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Effects of Conservation Tillage and Nutrient Management Practices on Soil Fertility and Productivity of Rice (*Oryza sativa* L.)–Rice System in North Eastern Region of India

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Abstract: Over centuries and even today, traditional farming practices are well performed without any ecological degradation. However, management practice such as conservative tillage combined with nutrient and residue could increase the crop production as well as soil fertility. A three-year replicated study was conducted to assess the effects of agronomic modification of traditional farming practices on productivity and sustainability of rice (wet season)–rice (dry season) system (RRS). The replacement of farmers practice (T_2) with conservation effective tillage (no-till (NT)) and integrated nutrient management (INM) practice along with 30% residue retention (T_5) enhanced the straw, root and biomass yield of both wet season rice (WR), dry season rice (DR) and system as a whole over T_2. Treatment T_5 recorded significantly lower soil bulk density (ϱ_b) and higher pH than the T_2 after three years of the experiment. Further, treatment T_5 increased total soil organic carbon (2.8%), total soil organic carbon stock (2.8%), carbon sequestration rate (336.5 kg ha^{-1} year^{-1}), cumulative carbon stock (142.9%) and carbon retention efficiency (141.0%) over T_2 of 0–20 cm depth after three year. The soil microbial biomass carbon concentration was significantly the highest under T_5. Similarly, the dehydrogenase activity was the maximum under T_5. Adoption of conservation tillage and nutrient management practice involving NT and INM along with residue retention can enhance the system productivity, and C and N sequestration in paddy soils is thereby contributing to the sustainability of the RRS.

Keywords: soil carbon sequestration; rice–rice cropping system; system productivity; conservation tillage; soil quality

1. Introduction

Rice (*Oryza sativa* L.) is one of the world's most important food crops. India, as a major rice producer, alone contributes 30% of total area and 22% of the total production of the world [1,2]. The North Eastern Region (NER) of India located in the eastern Himalayas is inhabited by 45.5 million people with a geographical area of 26.2 million hectares (M ha) [3]. Rice is a staple food of the people in this region and cultivated on about 3.5 M ha, which accounts almost 8% area and 6.5% of the country's rice production [1]. Average annual rainfall is 2000 mm and rain is mainly from June to September. Rivers, farm ponds, and deep tube-well are used as the source of irrigation during the dry (winter) season in limited areas, especially in valleys [4]. The temperature during February to November is the most favorable for rice production, which allows growing rice twice a year. The excess water from surrounding hillocks comes down as runoff and creates temporary flooding in Valley lands [5,6]. Because of high water table and seepage from surrounding hills during winter, cultivation of crops other than rice is not feasible in this region [3,6]. Therefore, rice–rice cropping system is the most dominant system in the region [4]. Moreover, food security in this region entirely depends on rice as no other cereals are grown by the farmers due to food habits and agro-climatic situations [7]. Thus, self-sufficiency in food grains in the region can be achieved only through the increase in productivity of RRS [7]. The major concern is that, despite favorable edaphic and climatic conditions, the rice productivity in the region hardly exceeds 2 Mg ha^{-1}, compared to the national average of 2.8 Mg ha^{-1} in India and 4.42 Mg ha^{-1} in neighboring Bangladesh [7].

Farmers of the regions are cultivating rice from time immemorial by wisdom and tradition, and for subsistence [7]. Farmers mostly use locally available resources with minimal dependence on external resources such as fertilizer and pesticides [4]. It is a common practice to leave at least 30–60% crop residues/standing stubbles in the field. The field is plowed 2–4 times, mostly with bullock drawn indigenous plow and the straw of previous rice crops, and weed biomass is incorporated into the soil before the next rice crop is transplanted [8]. Depending on the availability of organic manure, farmers traditionally apply farmyard manure (FYM)/composts @ 5–10 Mg ha^{-1} (average 5.0 Mg ha^{-1}) at least once in two years. Farmers also apply a minimum dose of mineral fertilizer (40 kg N and 9 kg P ha^{-1} year^{-1}). This showed that the farmers NER, India, cultivate rice with sub-optimal fertilizer and manure application [7] and rely mostly on inherent soil fertility and residue incorporation [8]. In this context, proper management of crop residues is imperative in NER of India.

Cultivation of rice–rice system under traditional farming practices provides 5–6 Mg ha^{-1} of grain yield year^{-1} [9]. With increased population and a decrease in per capita land holding (<0.15 ha capita^{-1}), the pressure on land is increasing more than ever before [10]. Hence, the region is projected to be in deficit of about 60% of its rice requirement by 2050, despite its rich natural resource base and the potential for substantially enhancing productivity [11]. Inadequate management of rice fields has been reported to degrade soil quality in terms of reduction in soil organic carbon (SOC), macro- and micronutrient deficiencies [11]. Climate change, frequent drought and occasional floods are the major threat to the rice farmers. Therefore, sustaining system productivity and sustainability of the rice–rice system is the major challenge in South Asian Countries including India, and especially the NER of India. Thus, there is urgent need to refine traditional rice production practices with efficient resource conservation technologies (no-till, residue retention, and improved nutrient management) to meet future challenges.

Resource conserving technologies (RCTs) (e.g., reduced tillage (RT), no-till (NT), integrated nutrient management (INM), use of micronutrients, and residue retention) in rice-wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.)–wheat cropping systems have been validated under irrigated conditions in the Indo-Gangetic Plains [12]. However, the research information on the impact of RCTs on productivity and sustainability of rice-rice system under rain-fed hill ecosystems is insufficient [13]. Several researchers [7,9,10,14] have observed that conversion to RT and NT did not affect crop yield under humid conditions. In clay soils of NER, where percolation rates are inherently low, and the water table is high during the rainy season, puddling has a negligible effect on rice yield [15]. The beneficial effects of puddling can be suppressed by continuous submergence. Therefore adoption of RT and NT can substitute the conventional tillage (CT) in rainy season [7]. Recycling of residues, plant biomass, and FYM in the soil are done for replenishing soil fertility, improving physicochemical properties, and enhancing/sustaining crop yield [7,15–17]. Further crop residue retention with organic manure are also important for sequestering soil organic carbon (SOC), and improving soil quality [7,18–20]. During the rainy season, high amount of litter is easily available to the soil as green manure [21]. Therefore, we hypothesized that NT combined with nutrient and residue management could increase the rice yield as well as soil fertility in rice–rice cropping in NER of India. The main objective of present study is to study the effect of conservation tillage, nutrient and residue management on rice productivity and soil health in the low land condition of NER of India.

2. Materials and Methods

2.1. Experimental Site

A 3-year study (2013–2015) on RRS was conducted in the lowland rice field at the Agronomy experimental farm (*Cocotilla* farm) of the Indian Council of Agricultural Research (ICAR), Research Complex for North Eastern Hill Region, Tripura Centre, Lembucherra, Tripura India (Latitude of 23°54′24.02′′ N and 91°18′58.35′′ E and altitude of 162 m above mean sea level). Prior to the beginning of the actual experiment, one wet season rice (WR) was grown (2012) uniformly with traditional farmers practice for treatment stabilization. The average annual rainfall of the experimental site is 2200 mm. However, annual rainfall received during the investigation period, i.e., 2013, 2014 and 2015, was 2056.8, 1821.1 and 2397.2.8 mm, respectively. The average monthly distribution of rainfall, temperature and relative humidity (RH) of three year (2013–2015) are shown in Figure S1 (Supplementary Materials). The sandy clay loam soil was classified as *Typic Kandihumults*, was sampled from Ap horizon (0–20 cm) and analyzed before beginning the experiment. The control soil contain 10.2 g kg^{-1} total organic soil carbon (TOC) by the dry combustion method [22] using a TOC analyzer (Elementar Vario Select, Germany), 1.01 g kg^{-1} total soil nitrogen (TSN) by Kjeldahl digestion [23], 9.5 mg kg^{-1} available phosphorus (P) and 295.7 mg kg^{-1} available potassium (K) by the method of Prasad et al. [24]. Soil pH and bulk density were 5.1 and 1.33 Mg m^{-3}, respectively.

2.2. Experimental Design and Crop Management

The experiment was carried out in a complete randomized block design (CRBD) with three replications. The experiment consisted of five combinations of agronomic modification of traditional rice farming practices. The gross and net plot sizes were 6 × 5 m^2 and 5 × 4 m^2, respectively. Detail description of experimental treatment is shown in Table 1 and about tillage and other treatments in Table S1 (Supplementary Materials).

Wet bed rice nursery with 12 kg seed was grown on an area of 120 m^2 for each crop. Twenty–one-day-old rice seedlings of popular high yielding rice varieties Naveen for DR and Gomatidhan for WR were manually transplanted at 20 × 20 cm^2 spacing with two seedling hill. The DR nursery was sown in the first week of January and transplanted on last week January, whereas WR nursery was sown in the second week of June and transplanted during the first week of July.

A full dose of P and K and one split of N were applied as basal before transplanting of rice, and the remaining splits of N were applied as a top dressing, as per the treatments. While The N dose was applied as per treatment structure in the form of urea (46–0–0), P and K were applied in the form of single super phosphate (SSP) (0–7.2–0) and muriate of potash (MOP) (0–0–50), respectively. FYM was applied at the time of second plowing (15 days before transplanting), in CT and incorporated into the soil. In plot with NT, FYM and green leaf manure (GLM) were applied on the surface. Thirty percent of rice straw was retained in the field as per treatment. The rice biomass (straw + root), FYM and GLM contained 43.1%, 20.1%, and 13.2% C, and 0.56%, 0.50%, and 2.30% N, respectively. GLM was obtained from the *Glyricidia* sp. grown on the farm fences the N-rich leaf biomass in the nearby area. The leaves along with tender twigs were used as GLM.

Table 1. Details of treatment description of experiments.

SN.	Wet Season (*Aman*) Rice		Dry Season (*Boro*) Rice	
	Treatment	Symbol	Treatment	Symbol
T_1	Conventional tillage (CT) + 30% residue incorporation (RI) + no fertilizer and no manure (NF)	FP – NF	CT + 30% RI + NF	FP – NF
T_2	CT + 40 kg nitrogen (N) and 9 kg phosphorus (P) ha^{-1} + 30 RI + FYM 5 Mg ha^{-1} once in two years (FP)	FP	CT + 40 kg N and 9 kg P ha^{-1} + 30% RI (FP)	FP
T_3	CT + 40 kg N and 9 kg P ha^{-1} + No residue (NR) + FYM 5Mg ha^{-1} once in two years	FP – NR	CT + 40 kg N and 9 kg P ha^{-1} + NR	FP – NR
T_4	No-till (NT) + 40 kg N and 9 kg P ha^{-1} + 30% residue retention (RR) + FYM 5 Mg ha^{-1} once in two years	NT + FP	Reduce tillage (RT) + 40 kg N and 9 kg P ha^{-1} + 30% RR	RT + FP
T_5	NT + 25% N through green leaf manure (GLM) + 60 kg N, 9 kg P, 17 kg potassium (K), 2 kg Boron (B) and 5 kg zinc (Zn) ha^{-1} (INM) + 30% RR + cellulose decomposing microorganism (CDM)	NT + INM + RR + CDM	NT + 100 kg N, 18 kg P and 33.3 kg K ha^{-1} (RDF) + 30% RR + CDM	NT + RDF + RR + CDM

Weeds in NT plots were controlled with glyphosate (N-(phosphonomethyl) glycine) at 5 mL L^{-1} using flat fan nozzle (Knapsac sprayer, model AGM/001) seven days before transplanting of both DR and WR. Two days after transplanting (DAT) of rice seedlings, pretilachlor (2-Chloro-N-(2,6-diethylphenyl)-N-(2-propoxyethyl) acetamide at 1200 g (a.i.) ha^{-1} was applied manually (both the crops). One manual weeding was also done at 30 DAT for both WR and DR to manage the weeds.

While the WR rice was grown under rainfed conditions, DR was grown with assured irrigation. Irrigation for DR crop was adjusted with rainfall and soil conditions. The DR plots were kept flooded (5 cm of standing water) for the first 2 weeks, followed by irrigation (5 cm depth) at the appearance of cracks on the soil surface until 15 days before maturity. On average, total irrigation water used in DR ranged between 800 and 900 ha-mm across the treatments. However, the highest amount of irrigation water was required under CT (900 ha-mm) because of puddling (consumed 200 ha-mm water) and the lowest under NT plots (800 ha-mm) due to no puddling. Irrigation was provided to rice at all the critical growth stages for different treatments so that crops did not suffer due to moisture stress and, thus, had no major adverse effect on yields.

2.3. Harvesting, Economic Yield, and Biomass Measurement

Both WR and DR were harvested at maturity during the second fortnight of November and the last week of May to first week of June, respectively, in all years. Both the rice crops were harvested manually using a sickle in such a way that 30% standing stubbles were retained in the field. For yield measurement, a net plot area of 5×4 m^2 was harvested and kept on the threshing floor to allow the biomass to dry for 4–5 days. The harvested plants were then weighed and threshed manually to separate the grains from straw. Subsamples of grains and straw were dried in the oven at 70 °C to the constant weight. Grain yields were adjusted to 14% moisture content for both WR and DR. The dry weight of straw was determined after oven drying at 70 °C to a constant weight.

Root samples of both the rice crops were collected at harvesting from 20 cm soil depth using a core sampler (5.8 cm height and 5.4 cm diameter). Five hills were randomly selected from each plot for obtaining root samples. The core sampler was placed on soil keeping the base of the stem in the center of the sampler and then pushed vertically to the desired depth. The core samples with roots and soil were soaked in water for at least 12 hours following the procedure described by Bohm [25]. The soil–root suspension was stirred well and then passed through a 0.5 mm sieve. Root and organic debris retained on the sieve were stored at 5 °C in plastic bags containing 17% (*v/v*) acetic acid solution immediately after sampling. The roots were cleaned off the soil, and dead organic debris and the fresh roots were oven-dried at 70 ± 1 °C until constant weight and the dry biomass was determined and converted in Mg ha^{-1}.

2.4. Soil Sampling and Analysis

Soil samples were collected (500 g composite sample, one sample from each plot) from 0–20 cm depth to analyze the pH, SOC, TSN, soil microbial biomass carbon (MBC) and dehydrogenase activities (DHA) after three years of study. The total C was determined by the dry combustion method [22] using a TOC analyzer (Elementar Vario Select, Germany). Soil pH was determined using 1:2.5 soil to water ratio [26]. The SOC was assumed to be equal to the total C with negligible inorganic C concentrations as the soil was acidic in reaction [27]. Soil samples were analyzed for total N by Kjeldahl digestion [23]. The MBC was estimated by soil fumigation technique. Soil DHA was estimated by the procedures described by Tabatabai [28] by reducing 2,3,5-triphenyl tetrazolium chloride [29]. Bulk density (ϱ_b) was determined by the core method [30] using cores of 5.8 cm height and 5.4 cm diameter at 0–20 cm depth and oven dried at 105 °C (one sample per plot).

2.5. Computation of C and N Stock

Total SOC and N stocks (Mg ha^{-1}) of the 0–20 cm were calculated using the fixed depth (FD) method with following Equation (1) [31]

$$M_{C/N} = \varrho_b \times D_f \times C_{C/N} \times 10^4 \quad (1)$$

where $M_{C/N}$ is the SOC/N mass per unit area (Mg C/N ha^{-1}), ϱ_b is the soil bulk density (Mg m^{-3}), $C_{C/N}$ is the concentration of SOC/N (Mg C/N Mg^{-1}), D_f is the depth of the fixed soil layer (m), and 10^4 is a unit conversion factor (m^2 ha^{-1}).

Sequestration of SOC/N was computed using Equation (2):

$$\text{C sequestered (Mg C/N ha}^{-1}\text{ soil)} = \text{SOC/N current (Mg ha}^{-1}) - \text{SOC/N initial (Mg ha}^{-1}) \quad (2)$$

Carbon retention efficiency (CRE) was calculated using Equation (3):

$$\text{CRE (\%)} = (\text{SOC final} - \text{SOC initial}) \times 100 \div \text{ECI} \quad (3)$$

SOC final and SOC initial represent SOC (Mg ha^{-1}) in the final and initial soils, respectively, and ECI is cumulatively estimated C input (Mg ha^{-1}) to the soil between the initial and final year of experimentation.

2.6. Statistical Analysis

Data were subjected to ANOVA, to test the significance of the overall differences among treatments by the "F" test. When the "F" value was found to be significant, the critical difference (CD) at $p = 0.05$ was computed to test the significance of the difference between the two treatment means [6].

3. Results and Discussions

3.1. Biomass Production and Recycling of Carbon and Nitrogen

Plant biomass is the synopsis of the above and below ground biomass. In the present study, total biomass for rice crop includes grain, straw, and root mass. Straw and root mass are important to recycle the C and N into the rice soil system. Although the rice straw is not considered as good quality feed for cattle, it is still used as dry fodder for animals in NER, especially during the lean season. Despite this, most farmers of the NER retain about 30% rice stubbles in the field for recycling of C and N. However, the amount of straw and root mass recycled in paddy field may vary according to the production of total biomass and farmers need. In the present study, straw, root and total biomass yield of both the rice crops as well as of the system were significantly affected by the agronomic modification of traditional rice farming practices (Tables 2 and 3). The modification of farmers practice T_2 and T_5 enhanced the straw, root and biomass yield of both WR and DR rice as well as the system as a whole over the FP. Treatment T_5 increased the average straw yield by 26.7%, root mass by 29.7% and total biomass by 28.4% compared to T_2 (Table 4). The modification of FP is needed for more amounts of biomass production and recycling. The amount of biomass and carbon available for recycling and actual amount recycled varied among the treatments (Table 5). We applied 30% straw and considered root mass up to 20 cm soil depth of each crop during all the experiments for recycling of biomass, C and N. In addition, C and N were also added through GLM and fertilizer as per respective treatment. Therefore, the amount of biomass, C, and N recycled through 30% straw incorporation + root biomass varied among the treatments.

The highest biomass, C, and N recycled through 30% straw + root biomass (20 cm soil depth) were recorded under T_5 plots due to higher straw and root mass production. However, total biomass and C recycling showed the different trend as biomass and C added through 30% straw incorporation + root biomass. The highest total biomass and C were recycled under FP (T_2). However, the amount of N recycled was the highest under T_5 (Table 5). Other researchers have also reported higher C and N recycling potential from retention of rice straw and with the application of FYM and GLM [32] and rice straw and weed biomass [7,15] under NT in lowland rice compared to farmers practices.

Table 2. Effect of agronomical modification of traditional farming practices on wet and dry season rice yield.

Treatment	Wet Season (*Aman*) Rice									Dry Season (*Boro*) Rice								
	Straw Yield (Mg ha^{-1})			Root Biomass (Mg ha^{-1})			Total Biomass (Mg ha^{-1})			Straw Yield (Mg ha^{-1})			Root Biomass (Mg ha^{-1})			Total biomass (Mg ha^{-1})		
	2013	2014	2015	2013	2014	2015	2013	2014	2015	2013	2014	2015	2013	2014	2015	2013	2014	2015
FP – NF	3.20 ^{d}	2.81 ^{d}	2.60 ^{d}	0.60 ^{d}	0.53 ^{d}	0.49 ^{d}	6.10 ^{d}	5.44 ^{d}	5.04 ^{d}	3.39 ^{d}	3.28 ^{d}	3.01 ^{d}	0.64 ^{d}	0.62 ^{c}	0.56 ^{c}	6.54 ^{d}	6.33 ^{e}	5.77 ^{e}
FP	4.55 ^{b}	4.70 ^{b}	4.53 ^{b}	0.85 ^{b}	0.87 ^{b}	0.84 ^{b}	8.63 ^{b}	8.90 ^{b}	8.58 ^{b}	4.33 ^{b}	4.35 ^{a}	4.33 ^{b}	0.82 ^{b}	0.82 ^{a}	0.82 ^{b}	8.36 ^{b}	8.39 ^{b}	8.36 ^{b}
FP – NR	3.98 ^{c}	3.74 ^{c}	3.53 ^{c}	0.74 ^{c}	0.69 ^{c}	0.65 ^{c}	7.54 ^{c}	7.08 ^{c}	6.68 ^{c}	3.94 ^{c}	3.59 ^{c}	3.25 ^{c}	0.75 ^{c}	0.68 ^{b}	0.62 ^{b}	7.61 ^{c}	6.91 ^{d}	6.28 ^{d}
NT/RT + FP	3.95 ^{c}	3.78 ^{c}	3.57 ^{c}	0.73 ^{c}	0.70 ^{c}	0.66 ^{c}	7.48 ^{c}	7.16 ^{c}	6.76 ^{c}	4.08 ^{c}	4.01 ^{b}	3.79 ^{c}	0.77 ^{c}	0.75 ^{b}	0.72 ^{b}	7.87 ^{c}	7.72 ^{c}	7.29 ^{c}
NT + INM/RDF + RR + CDM	6.00 ^{a}	6.30 ^{a}	6.40 ^{a}	1.12 ^{a}	1.17 ^{a}	1.18 ^{a}	11.44 ^{a}	11.92 ^{a}	12.03 ^{a}	5.39 ^{a}	4.45 ^{a}	5.40 ^{a}	1.05 ^{a}	0.92 ^{a}	1.02 ^{a}	10.56 ^{a}	9.39 ^{a}	10.40 ^{a}

Within a Column, data for each parameter followed by same letter are not significantly different according to LSD ($p = 0.05$). FP – NF: Conventional tillage (CT) + 30% residue incorporation (RI) + no fertilizer and no manure (NF); FP: CT + 40 kg nitrogen (N) and 9 kg phosphorus (P) ha^{-1} + 30 RI + FYM 5 Mg ha^{-1} once in two years; FP – NR: CT + 40 kg N and 9 kg P ha^{-1}+ No residue (NR) + FYM 5 Mg ha^{-1} once in two years; NT + FP (wet season): No-till (NT) + 40 kg N and 9 kg P ha^{-1} + 30% residue retention (RR) + FYM 5 Mg ha^{-1} once in two years; RT + FP (dry season): Reduced-tillage (RT) + 40 kg N and 9 kg P ha^{-1} + 30% residue retention (RR) + FYM 5 Mg ha^{-1} once in two years; NT + INM + RR + CDM (wet season): NT + 25% N through green leaf manure (GLM) + 60 kg N, 9 kg P, 17 kg potassium (K), 2 kg Boron (B) and 5 kg zinc (Zn) ha^{-1} (INM) + 30% RR + cellulose decomposing microorganism (CDM); NT + RDF + RR + CDM (dry season): No-till (NT) + 100 kg N, 18 kg P and 33.3 kg K ha^{-1} + 30% RR + cellulose decomposing microorganism (CDM).

Table 3. Effect of agronomic modification of traditional farming practice on yield of rice–rice system and recyclable biomass and carbon production of rice–rice system.

Treatment	Straw Yield (Mg ha^{-1})			Root Biomass (Mg ha^{-1})			Total Biomass (Grain + Straw + Root) Mg ha^{-1}			Recyclable Biomass Production (Mg ha^{-1}) Straw + Root Mass			Recyclable Carbon Production (Mg ha^{-1})		
	2013	2014	2015	2013	2014	2015	2013	2014	2015	2013	2014	2015	2013	2014	2015
T_1	6.59 ^{d}	6.09 ^{d}	5.61 ^{d}	1.24 ^{c}	1.15 ^{c}	1.05 ^{c}	12.64 ^{d}	11.77 ^{d}	10.81 ^{d}	7.83 ^{d}	7.24 ^{d}	6.67 ^{d}	3.37 ^{d}	3.12 ^{d}	2.87 ^{d}
T_2	8.88 ^{b}	9.05 ^{b}	8.86 ^{b}	1.67 ^{b}	1.69 ^{b}	1.66 ^{b}	16.99 ^{b}	17.29 ^{b}	16.94 ^{b}	10.55 ^{b}	10.74 ^{b}	10.52 ^{b}	4.55 ^{b}	4.63 ^{b}	4.54 ^{b}
T_3	7.92 ^{c}	7.32 ^{c}	6.78 ^{c}	1.49 ^{b}	1.37 ^{b}	1.27 ^{b}	15.15 ^{c}	14.00 ^{c}	12.96 ^{c}	9.41 ^{c}	8.70 ^{c}	8.05 ^{c}	4.06 ^{c}	3.75 ^{c}	3.47 ^{c}
T_4	8.03 ^{c}	7.79 ^{c}	7.36 ^{c}	1.50 ^{b}	1.45 ^{b}	1.38 ^{b}	15.35 ^{c}	14.88 ^{c}	14.05 ^{c}	9.53 ^{c}	9.25 ^{c}	8.74 ^{c}	4.11 ^{c}	3.98 ^{c}	3.77 ^{c}
T_5	11.39 ^{a}	10.75 ^{a}	11.80 ^{a}	2.17 ^{a}	2.09 ^{a}	2.20 ^{a}	22.01 ^{a}	21.31 ^{a}	22.43 ^{a}	13.57 ^{a}	12.84 ^{a}	14.00 ^{a}	5.85 ^{a}	5.53 ^{a}	6.03 ^{a}

Within a Column, data for each parameter followed by same letter are not significantly different according to LSD ($p = 0.05$). T_1: Conventional tillage (CT) + 30% residue incorporation (RI) + no fertilizer and no manure (NF) in wet season rice (WR) and CT + 30% RI + NF in dry season rice (DR); T_2: CT + 40 kg nitrogen (N) and 9 kg phosphorus (P) ha^{-1} + 30 RI + FYM 5 Mg ha^{-1} once in two years in WR and CT + 40 kg N and 9 kg P ha^{-1} + 30% RI in DR; T_3; CT + 40 kg N and 9 kg P ha^{-1} + No residue (NR) + FYM 5 Mg ha^{-1} once in two years in WR and CT + 40 kg N and 9 kg P ha^{-1} + NR in DR; T_4: No-till (NT) + 40 kg N and 9 kg P ha^{-1} + 30% residue retention (RR) + FYM 5 Mg ha^{-1} once in two years in WR and Reduce tillage (RT) + 40 kg N and 9 kg P ha^{-1} + 30% RR in DR; T_5: NT + 25% N through green leaf manure (GLM) + 60 kg N, 9 kg P, 17 kg potassium (K), 2 kg Boron (B) and 5 kg zinc (Zn) ha^{-1} (INM) + 30% RR + cellulose decomposing microorganism (CDM) in WR and NT + 100 kg N, 18 kg P and 33.3 kg K ha^{-1} (RDF) + 30% RR + CDM in DR.

Table 4. Effect of agronomic modification of traditional farming practice on biomass, carbon and nitrogen inputs of rice–rice system.

Treatment	Biomass Added in Soil (through 30% Straw + Root Biomass Mg ha^{-1})	Total Biomass Added in Soil (Mg ha^{-1})	Carbon Added in Soil (through 30% Straw + Root Biomass Mg ha^{-1})	Total Carbon Added in Soil (Mg ha^{-1})	N added in Soil (through 30% Straw + Root Biomass kg ha^{-1})	Total N Added in Soil (kg ha^{-1})
T_1	8.93 ^{d}	8.93 ^{d}	3.85 ^{d}	3.85 ^{d}	21.6 ^{c}	21.6d
T_2	13.06 ^{b}	23.06 ^{a}	5.63 ^{b}	7.64 ^{a}	31.5 ^{b}	281.6 ^{b}
T_3	4.13 ^{e}	14.13 ^{e}	1.78 ^{e}	3.79 ^{e}	9.9 ^{d}	260.0 ^{d}
T_4	11.29 ^{c}	21.29 ^{b}	4.87 ^{c}	6.88 ^{c}	27.2 ^{c}	277.3 ^{c}
T_5	16.64 ^{a}	19.04 ^{c}	7.17 ^{a}	7.49 ^{b}	40.2 ^{a}	528.1 ^{a}

Within a Column, data for each parameter followed by same letter are not significantly different according to LSD (*p = 0.05*). T_1: Conventional tillage (CT) + 30% residue incorporation (RI) + no fertilizer and no manure (NF) in wet season rice (WR) and CT + 30% RI + NF in dry season rice (DR); T_2: CT + 40 kg nitrogen (N) and 9 kg phosphorus (P) ha^{-1} + 30 RI + FYM 5 Mg ha^{-1} once in two years in WR and CT + 40 kg N and 9 kg P ha^{-1} + 30% RI in DR; T_3; CT + 40 kg N and 9 kg P ha^{-1} + No residue (NR) + FYM 5 Mg ha^{-1} once in two years in WR and CT + 40 kg N and 9 kg P ha^{-1} + NR in DR; T_4: No-till (NT)+ 40 kg N and 9 kg P ha^{-1} + 30% residue retention (RR) + FYM 5 Mg ha^{-1} once in two years in WR and Reduce tillage (RT) + 40 kg N and 9 kg P ha^{-1} + 30% RR in DR; T_5: NT + 25% N through green leaf manure (GLM) + 60 kg N, 9 kg P, 17 kg potassium (K), 2 kg Boron (B) and 5 kg zinc (Zn) ha^{-1} (INM) + 30% RR + cellulose decomposing microorganism (CDM) in WR and NT + 100 kg N, 18 kg P and 33.3 kg K ha^{-1} (RDF) + 30% RR + CDM in DR.

Table 5. Effect of agronomic modification of traditional farming practice on total organic carbon and total nitrogen concentration, stocks, cumulative sequestration, sequestration rate, C:N ratios and retention efficiency in soils of rice–rice system.

Treatment	Total Organic Carbon (g kg^{-1})	Total Organic Carbon Sock (Mg ha^{-1})	Cumulative Carbon Sequestration (Mg ha^{-1})	Carbon Sequestration Rate (kg ha^{-1} Year^{-1})	Total Soil Nitrogen (g kg^{-1})	Total Nitrogen Stock (Mg ha^{-1})	Cumulative Nitrogen Sequestration (kg ha^{-1})	Nitrogen Sequestration Rate (kg ha^{-1} Year^{-1})	C/N Ratio	CRE (%)
Initial	10.20	20.35	-	-						-
T_1	10.00 ^{c}	20.11 ^{c}	−0.23 ^{d}	−82.3 ^{d}	0.964 ^{b}	1.94 ^{b}	−76.8 ^{d}	−25.6 ^{d}	10.40 ^{a}	−6.00 ^{d}
T_2	10.42 ^{b}	20.77 ^{b}	0.42 ^{c}	141.6 ^{c}	1.019 ^{a}	2.03 ^{a}	18.0 ^{b}	6.0 ^{b}	10.22 ^{a}	5.59 ^{c}
T_3	9.98 ^{c}	20.07 ^{c}	−0.34 ^{e}	−115.8 ^{e}	0.987 ^{b}	1.98 ^{b}	−30.3 ^{c}	−10.1 ^{c}	10.12 ^{a}	−9.00 ^{e}
T_4	10.62 ^{a}	21.18 ^{a}	0.83 ^{b}	276.1 ^{b}	1.019 ^{a}	2.03 ^{a}	18.0 ^{b}	6.0 ^{b}	10.42 ^{a}	12.04 ^{b}
T_5	10.71 ^{a}	21.36 ^{a}	1.02 ^{a}	336.5 ^{a}	1.033 ^{a}	2.06 ^{a}	45.1 ^{a}	15.0 ^{a}	10.37 ^{a}	13.47 ^{a}

Within a Column, data for each parameter followed by same letter are not significantly different according to LSD (*p = 0.05*). T_1: Conventional tillage (CT) + 30% residue incorporation (RI) + no fertilizer and no manure (NF) in wet season rice (WR) and CT + 30% RI + NF in dry season rice (DR); T_2: CT + 40 kg nitrogen (N) and 9 kg phosphorus (P) ha^{-1} + 30 RI + FYM 5 Mg ha^{-1} once in two years in WR and CT+ 40 kg N and 9 kg P ha^{-1} + 30% RI in DR; T_3; CT + 40 kg N and 9 kg P ha^{-1} + No residue (NR) + FYM 5 Mg ha^{-1} once in two years in WR and CT + 40 kg N and 9 kg P ha^{-1} + NR in DR; T_4: No-till (NT)+ 40 kg N and 9 kg P ha^{-1} + 30% residue retention (RR)+ FYM 5 Mg ha^{-1} once in two years in WR and Reduce tillage (RT) + 40 kg N and 9 kg P ha^{-1} + 30% RR in DR; T_5: NT +25% N through green leaf manure (GLM) + 60 kg N, 9 kg P, 17 kg potassium (K), 2 kg Boron (B) and 5 kg zinc (Zn) ha^{-1} (INM) + 30% RR + cellulose decomposing microorganism (CDM) in WR and NT + 100 kg N, 18 kg P and 33.3 kg K ha^{-1} (RDF)+ 30% RR + CDM in DR.

3.2. Bulk Density and Soil pH

Agronomic modification of traditional farming practices did not have any significant effect on soil ϱ_b (bulk density) (Figure 1A). Treatment T_1 and T_2 slightly increased ϱ_b than that for the other treatments. However, treatments with NT component (T_4 and T_5) did not cause a significant difference to initial ϱ_b. Continuous imposition of FP (T_1) over three years did not affect the ϱ_b significantly, probably due to the incorporation of 30% straw and FYM. Positive effect of crop residues on soil ϱ_b at the surface 10 cm depth has been reported previously [33–35]. Puddling (wet tillage) in rice is known to increase soil ϱ_b immediately below the plow layer due to the destruction of soil aggregates, filling of macropores with finer soil particles, which ultimately reduces the porosity and direct physical compaction caused by the tillage implements [36,37]. Our results suggest that T_2 and T_5 have a relatively positive effect on soil ϱ_b. In contrast, other studies have reported higher ϱ_b under NT at 0–5 cm depth compared to CT in cropping systems other than RRS [35,38,39].

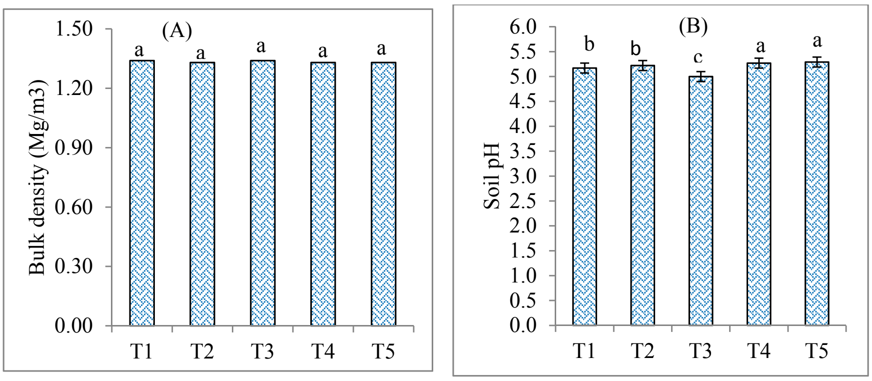

Figure 1. Effect of agronomic modification of traditional farming practice on: bulk density (**A**); and pH (**B**) of soils under rice–rice system (the vertical bars indicate LSD at $p = 0.05$). Bars for each parameter followed by the same letter are not significantly different according to LSD ($p = 0.05$). T_1: Conventional tillage (CT) + 30% residue incorporation (RI) + no fertilizer and no manure (NF) in wet season rice (WR) and CT + 30% RI + NF in dry season rice (DR); T_2: CT + 40 kg nitrogen (N) and 9 kg phosphorus (P) ha^{-1} + 30 RI + FYM 5 Mg ha^{-1} once in two years in WR and CT + 40 kg N and 9 kg P ha^{-1} + 30% RI in DR; T_3: CT + 40 kg N and 9 kg P ha^{-1} + No residue (NR) + FYM 5 Mg ha^{-1} once in two years in WR and CT + 40 kg N and 9 kg P ha^{-1} + NR in DR; T_4: No-till (NT) + 40 kg N and 9 kg P ha^{-1} + 30% residue retention (RR) + FYM 5 Mg ha^{-1} once in two years in WR and Reduce tillage (RT) + 40 kg N and 9 kg P ha^{-1} + 30% RR in DR; T_5: NT +25% N through green leaf manure (GLM) + 60 kg N, 9 kg P, 17 kg potassium (K), 2 kg Boron (B) and 5 kg zinc (Zn) ha^{-1} (INM) + 30% RR + cellulose decomposing microorganism (CDM) in WR and NT + 100 kg N, 18 kg P and 33.3 kg K ha^{-1} (RDF) + 30% RR + CDM in DR.

Soil pH is an important soil quality factor affected by farmers practice and its modifications in the present study (Figure 1B). The T_5 increased soil pH (5.29) significantly, as compared to T_2 (5.22) and the initial (5.20) value. However, treatment T_4 also increased soil pH significantly than that under T_2 and the initial value. This might be due to the addition of more organic matter by rice residue and FYM/GLM in these treatments than under FP [40,41]. Many researchers have shown that, if organic residues are returned to the soil, pH can be increased due to the decarboxylation of organic anions on decomposition by microorganisms [42,43]. Many reports have indicated the increase in soil pH with crop residues retention/ incorporation [40,42–44].

3.3. Soil Organic Carbon and Stocks

TOC, TOCS, CSR, CCS and CRE were significantly affected by agronomic modification of FP after three consecutive years of RRS (Table 5). The TOC concentration increased by 2.1% and 5% under T_2

and T_5, respectively, compared with the initial TOC. The data showed that T_2 maintained a consistent TOC concentration and TOCS in the soil. Same treatment (T_2) recorded CCS of 0.42 Mg ha^{-1} after three years at a rate of 141.6 kg ha^{-1} $year^{-1}$ with 5.59% CRE. Traditional farming practice increased an average SOC by 2.23% over the initial value, as was also reported by Smith et al. [45]. Our results show that the maintenance of TOC concentration and stocks under T_2 may be attributed to the incorporation of 30% rice residue of each crop and application of 5 Mg FYM ha^{-1} to the first crop at every two-year interval by farmers [43,46]. Several researchers have indicated beneficial effects of residue incorporation/retention and application of organic manure on the improvement of TOC concentration and stocks in a rice field [45,47]. Agronomic modification by the replacement of CT with NT in WR and replacement of CT with RT in DR (T_4) under the same set of FP (T_2) significantly increased the TOC (1.9%), TOCS (2.0%), CSR (95.0%), CCS (97.6%) and CRE (115.4%) over T_2 in 0–20 cm depth. Further, T_5 increased (%) TOC (2.8), SOCS (2.8), CSR (137.6), CCS (142.9) and CRE (141.0) over FP in 0–20 cm after three years. Significant differences in SOC concentration (0–40 cm) after four years of tillage and straw retention practices in China followed the order of NT > PT > RT [48]. The positive effect of conservation tillage along with organic manure and residue retention/incorporation in increasing the TOC in paddy soils of India have also been reported [7,43,45,49]. Further, the integrated uses of organics with inorganic fertilizers also have been reported to enhance productivity and SOC concentration over that with the sole application of fertilizer or manure [35,50].

Our results demonstrated that the cultivation of RRS under RT/NT system with INM and retention of 30% rice residue sequestrated three times more TOC in soil systems than that in soil under FP. The variation in TOC stock and sequestration were attributed largely to addition of carbon through recycling of organic sources (FYM/GLM), reduction in tillage intensity (RT/NT), crop residue cover (30% residue), root biomass, nutrient-use pattern, soil texture and prevailing ecosystem [35,51]. Therefore, the data suggested a modification of traditional FP with conservation tillage (NT/RT), INM, incorporation/retention of crop residue in cropping systems, use of micro nutrient and application of CDM for enhancing SOC concentration and stock in the region. Enhancement of the TOC stocks of paddy soils can improve soil quality and has the potential to mitigate global warming. Moreover, a continuation of CT practice can enhance SOC and N mineralization by increasing oxidation of organic matter, disruption of soil aggregates, and increasing aeration, hence causing a reduction in SOC stocks [3,52]. Consequently, NT farming has been widely recommended as an alternative to CT for enhancing SOC sequestration in soils [3,18,51–54]. Some studies have reported that NT practices can increase the SOC stock compared to CT in paddy agro-ecosystems [35,52] and the application of rice residues along with inorganic fertilizer could enhance SOC sequestration in the double-rice cropping system in some soils and ecoregions of India [55].

The CRE is an important measure of the amount of C applied and retained in soil [55]. The CRE in the present study ranged from −9.0% to 13.47% across the treatments. T_3 showed the lowest CRE (−9%), and treatment T_5 had the highest CRE (13.47%). Although the highest amount of C (7.64 Mg ha^{-1}) was added under T_2, CRE was recorded to be the highest in T_5. This trend reflected that RT/NT systems under RRS are a potential option for C sequestration compared to the CT based systems that prevail elsewhere [55]. This might be also due to the slow decomposition of applied biomass in paddy soil owing to anaerobic conditions for most part of the year [56].

3.4. Total Soil Nitrogen and Stocks

Total soil N (TSN) concentration, stock (TNS), cumulative N sequestration (CNS), N sequestration rate (NSR) and C/N ratio (CNR) were also significantly affected by the agronomic modification of FP after completion of three years of the study in RRS (Table 5). Similar trends were observed for the TSN, TNS, CNS, and NSR after three years as that of TOC. However, treatment T_5 recorded significantly the highest value of TSN (1.03 N g kg^{-1}), TNS (2.06 Mg ha^{-1}), CNS (45.1 kg ha^{-1}) and NSR (15.0 kg ha $^{-1}$ $year^{-1}$) compared to those for T_1 and T_3, but did not show significant difference with T_2 and T_4. The data presented show that TSN, TNS, CNS, and NSR increased significantly with the decrease in tillage frequency and intensity along with an increase in the application of organic manure (FYM/GLM) and retention/incorporation of crop residue. The TN concentrations significantly decreased with the increase in the tillage frequency and intensity and followed the order of NT > RT > PT at 0–5 cm depth in both years [54]. Therefore, conservation tillage (NT/RT) based farming practices have been widely recommended for improving the TSN and N sequestration in soils [7,18,52,53,56]. However, C:N ratio has not been significantly affected by different treatments in the present study (Table 5).

3.5. Soil Microbial Biomass Carbon and Dehydrogenase Activities

Soil microbial biomass carbon (MBC) and dehydrogenase activities (DHA) ranged from 142.0 to 304.4 µg g^{-1} and 4.30 to 9.49 µg g^{-1} dry soil, respectively, across the treatments after three year of experimentations. The MBC concentration was significantly higher under T_5 (304.4 µg g^{-1} dry soil) and the minimum under T_1 (142 µg g^{-1} dry soil) (Figure 2A). Similarly, the DHA activity was also the maximum in T_5 (9.49 µg TPF g^{-1} dry soil) and the minimum under T_1 (4.3 µg TPF g^{-1} dry soil) (Figure 2B). The MBC and DHA are soil quality indicators because of their relevance to soil biology and rapid response to changes in soil management [7,57] In the present study, NT systems with INM and residue retention had significantly increased SBMC and DHA than that under other treatments. The MBC and DHA under T_5 were 17.8 and 44%, higher than that under T_4 respectively. Pandey et al. [58] concluded that higher DHA in soils under NT was due to larger proportions of MBC than that in soil under CT. Higher activity of soil DHA and SMBC under NT compared to that under CT has been also reported by other researchers [43,58,59]. The accumulation of crop residues on the soil surface results in enrichment of SOM in the surface layer and the microbial activity in soil under NT and RT [47,60]. The rate of biomass-C input from plant residues is a strong control of the amount of SMBC in soil [61]. The continuous and uniform supply of biomass-C is an energy source for microorganisms and enhances soil biological health [3].

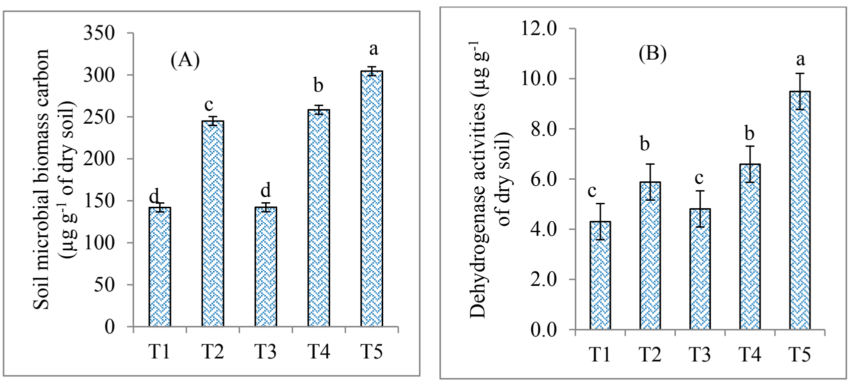

Figure 2. Effect of agronomic modification of traditional farming practice on: soil microbial biomass carbon (**A**); and dehydrogenase activity (**B**) of soils under rice–rice system (the vertical bars indicate LSD at $p = 0.05$). Bars for each parameter followed the by same letter are not significantly different according to LSD ($p = 0.05$). T_1: Conventional tillage (CT) + 30% residue incorporation (RI) + no fertilizer and no manure (NF) in wet season rice (WR) and CT + 30% RI + NF in dry season rice (DR); T_2: CT + 40 kg nitrogen (N) and 9 kg phosphorus (P) ha^{-1} + 30 RI + FYM 5 Mg ha^{-1} once in two years in WR and CT + 40 kg N and 9 kg P ha^{-1} + 30% RI in DR; T_3; CT+ 40 kg N and 9 kg P ha^{-1} + No residue (NR)+ FYM 5 Mg ha^{-1} once in two years in WR and CT + 40 kg N and 9 kg P ha^{-1} + NR in DR; T_4: No-till (NT) + 40 kg N and 9 kg P ha^{-1} + 30% residue retention (RR)+ FYM 5 Mg ha^{-1} once in two years in WR and Reduce tillage (RT) + 40 kg N and 9 kg P ha^{-1} + 30% RR in DR; T_5: NT + 25% N through green leaf manure (GLM) + 60 kg N, 9 kg P, 17 kg potassium (K), 2 kg Boron (B) and 5 kg zinc (Zn) ha^{-1} (INM) + 30% RR + cellulose decomposing microorganism (CDM) in WR and NT + 100 kg N, 18 kg P and 33.3 kg K ha^{-1} (RDF) + 30% RR + CDM in DR.

3.6. Economic Productivity

Economic yields of both WR and DR were significantly affected by agronomic modification of traditional farming practices (Figure 3). The T_2 produced almost consistent grain yield to that for WR (3.21 to 3.33 Mg/ha) as well as DR (3.21 to 3.22 Mg/ha). Nevertheless, T_5 had significantly increased the yield of both WR (35.3%) and DR (25.7%) over that of T_2 across the years. The cultivation of RRS under T_5 produced on average 30.6% higher grain yield over that of T_2 (Figure 4).

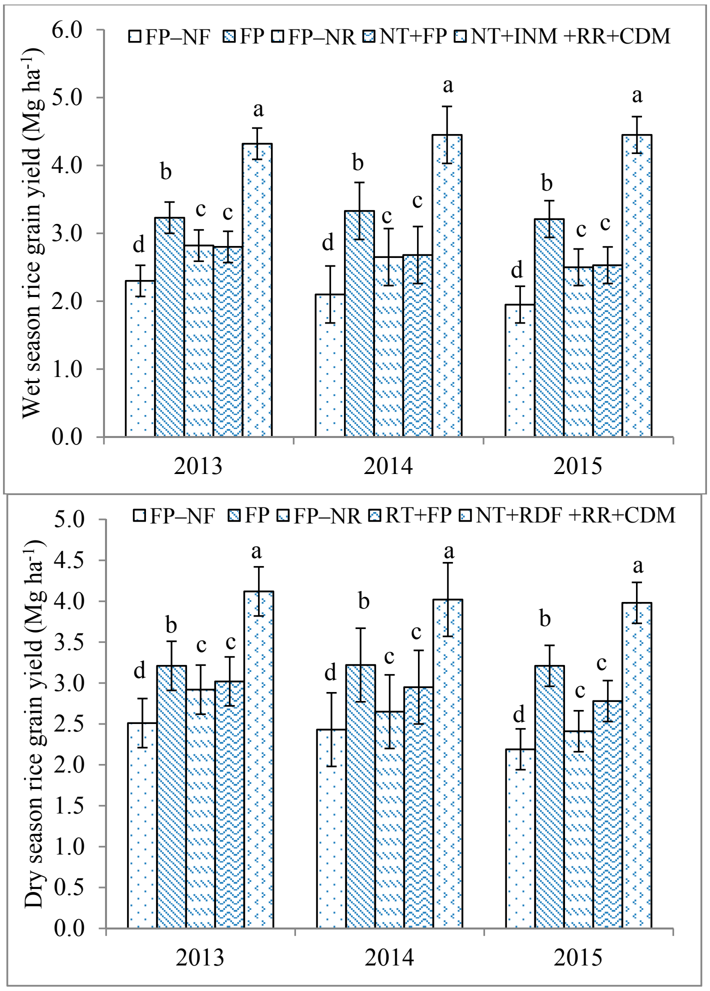

Figure 3. Effect of agronomic modification of traditional farming practice on grain (economic) yield of wet season rice (the vertical bars indicate LSD at $p = 0.05$). Bars for each parameter followed the by same letter are not significantly different according to LSD ($p = 0.05$). FP–NF: Conventional tillage (CT) + 30% residue incorporation (RI) + no fertilizer and no manure (NF); FP: CT + 40 kg nitrogen (N) and 9 kg phosphorus (P) ha^{-1} + 30 RI + FYM 5 Mg ha^{-1} once in two years; FP–NR: CT + 40 kg N and 9 kg P ha^{-1} + No residue (NR) + FYM 5Mg ha^{-1} once in two years. NT + FP: No-till (NT) + 40 kg N and 9 kg P ha^{-1} + 30% residue retention (RR) + FYM 5 Mg ha^{-1} once in two years; NT + INM + RR + CDM: NT + 25% N through green leaf manure (GLM) + 60 kg N, 9 kg P, 17 kg potassium (K), 2 kg Boron (B) and 5 kg zinc (Zn) ha^{-1} (INM) + 30% RR + cellulose decomposing microorganism (CDM); RT + FP: Reduced-tillage (RT) + 40 kg N and 9 kg P ha^{-1} + 30% residue retention (RR) + FYM 5 Mg ha^{-1} once in two years; NT + RDF + RR + CDM: No-till (NT) +100 kg N, 18 kg P and 33.3 kg K ha^{-1} + 30% RR + cellulose decomposing microorganism (CDM).

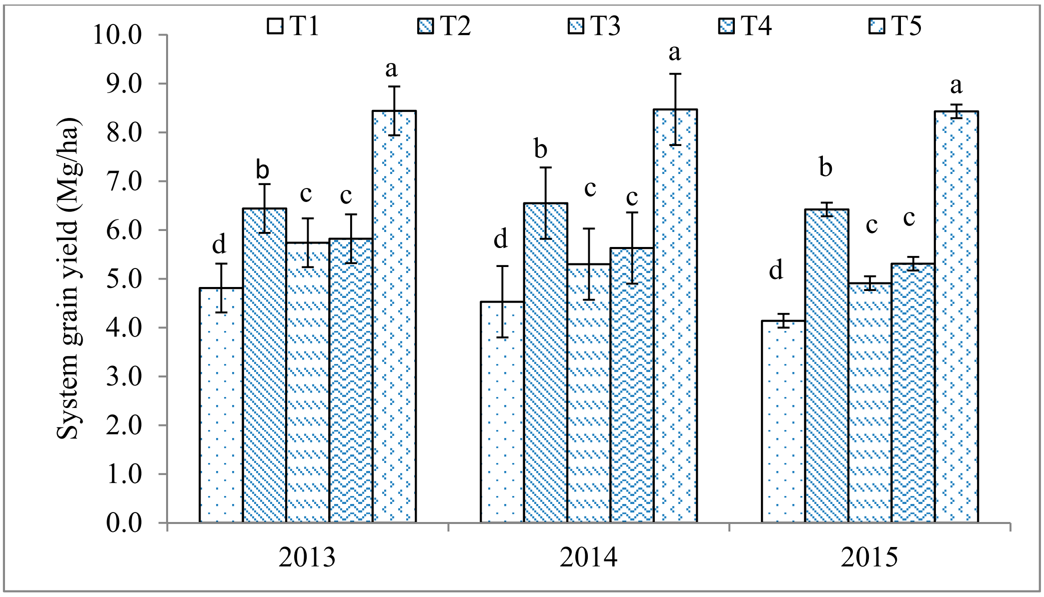

Figure 4. Effect of agronomic modification of traditional farming practice on grain (economic) yield of rice–rice system (the vertical bars indicate LSD at p = 0.05%). Bars for each parameter followed by the same letter are not significantly different according to LSD (p = 0.05). T_1: Conventional tillage (CT) + 30% residue incorporation (RI) + no fertilizer and no manure (NF) in wet season rice (WR) and CT + 30% RI + NF in dry season rice (DR); T_2: CT + 40 kg nitrogen (N) and 9 kg phosphorus (P) ha^{-1} + 30 RI + FYM 5 Mg ha^{-1} once in two years in WR and CT + 40 kg N and 9 kg P ha^{-1} + 30% RI in DR; T_3; CT+ 40 kg N and 9 kg P ha^{-1} + No residue (NR)+ FYM 5 Mg ha^{-1} once in two years in WR and CT + 40 kg N and 9 kg P ha^{-1} + NR in DR; T_4: No-till (NT) + 40 kg N and 9 kg P ha^{-1} + 30% residue retention (RR)+ FYM 5 Mg ha^{-1} once in two years in WR and Reduce tillage (RT) + 40 kg N and 9 kg P ha^{-1} + 30% RR in DR; T_5: NT + 25% N through green leaf manure (GLM) + 60 kg N, 9 kg P, 17 kg potassium (K), 2 kg Boron (B) and 5 kg zinc (Zn) ha^{-1} (INM) + 30% RR + cellulose decomposing microorganism (CDM) in WR and NT + 100 kg N, 18 kg P and 33.3 kg K ha^{-1} (RDF)+ 30% RR + CDM in DR.

These trends indicate an opportunity for NT with improved nutrient management in lowland rice cultivation with some yield advantage [3]. Similar grain yield of rice under puddled and minimum or unpuddled conditions have also been reported [3,62]. Further, conversion from traditional farming practices to NT based farming can also increase crop yield under humid conditions [3,14,63,64]. In areas where rainfall and water table are high [3], water percolation is not a problem (a similar condition exists in the NEH region), and soil puddling has no effect on rice yield [3]. Therefore, a good rice yield of RRS under T_5 in the present study may be due to a balanced application of nutrients and residue recycling. In a study in Bangladesh, minimum tillage unpuddled transplanting had no negative effect on rice yields across seasons and years, but reduced the time taken for land preparation and crop establishment and decreased the cost of production [9]. The negative effects of RT/NT on crop growth do not necessarily become concerns in wet-seeded flooded rice production systems [39]. The increase in rice yield in the present study may not only be due to tillage, but also due to the combined effect of conservation tillage, residue and nutrient management practices. Further, balanced application of nutrients along with micronutrient and residue incorporation can increase the yield of rice [65]. Many studies have reported increased of RRS productivity under conservation tillage (RT/NT) with integrated nutrient and residue management [9] but effects vary with region due to differences in climatic and edaphic factors [54,59]. Our results suggest that cultivation of WR with NT in conjunction with INM and residue management and DR under NT with the recommended dose of fertilizer and residue management will be most suitable for RRS in the region because of improvement in crop yields, enhancement of soil physical quality, and increase in SOC concentration and stock.

4. Conclusions

The modification of FP with NT, INM and proper residue management increased the rice yield, and C and N sequestration in soils of RRS in NER, India. Overall, our results indicate that traditional farming practice maintained/improved soil health and produced consistent grain and straw yields of rice under RRS and modifications of FP with inclusions of NT/RT improved soil health and increased the system productivity by an average of 30.6%. Rice under T_5 recorded the highest TOC/TSN concentration, stock, accumulation, sequestration CRE, SMBC, DHA and lower ϱ_b. These parameters are principal determinants of soil health and crop productivity. Therefore, cultivation of RRS under T_5 is recommended for improving system productivity and sustainability in study site and similar agroecosystems in other rice growing countries. However, further studies are needed to improve the productivity of DR under NT/RT and RRS for adoption CA in South Asian Region.

Supplementary Materials: The following are available online at www.mdpi.com/2071-1050/9/10/1816/s1, Figure S1: Average monthly weather data from 2013–2015, Table S1: Details of the tillage and other cultural operations done in rice–rice system.

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Author Contributions: Gulab Sing Yadav and Ram Swaroop Meena conceived and designed the experiments; Gulab Singh Yadav, Mrinmoy Datta and S. N. Bhowmik performed the experiments; Poulami Saha and Rattan Lal analyzed the data; Subash Babu, Pawan Kumar Mishra and Anup Das contributed reagents/materials/analysis tools; Gulab Singh Yadav, Shamina Imran Pathan, Rahul Datta and Ram Swaroop Meena wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest.

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