Original Research Article

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

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^{-1}) 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.

Keywords: Crop Residue Management, Soil Health, Zero tillage, Mulching, RDF, tillage, cropping system.

INTRODUCTION

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. Bihar is potentially an important wheat growing state that contributes 5.7% towards national production from 8% of wheat growing area of the country with a low productivity of 1.9 tonnes/ha. The area, production and productivity, averaged over last five years are 2.1 million ha, 4 million tonnes and 1.9 tonnes/ha respectively. (ICAR Website https://icar.org.in/node/17260). 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.

Crop residues are vital natural resources, and their efficient recycling significantly enhances the physical, chemical, and biological properties of soil. Research indicates that a rice-wheat cropping system, yielding 4 t ha^{-1} of rice and 3 t ha^{-1} of wheat, removes more than 280 kg N, 26 kg P, and 245 kg K ha^{-1} from the soil. The residues from these crops can amount to as much as 6–11 t ha^{-1} yr^{-1}. Indian farmers often face challenges in managing 4–6 t ha^{-1} of rice residues to prepare the land for the next crop, particularly wheat. The available management options for rice residues include burning, incorporation, surface retention and mulching, as well as baling and removing the straw. While burning has some advantages, such as eliminating harmful pests and clearing the field quickly for wheat planting, it leads to significant nutrient losses: up to 76% of nitrogen, 28% of phosphorus, 18% of potassium, and 27% of sulfur. Additionally, burning contributes to air pollution (emitting up to 11 t ha^{-1} of CO_2) and depletes soil organic matter (SOM), which is a critical factor in sustainable farming. Conversely, incorporating crop residues into the soil helps increase SOM and enrich the soil with nitrogen, phosphorus, and potassium (Singh *et al.*, 2019). Effective residue management is essential for enhancing soil health and ensuring the long-term sustainability of agricultural systems.

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 underClimate Resilient Agriculture Projectwith 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_3planting 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 paddycrop residue is burned by farmersbefore planting is used for wheat crop after that zero tillagemachine 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 (1934), available nitrogen with alkaline $KMNO_4$ method, available phosphorous with Olsen's method (1954) and available potash with Flamphotometrically method. The pH (Thomas, 1996) and ECe (Rhoades, 1996) were measured in soil and microbial biomass determined by microbial biomass technique (Vance et al. 1987), arginine ammonification technique for microbial activity (Alef & Kleiner 1986, Alef & Kleiner 1987, Alef *et al*. 1988)

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 (Donalad & Hamblin, 1976)

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 (Pradhan *et al*. 2024, 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 *etal*.(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. In this cropping system, more increase in carbon content of soil in zero tilled residue retained plots. Higher soil organic carbon content in residue retention could be attributed to more annual nutrient recycling in respective treatments and decreased intensity of mineralization (Kaisi and yin, 2005). Carbon input in the form of crop residue had primary factor for stabilization of soil carbon (Singh, 2011). The microbial activity was found more on residue retained plots (Mandal *et al*., 2004) so that soil organic carbon level increased with the residue retention (Duiker and Lal, 1999). It might also be associated to less emission of soil carbon in the form of GHGs.

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).

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

The significantly higher panicle density (266 m^{-2}) and panicle weight (3.15 g) observed under ZT (RDF) + Mulching highlight its positive impact on rice productivity. This improvement can be attributed to enhanced soil moisture retention, improved nutrient availability (particularly nitrogen and phosphorus), and better root-zone conditions created by the mulching practice. Mulching conserves soil moisture, reduces weed pressure, and maintains an optimal microclimate, all of which are conducive to healthy tiller and panicle development.

In contrast, residue burning resulted in the lowest panicle density and weight. This decline is likely due to the negative effects of burning, such as loss of soil organic matter, depletion of surface nutrients, and damage to soil microbial communities. These findings align with the observations of Singh et al. (2019), Singh *et al. (2022)* who reported that burning crop residues adversely affects soil health and subsequent crop performance.

Grain and Straw Yield

The study revealed that ZT (RDF) + Mulching resulted in the highest grain yield (80.01 qt ha^{-1}) and straw yield (84.25 qt ha^{-1}, outperforming the control (58.51 and 60.49 qt ha^{-1}, respectively) and residue-burning treatments. This substantial increase in yield under mulching practices can be attributed due to mulching enhances soil organic carbon content, aggregate stability, and microbial activity, creating favorable conditions for root development and nutrient uptake. In contrast, residue burning resulted in significantly lower grain (55.40q ha^{-1}) and straw yields (60.25 q ha^{-1}). The practice of burning residues depletes surface organic matter, reduces nutrient availability, and negatively impacts soil microbial communities. These detrimental effects likely contributed to the lower productivity observed in the residue-burning treatment (Singh *et al*., 2022 and Yadav *et al.*, 2015).

Harvest Index and Economic Viability

The harvest index (HI)**,** reflecting the proportion of biomass allocated to grain versus straw, remained consistent across treatments, with a value of 0.49. This stability in HI suggests efficient resource allocation under varying management systems, underscoring the potential for sustainable production without compromising yields. From an economic standpoint, the benefit-cost (B:C) ratio provides a practical measure of financial returns relative to investment. Among the evaluated practices**,** zero tillage with recommended doses of fertilizer (ZT + RDF) and mulching emerged as the most economically viable system, achieving a B:C ratio of 3.18. This outcome reflects both lower operational costs and higher resource-use efficiency attributed to residue retention practices like mulching, which simultaneously conserve soil moisture and enhance nutrient cycling. In contrast, the control treatment (B:C of 2.39**)** and particularly residue burning (B:C of 2.32) demonstrated significantly lower economic returns. Burning residues, while a convenient way to clear fields for the next crop, leads to nutrient losses and environmental damage, limiting its economic sustainability (Singh *et al.* 2019)

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	-

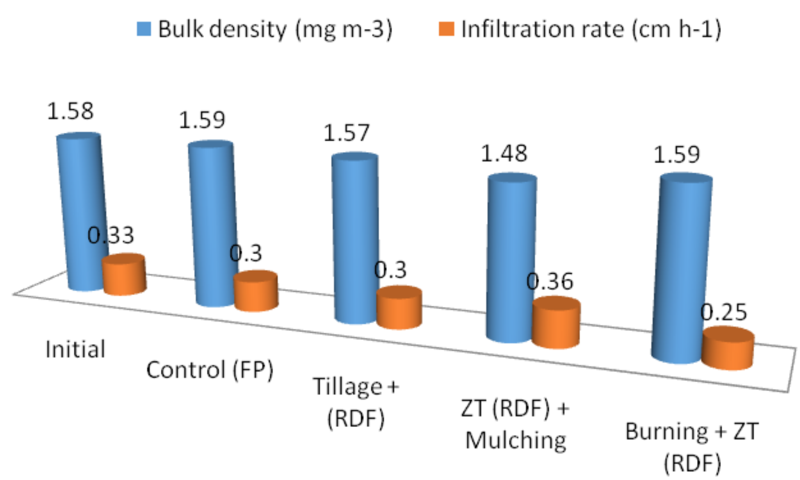


Fig 1. Effect of different treatment on Physical properties of soil

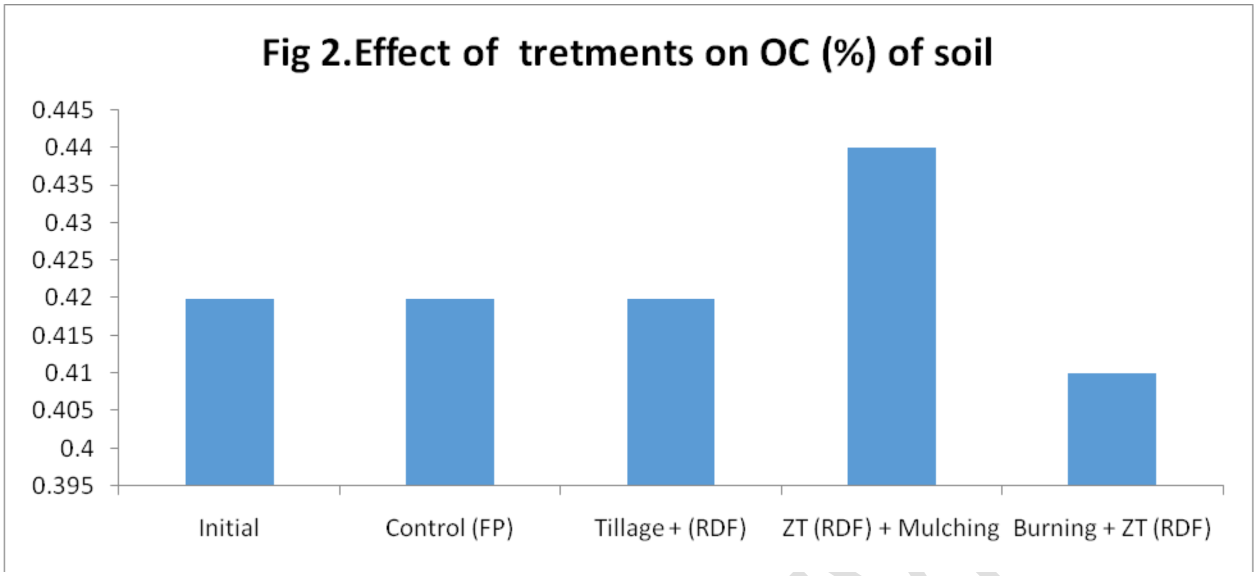


Fig 2.Effect of tretments on OC (%) of soil
0.445
0.44
0.435
0.43
0.425
0.42
0.415
0.41
0.405
0.4
0.395
Initial
Control (FP)
Tillage + (RDF)
ZT (RDF) + Mulching
Burning + ZT (RDF)

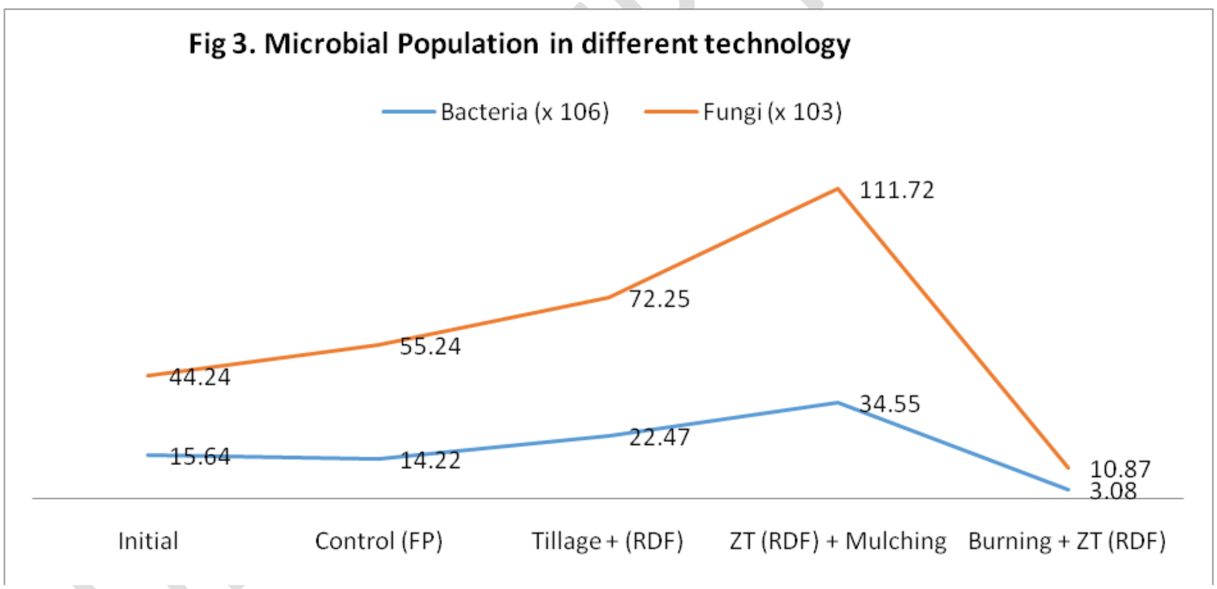
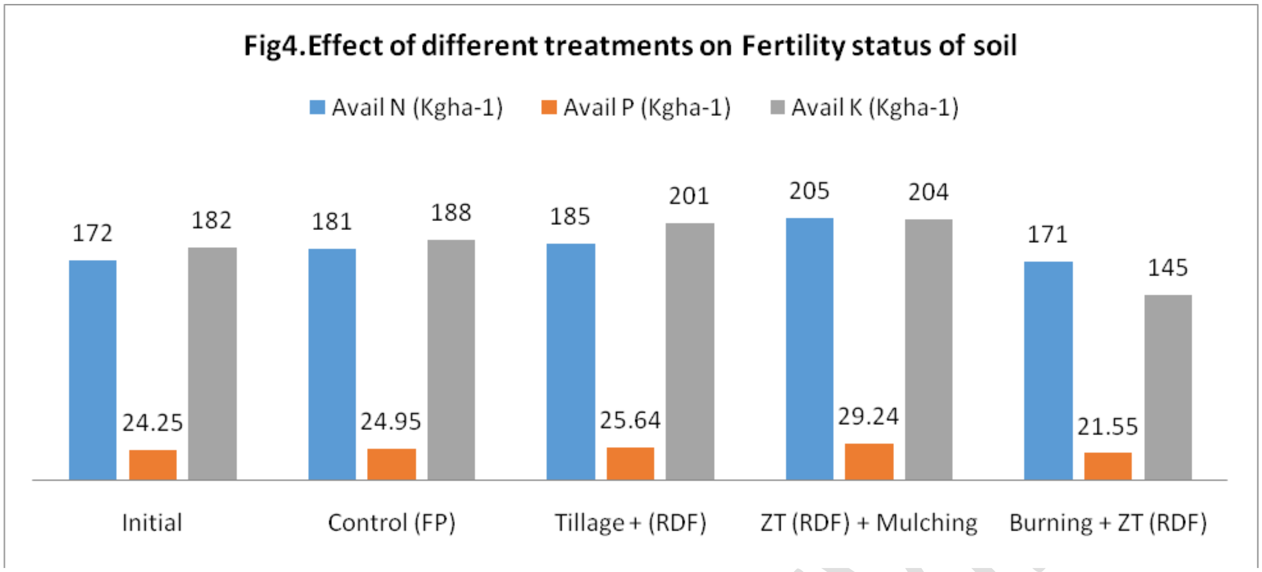


Fig 3. Microbial Population in different technology
Bacteria (x 106)
Fungi (x 103)
111.72
72.25
55.24
44.24
34.55
22.47
15.64
14.22
10.87
3.08
Initial
Control (FP)
Tillage + (RDF)
ZT (RDF) + Mulching
Burning + ZT (RDF)



Conclusion and Implications

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.

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