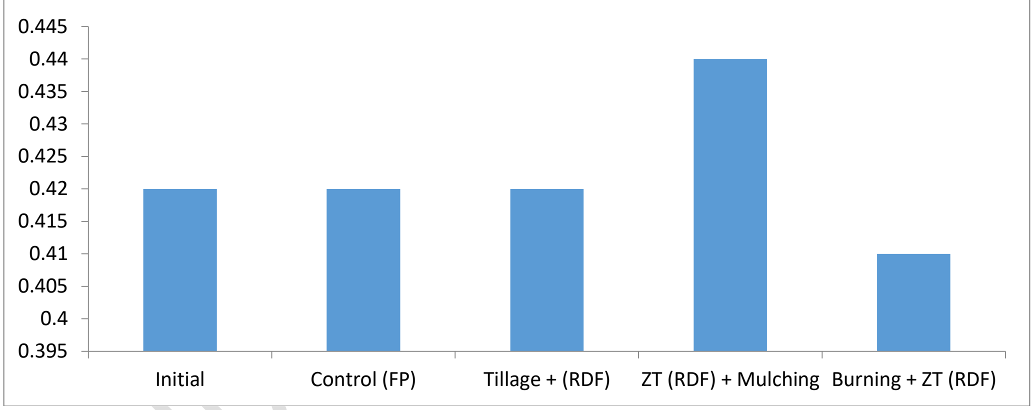

Fig 2.Effect of tretments on OC (%) of soil

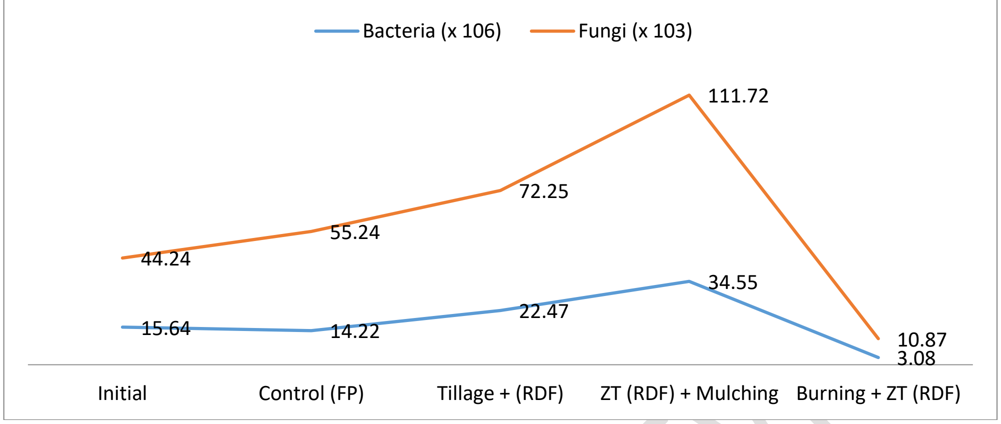

Fig 3. Microbial Population in different technology

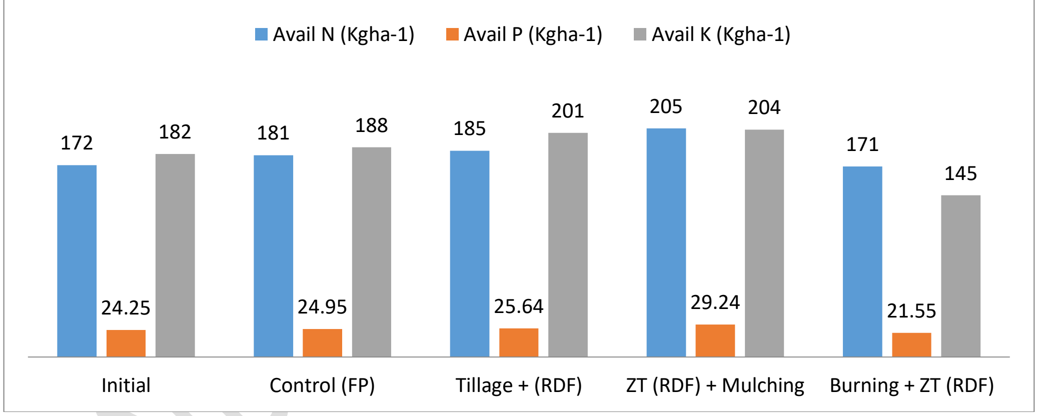

Fig4.Effect of different treatments on Fertility status of soil


90
80
70
60
50
40
30
20
10
0
Control (FP)
Tillage + (RDF)
ZT (RDF) + Mulching
Burning + ZT (RDF)
Rice
Wheat

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