**Soil properties influenced by long-term management practices in the rice-wheat system of the Terai-Teesta Alluvial Zone, India**

**ABSTRACT**

A factorial randomized block design was employed **at Pundibari, Cooch Behar, West Bengal, India to study the long-term effects of tillage** (zero tillage, ZT; conventional tillage, CT), crop residue (R) addition, and biofertilizers (B) on soil properties and wheat yield in the rice-wheat system of the Terai-Teesta Alluvial Zone. The results revealed that soil pH ranged from acidic to slightly acidic in the surface layer (0–10 cm), with the highest pH observed in ZTR1B1. Organic carbon (OC) was higher in the surface layer than in deeper layers, with the maximum OC (0.98%) recorded in ZTR1B0. However, no significant changes in OC were in deeper layers (10–40 cm). ZT treatment resulted in higher wheat yields than CT, although the combined effects of tillage and R addition did not significantly influence yield. However, significant interaction effects were between R addition and B and tillage and B on grain yield. These findings highlight the importance of soil management practices in optimizing soil health and crop productivity.

***Keywords:*** *Zero tillage, Conventional tillage, Organic carbon, Biofertilizer, Crop residue*

**1. INTRODUCTION**

The rice-wheat cropping system **practiced** in an estimated 11 million hectares of land, is the most popular in India. In the Indo-Gangetic plains in northwest India, rice-wheat cropping is heavily mechanized, and the harvesting of 90% of cereals using a combine harvester leaves the residues in the field. Increasing soil organic matter and nutrient-supplying capability, while minimizing the negative impact of residue-burning, crop residue (R) management is a crucial element of sustainable farming systems (Bhatt et al., 2021). Mulching rice residue at wheat sowing gives the option of surface-applied rice residue rather than incorporation and burning, is less likely to result in nitrogen immobilization, and provides non-nitrogen benefits like soil conservation, water retention, and weed suppression (Kaur et al., 2021). The first process in a series is nutrient release. Rates of decomposition and nutrient release from residue organic forms into soil mineral forms are influenced by environmental factors like air temperature, precipitation, soil characteristics and the biochemical makeup of residue material. Rice-wheat production system plays a significant role in providing staple grain (8%) for the world’s population (Qamar *et al*., 2021).

Conservation agriculture principles, including crop residue management, minimum tillage, and crop rotation, improve soil organic carbon, enhance microbial activity, and support nutrient cycling (Padbhushan et al., 2023). Zero tillage (ZT), especially when combined with mulching or diverse cropping systems, improves soil properties and boosts crop yields by enhancing nutrient transport and retention. In the rice-wheat cropping system, vital for global food security and dominant in India’s Indo-Gangetic plains, sustainable residue management, like mulching, increases soil organic matter, retains moisture, and suppresses weeds while avoiding the harmful effects of residue burning. Compared to the soil continually tilled, the ZT technique enriches the soil with continuous pores volume between the subsurface and the surface. This results in the rapid transport of soluble nutrients into deeper portions of the soil profile.

This study was done to assess the impact of long-term tillage, R management and biofertilizers inoculation on soil properties and crop yield in the rice-wheat system of the Terai-Teesta Alluvial Zone. We hypothesized that soil properties and management practices influence crop yield.

**2. MATERIALS AND METHODS**

The study was on a long-term conservation agriculture trial established in 2006 under a rice-wheat cropping system at the Research Farm, Pundibari, Cooch Behar, West Bengal, India. The 15th crop cycle (2020-21) involved wheat grown during the winter season. The site lies in the Terai agroecological region, characterized by a humid subtropical climate, receiving over 2500 mm of annual rainfall (80% from June to October). Winters are cold, summers mild, with average temperatures ranging from 19°C to 30°C.

Each of the three treatment components in the experiment had two levels or alternatives, such as ZT and CT, the two types of tillage practices. The addition of crop residue (R1) and removal of crop residue (R0) were the two types of crop residue practices. The addition of biofertilizers (B1) and without biofertilizers (B0) was combined to create eight treatments in all, namely T1, T2, T3, T4, T5, T6, T7, and T8, i.e. T1-ZTR0B0 (Zero Tillage), T2-ZTR0B1 (Zero-tillage+ Biofertilizer),  T3-ZTR1B0 (Zero tillage +Crop residue addition),  T4-ZTR1B1 (Zero Tillage+ Crop residue addition+ Biofertilizers),  T5-CTR0B0 (Conventional Tillage),  T6-CTR0B1 (Conventional tillage + Biofertilizer),   T7-CTR1B0 (Conventional tillage + Crop residue addition) and T8-CTR1B1 (Conventional Tillage + Crop residue addition + Biofertilizer). Twenty-four plots were created by replicating each treatment three times arranged in a randomized block design. The recommended dose of fertilizer, irrigation, and intercultural operation were performed in rice and wheat crops.

Harvesting the wheat crop at maturity and yield from individual plots was recorded at the 12% moisture level. Composite soil samples were collected from 0–5 cm, 5–20 cm and 20-40 cm depths in each treatment plot after harvesting wheat and rice. Five cores per plot were combined, homogenized, and reduced to 500 g by removing stubbles, roots, and debris. Samples were air-dried, pulverized, sieved (2 mm), and stored in airtight polythene containers for analysis. Took soil samples and distilled water (1:2 ratio) in a 50-ml beaker. The soil water solution was stirred occasionally for 30 minutes, and then the pH reading was measured using a glass electrode pH meter (Jackson, 1973) and weighed 0.5 gm of the soil in a 500 ml Erlenmeyer flask. Add 10 ml of 1 N potassium dichromate and 20 ml of sulphuric acid to the soil and keep in the dark for 30 minutes. After 30 minutes, add 200 ml of distilled water. Reducing agent orthophosphoric acid (10 ml) and a pinch of sodium fluoride were added and titrated with 0.5 N ferrous ammonium sulphate. Observe the colour change as the endpoint (dark purple to bottle green) and record the final titre value (FTV). Blank was also simultaneously done. The analysis process was similarly followed without the soil sample and recorded blank titre value (BTV). The SOC was determined using the formula given by Walkley and Black (1934):

$$OC=\frac{\left(BTV-FTV\right)\*0.5\*0.003\*100}{Wt. of soil}\*correction factor$$

The analysis of data was done using the Analysis of Variance in a randomized block design. Average ± standard error was used to represent the data in Table/Figure, showing a 5% significance level.

**3. RESULTS AND DISCUSSION**

**3.1 SOIL pH**

Soil pH is one of the important soil parameters that influence a plant's nutrient availability. It is a measure of soil acidity or alkalinity. It affects crop yield, crop suitability, and soil microbial activity and is thus a vital indicator of soil health. Data related to interactive impacts of tillage, residue management and biofertilizer inoculation on soil pH is shown in Figure 1, revealing that after the 15th crop cycle, soil pH was varied in the soil layer 0-10 cm, while no impact was in the deeper soil layers from 10 to 40 cm. Soil pH in all the treatments was acidic to slightly acidic in the surface layer. Comparatively, a higher value was in ZTR1B1 (6.89) followed by ZTR1B0 (6.04) in the soil depth of 0-10 cm. CT-included treatments had lower soil pH than ZT-included treatments (Figure 1). The findings in this study agreed with the results of Umar et al. (2011) and Duiker and Beegle (2006), who attributed the upward changes in pH to the buffering effect of accumulated soil organic matter under conservation agriculture. soil. **Ligowe et al. (2017) in their long-term CA experiment registered that on average, 14 and 21% higher pH and SOM, respectively, than the conventional practices.**

**Figure 1: Effect of tillage, residue addition and biofertilizer inoculation on soil pH in post-wheat soil after the 15th crop cycle (ZT-Zero-tillage, CT-Conventional tillage, R-Residue (1-with and 0-without), B-Biofertilizer inoculation (1-with and 0-without), NS-Non-significant)**

**3.2 ORGANIC CARBON**

Organic carbon is the measured carbon contained within organic matter. It is one of the critical chemical indicators in the soil, increased by adding organic manure, crop residue, ZT, and legume-based crop rotation. Data related to interactive impacts of tillage, residue management and biofertilizer inoculation on OC was in Figure 2. It was evident that after the 15th crop cycle, OC varied in the soil layer from 0-10 cm, while no impact was in the deeper soil layers from 10 to 40 cm. OC in all the treatments was high in the surface layer (0-10 cm) and declined in the deeper layer, showing a trend of 10-20 cm and 20-40 cm in decreasing order (Figure 2). Comparatively, a higher value of OC was in ZTR1B0 (0.98%), followed by ZTR1B1 (0.92%) in the 0-10 cm layer. CT added with residue had higher OC than ZT done without adding residue, showing residue addition can improve the OC in intensive cultivation irrespective of changing tillage practices.

**Figure 2: Effect of tillage, residue addition and biofertilizer inoculation on soil organic carbon (%) in post-wheat soil after the 15th crop cycle (ZT-Zero-tillage, CT-Conventional tillage, R-Residue (1-with and 0-without), B-Biofertilizer inoculation (1-with and 0-without), NS-Non-significant)**

**3.3 WHEAT YIELD**

Data related to wheat yield is in Table 1, which shows the impacts of tillage practices, residue management, and biofertilizer inoculation on wheat yield after the 15th crop cycle. On comparing the wheat yield and tillage practices, a higher yield was in ZT over the CT. The average grain yield in ZT was 3.55 t ha-1, and in CT was 3.41 t ha-1. Dixit et al. (2018) observed the positive impacts of ZT on wheat yield over five years of cultivation. The higher yield of wheat in ZT is due to the compound effects of additional nutrients held in the system **(Timalsina et al*.,* 2021)**, lesser weed population (Chauhan et al*.,* 2007), improved soil physical health, better water regimes and improved nutrient use efficiency compared to CT (Jat et al*.,* 2013; Singh et al*.,* 2016). In the case of residue addition (R1), there was no variation in grain yield relative to no residue addition (R0). Continuous biofertilizer inoculation (B1) significantly increased the grain yield over no biofertilizer inoculation (B0). The grain yield in B1 and B0 was 3.66 t ha-1 and 3.30 t ha-1, respectively.

The combined effect of tillage and residue addition did not show a positive result on grain yield, and the interaction effect of residue addition and biofertilizer inoculation, as well as tillage and biofertilizer inoculants, showed a positive result on wheat yield. In the case of residue addition and biofertilizer inoculation, the highest grain yield was recorded in the R0B0, followed by R1B0, R1B1, and the lowest in R0B1. The yield trend was varying from the previous year’s data due to weather abnormalities and heavy rainfall that affected the wheat yield during this study. Due to the interactive effect of tillage and biofertilizer inoculation, the highest grain yield was in the ZTR0, followed by CTB0, CTB1 and the lowest in ZTB1 (Table 1). Three-way interaction of tillage, residue management and biofertilizer inoculation did not show a significant variation in grain yield

**Table 1: Effect of tillage, residue addition, and biofertilizer inoculation on wheat yield (t ha-1) after the 15th crop cycle (ZT-Zero-tillage, CT-Conventional tillage, R-Residue (1-with and 0-without), B-Biofertilizer inoculation (1-with and 0-without), NS-Non-significant)**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Main effect** | **Wheat yield** **(t ha-1)** | **Main effect** | **Wheat yield** **(t ha-1)** | **Main effect** | **Wheat yield** **(t ha-1)** |
| ZT | 3.55 | R0 | 3.48 | B0 | 3.30 |
| CT | 3.41 | R1 | 3.47 | B1 | 3.66 |
| SE (m) | 0.04 | SE (m) | 0.04 | SE (m) | 0.04 |
| LSD (0.05) | 0.11 | LSD (0.05) | NS | LSD (0.05) | 0.11 |
| Interaction |  | Interaction |  | Interaction |  |
| ZTR0 | 3.54 | R0B0 | 3.77 | ZTB0 | 3.82 |
| ZTR1 | 3.56 | R0B1 | 3.20 | ZTB1 | 3.28 |
| CTR0 | 3.43 | R1B0 | 3.56 | CTB0 | 3.51 |
| CTR1 | 3.39 | R1B1 | 3.39 | CTB1 | 3.31 |
| SE (m) | 0.05 | SE (m) | 0.06 | SE (m) | 0.06 |
| LSD (0.05) | NS | LSD (0.05) | 0.15 | LSD (0.05) | 0.15 |
| Interaction |  |
| ZTR0B0 | 3.15 |
| ZTR0B1 | 3.93 |
| ZTR1B0 | 3.41 |
| ZTR1B1 | 3.71 |
| CTR0B0 | 3.25 |
| CTR0B1 | 3.60 |
| CTR1B0 | 3.37 |
| CTR1B1 | 3.41 |
| SE (m) | 0.09 |
| LSD (0.05) | NS |

**4. CONCLUSION**

The study highlights the influence of tillage, crop residue addition, and biofertilizer on soil properties and wheat yield. Zero tillage treatments, particularly with residue addition and biofertilizer (ZTR1B1), improved soil pH and organic carbon in the surface layer compared to conventional tillage. Wheat yield was higher under zero tillage, with significant interactions observed between residue addition, biofertilizer inoculation, and tillage methods. These findings underscore the potential of sustainable practices like zero tillage and residue management to enhance soil health and crop productivity.

**Disclaimer (Artificial intelligence)**

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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