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Unveiling Productivity Dynamics: A Comparative Study of Conservation vs. Conventional Tillage Practices in Wheat-Mungbean-T. Aman Rice Cropping Systems

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Intensive tillage for crop production has a negative impact on soil organic matter and soil quality, resulting in reduced crop yields. Conservation agriculture (CA) practices, which improve soil fertility and crop productivity through minimal soil disturbance, crop residue retention, and crop diversification, can solve these issues, especially in intensive rice-based rotations. We hypothesized that increased residue retention and decreased soil disturbance may lead to higher productivity and profitability for individual crops while maintaining soil fertility. An experiment was conducted to study the productivity and soil fertility of intensified rice-wheat (RW) systems by adding a third pre-rice crop of mungbean with five treatments: (T_1) strip planting + 30% crop residue; (T_2) power tiller-operated seeder (PTOS) + 30% crop residue; (T_3) zero planting + 30% crop residue; (T_4) bed planting + 30% crop residue; and (T_5) conventional tillage (CT) practices. In conservation agriculture-based practices, the average yield of two years shows that the wheat yield was 9 to 14.7%, the mungbean yield was 11.7 to 19%, the rice yield was equal, and the REY yield was 6.3 to 9.9% higher than conventional practices. Again, from the economic point of view, the CA method was more profitable than the conventional method. System productivity and fertility were evaluated under five levels of tillage options (strip, PTOS, zero, raised bed, and conventional tillage practice) in an RW-Mungbean cropping pattern. The results indicated that keeping standing 30% of crop residue in the field with minimum disturbance of soil had a significant contribution to grain yield of the wheat-mungbean-rice sequence compared to the conventional practice of well-tilling without crop residue retention.

Keywords: Conservation and conventional agricultural practices; productivity, cropping pattern.

1. INTRODUCTION

The importance of rice-based intensive cropping systems in the Eastern Gangetic Plain (EGP) for food and nutritional security is contradictory now as the conventional system requires higher production costs coupled with an inefficient use of inputs (labor and fertilizer) (Pooniya et al., 2021). More than 300 cropping systems are practiced in EGP depending on land types and suitability of irrigation water (Aggarwal et al., 2004). A rice-based intensive cropping system is important for global food security, which is common in EGP where wetland rice (*Oryza sativa* L.) is rotated annually with one or two additional crops by traditional conventional practice. Rice in Bangladesh is mostly planted on puddled soil after intensive tillage, followed by residue removal for cultivation of the following non-rice crop in the intensive rice-based systems. While puddling softens the soil, reduces water and nutrient loss through percolation, and limits weed occurrence (Humphreys et al. 2005), it causes aggregate breakdown, macropore destruction, and formation of subsurface compaction (Sharma et al., 2005), which adversely affects the succeeding dryland crop (Sharma et al., 2005). However, rice transplanting into soil without puddling did not result in a yield penalty (Haque et al., 2016). Furthermore, long-term use of puddling for rice and intensive tillage for dryland arable non-rice crops resulted in a decline in SOC (Shibu et al., 2010), negatively affecting soil functioning and posing a long-term threat to future yields (D’Haene et al., 2008).

Rice-based systems in the IGP, positive results in terms of increased yield, productivity, economic return, and resource efficiency have been recorded using conservation agriculture (CA) based on minimum tillage, residue retention, and crop rotation when compared to the conventional system (Gathala et al., 2015). Minimal tillage and residue management are promising alternatives for increasing soil organic matter (SOM), nutrients, and crop productivity. Crop residue retention over time increases SOM levels and N reserves while increasing macro- and micronutrient availability (Yadvinder-Singh et al., 2005). Crop rotation plays an important role in improving weed control, reducing disease risk, breaking plant pest cycles, reducing fertilizer input, increasing N availability, maintaining soil fertility, and improving crop yields (Jacobsen et al., 2012). Alam et al. (2018) observed that minimal soil disturbance and increased residue retention practiced continuously for five years increased SOC (0-10 cm soil depth) by 68% in intensive triple-cropping, rice-based cropping systems on the Grey Terrace soil of the EGP. In this soil, the strip planting (SP) system sequestered carbon at a rate of 0.24-0.53 Mg C ha^{-1} yr^{-1} (at 0-15 cm soil depth) while conventional tillage (CT) was associated with a carbon loss of 0.52–0.82 Mg C ha^{-1} yr^{-1} (Islam et al., 2022). Therefore, the contribution of CA practice and better nutrient management can potentially increase crop productivity and soil fertility by improving SOC status and reducing greenhouse gas emissions from rice-based cropping systems (Pooniya et al., 2021).

Conserving agriculture (CA) is being introduced among the farmers, and the farmers are showing interest in growing crops with CA because it reduces cultivation costs, protects degrading soil, and saves water without any yield sacrifice. Also, CA offers the opportunity to plant wheat in a timely manner. Due to scarcity and high cost of labor and for reducing cultivation costs, CA is essential for farming. Zero-till, bed planting strip tillage, and PTOS tillage options are known as CA. However, for getting expected crop yields with CA, a full package of production technologies, especially fertilizer management, should be provided. Broadcasting fertilizer enhances losses of fertilizer and reduces fertilizer use efficiency in CA tillage options. On the other hand, there is much evidence that residue retention has a significant contribution to crop productivity and soil fertility, with much evidence that residue retention has a significant contribution to crop productivity and soil fertility in a sustainable way.

Conservation Agriculture is a cropping system based on minimal soil disturbance, permanent surface cover through crop residue retention, and diverse associations following crop rotation. CA improves soil health, increases soil organic matter and soil biological diversity as well as reduces soil erosion, improves and maintains soil porosity, and thus prolongs the availability of plant-available soil water in times of drought. Conservation agriculture also helps reduce costs of production, saves time, increases yield through timelier planting, reduces diseases and pests through stimulation of biological diversity, and reduces greenhouse gas emissions. It has been widely established that soils under long-term NT or reduced tillage systems generally contain higher amounts of soil organic carbon in the soil surface than under conventional tillage. It may be giving strength to plants. So those plants can escape the stress from rough weather. With these points of view, this study has been taken to evaluate the effect of crop establishment methods on sustainable crop productivity and profitability of the wheat-maize-T. Aman rice cropping pattern.

2. MATERIALS AND METHODS

2.1 Site Description

The experiment was conducted at farmers' fields in Shibpur, Puthia, Rajshahi. The experimental sites belong to the AEZ-11 (High Ganges River Floodplain) with an elevation of 26 m above sea level and to the Sara soil series under suborder Ochrepts (SRDI, 2008). The land topography is medium-low land. Initial soil properties of the experimental field were determined. Morphological characteristics of the experimental fields are presented in Table 1a.

2.2 Weather Condition

Daily rainfall was collected from the experimental field, while temperature and relative humidity were collected from the nearest weather station at Rajshahi Division (Ahmmed et al. 2018).

Table 1a. Morphological characteristics of the experimental field

Characteristics		Description
Location and site	:	Shibpur, Upazila- Puthia, District- Rajshahi
Geographic position	:	
Agro-Ecological Zone	:	High Ganges River Floodplain (AEZ-11)
General Soil Type and USDA Soil Family	:	Calcareous Grey Flood Plain soil was classified as a Typic Haplaquept from the Arial/Sara soil series (Huq and Shoaib 2013; USDA 2014),
Soil Series	:	Sara
Parent material	:	Ganges river alluvium
Land type	:	Medium low land
Drainage	:	Well drained

Table 1b. Monthly average temperature, rainfall, relative humidity, average sunshine and evapotranspiration of Rajshahi district during the years 2018-2019

Months	Average temperature (^{0} C)				Relative Humidity (%)		Rainfall (mm)		Average Sunshine (hour/day)		Evapotranspiration (mm)	
	Maximum		Minimum									
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
January	22.5	25.5	8.51	10.4	88.0	83.9	0.0	0.00	5.80	9.56	0.92	1.15
February	28.9	27.6	14.2	13.4	80.8	80.3	12.4	47.1	5.76	7.63	1.40	1.43
March	34.2	32.1	19.1	17.5	72.2	74.1	8.60	67.6	9.92	7.84	2.28	1.91
April	34.1	34.5	22.2	23.0	79.7	79.6	72.7	114	7.68	7.15	2.17	2.02
May	33.4	35.9	24.0	32.3	84.3	82.3	175	147	5.70	7.42	1.93	2.11
June	35.7	35.8	26.2	26.3	84.8	84.1	140	122	5.76	5.94	3.90	2.10
July	33.9	34.5	26.7	26.5	88.7	88.7	238	261	4.26	4.51	1.59	1.39
August	34.6	34.5	27.0	26.9	86.6	87.5	83.9	115	5.31	5.60	1.97	1.47
September	34.4	33.4	26.1	26.2	89.6	91.3	118	188	6.19	4.70	1.63	1.39
October	41.4	31.4	21.7	23.0	89.2	92.1	81.5	174	7.22	6.18	1.58	1.27
November	30.0	30.0	16.7	18.3	90.0	91.0	0.0	3.40	7.52	6.36	1.30	1.15
December	25.2	23.7	11.6	11.7	87.3	89.3	17.2	0.20	6.28	3.77	0.91	0.90

(Source: Weather Station, Rajshahi, 2020); Daily temperature and rainfall data were collected by the weather station at Shyampur, Rajshahi, Bangladesh. The weather station is approximately 20 km from Shibpur.

Total precipitation was 947 and 1238 mm in the 1st and 2nd crop cycles, respectively. Most of the precipitation occurred from May to October in every crop cycle when mungbean and T. Aman rice were cultivated. Total rainfall received from April to October was 909 mm in 2018 and 1120mm in 2019 cropping year. Little rainfall was recorded from November to March in the 1st crop cycle, 38 mm, and the second 2nd crop cycle, 118mm (Table 1b).

The annual mean temperature, average relative humidity (RH), sunshine hours, and evapotranspiration in the 1st (January 2018-December 2018) and 2nd (January 2019-December 2019) crop cycles were shown in (Table 1b).

2.3 Design and Treatments

The experiment was initiated in November 2017 with wheat-mungbean-T. Aman rice cropping pattern under RCBD design with five treatments: (T_1) strip planting + 30% crop residue; (T_2) power tiller-operated seeder (PTOS) + 30% crop residue; (T_3) zero planting + 30% crop residue; (T_4) bed planting + 30% crop residue; and (T_5) conventional practices. CA= strip planting + 30% crop residue; (T_2) power tiller-operated seeder (PTOS) + 30% crop residue; (T_3) zero planting + 30% crop residue and (T_4) bed planting + 30% crop residue; CT= conventional practices; CR= crop residue, 30% rice and wheat residue and 100% mungbean residue. Seeds of dryland crops were sown using a BARI versatile multi-crop planter along with fertilizer in the CA system, while in the CT system, fertilizers were broadcast during final land preparation; later, seeds were also broadcast. The plot size was 8m x 5m and block-to-block distance was 1.5m and plot to plot distance was 1m.

2.4 Crop Sequence and Crop Variety

The crop sequence was wheat (*Triticum aestivum*) -mungbean (*Vigna radiata)*- T. Aman rice (*Oryza sativa L.*) in both years. The field duration was 112 to 114 days for wheat in 2018 and 2019 and 94 to 96 days for T. Aman rice during the same years, respectively. The selected varieties of the crops were BARI Gom-30 for wheat, BARI Mung-6 for mungbean, and BRRI Dhan75 for rice.

2.5 Land Preparation

Glycel (Glyphosate; Padma Ltd.), a non-selective pre-planting herbicide, was sprayed @ 3.75 L ha-1 on the whole experimental field three days prior to land preparation for each crop to destroy the standing weeds and make the field weed-free. In CA systems, the Versatile Multi-crop Planter was used for seed and fertilizer placement in a 3cm wide tilth soil with 20cm (wheat and rice) and 30cm (mungbean) wide undisturbed soils between crop residues retained in the inter-row. It has the potential advantage of providing suitable conditions for the establishment of various row crops while leaving surface residues in the inter-row area.

CT was used by high-speed rotary tiller with three passes followed by two leveling operations for wheat and mungbean sowing. In the case of rice cultivation, adequate irrigation was done in the plots, and then the soil was puddled with three passes by the power tiller followed by two times laddering.

Table 2. Fertilizer dose (FRG-2012) and application method for different crops

Name of crop	Recommended fertilizer dose (kg ha^{-1})	Application methods
Wheat (BARI Gom-30)	$N_{120}P_{24}K_{60}S_{10}Zn_2B_1$	Two-thirds of urea and the entire amount of TSP, MoP, gypsum, zinc sulfate, and boric acid was applied as basal, whereas one-third of urea was applied as top dressing at the crown root initiation (CRI) stage.
Mungbean (BARI Mung-6)	$N_{18}P_{12}K_{16}S_{3.6}$	The full amount of urea,TSP, MoP, and gypsum fertilizers were applied as basal. TSP was applied by VMP with seeds in SP and broadcasted in the CT system.
Rice (BRRI Dhan75)	$N_{90}P_8K_{35}S_8Zn_1$	One-third of urea and the full amount of other fertilizers were applied as basal, whereas the other two-thirds were applied in two equal splits at 20 and 45 days after transplanting (DAT).

2.6 Fertilizer Rates and Application Methods

The rates of chemical fertilizers for component crops and their application methods in the cropping sequence have been presented in the Table 2.

2.7 Sowing and Transplanting

2.7.1 Sowing of wheat and mungbean

Wheat (BARI Gom-30) seeds were sown on 25 November 2017 and 29 November 2018. In the CA systems, seeds were sown with a VMP machine, maintaining a 20 cm row-to-row distance with continuous seeding. In the CT system, seeds were broadcast. The seed rate of wheat was 110 kg ha^{-1}. The necessary gap filling was done within 10 days of sowing.

The seeds of mungbean (BARI Mung-6) were sown on 22 March 2018 and 4 April 2019. Seeds were sown maintaining a 30 cm row-to-row distance with a VMP machine in the SP system, while seeds were broadcast in the CT system. The seed rate of mungbean was 25 kg ha^{-1}. The necessary gap filling was done within 10 days of sowing.

2.7.2 Transplanting of rice

Thirty-day-old seedlings of T. Aman rice (BRRI Dhan75) were transplanted with 3 seedlings per hill on 2 August 2018 and 25 July 2019. In both years, spacing was maintained at 20cm × 15cm. Necessary gap filling was done within 7 days of transplanting.

2.8 Intercultural Operations

2.8.1 Wheat

Birds were chased up to 12 DAS to keep the optimum wheat population. A post-emergence selective herbicide, L-Maine 72 SL (2,4-D Dimethyl amine), @ 6 ml L^{-1} water was sprayed at 20 DAS to control broad leaf weeds partially. Hand weeding was done at 30 DAS and 32 DAS in 2018 and 2019, respectively, to control weeds and keep those in the same plot. In the 2018 cropping season, no irrigation was applied due to rain at the time of spike initiation and grain filling stage. However, in 2019, two irrigations were provided during the late booting (55 DAS) and early grain filling (72 DAS) stages. No plant protection measures were needed.

2.8.2 Mungbean

Two irrigations were provided at 3 and 24 days after sowing (DAS) every year. One-hand weeding was done at 23DAS, and uprooted weeds were kept in the same plot. Karate (Lambda-cyhalothrin; Syngenta) 2.5EC @ 1.0 ml L^{-1} and Imitaf 20SL (Imidacloprid; Auto Crop Care Ltd.) @ 0.5 ml L^{-1} were sprayed 5 times at 15, 25, 35, 45 and 55 DAS alternately to control mungbean insects.

2.8.3 Rice

A pre-emergence herbicide, Rifit 50 EC (Pretilachlor; Syngenta) @ 2 L ha^{-1} was applied at 5 DAT with stagnant water in the plot to control weed infestation in both the year. Two-hand weeding was done at 25 DAT and 40 DAT. The uprooted weeds were kept in the same plot. Virtako (Chlorantraniliprole 20% + thiamethoxam 20%; Syngenta) @ 75 g ha^{-1} was sprayed two times at 50 DAT and 65 DAT in 2018 and 52 DAT and 65 DAT in 2019 to control rice insects. The rice field was irrigated 10 times in 2018- and 12 times irrigation was provided in 2019, respectively.

2.9 Crop Harvest and Data Collection

2.9.1 Wheat

Wheat was harvested on 16 March 2017 and 22 March 2019. After sowing, two 4 m^2 areas in each plot were demarcated by two quadrates (2 m × 2 m), and all necessary data were recorded from those quadrates. Five plants from each quadrate and 10 plants in total from each plot were pre-identified by a colored thread. Plant height, number of tillers $hill^{-1}$, spike length, and grain $spike^{-1}$ were recorded from those 10 plants. Grain and stover were collected from a 4 m^2 area of each plot and finally converted to t ha^{-1}. The stover of wheat with grain was cut on a height basis according to residue retention levels (30 cm) in each plot and then oven-dried and weighed (expressed as t ha^{-1}). The grain yield was adjusted to 14% moisture content, whereas the straw yield was expressed on an oven-dry basis.

2.9.2 Mungbean

Mungbean was harvested twice on 28 May and 19 June 2018, while on 6 June and 24 June 2019. Like wheat, two quadrates selected two 4 m2 areas from each plot, and all the necessary data were collected from those quadrates. Five plants of each quadrate and 10 plants in total of each plot were pre-identified by a colored thread. Plant populations m^{-2}, plant height, number of pod plant$^{-1,}$ and seeds pod^{-1} were taken from those 10 plants. Seeds and stover were collected from the 2 m^2 area of each plot and finally converted to t ha^{-1}. The pods of mungbean were picked keeping the whole stover (100%) in each plot. The seed yield was adjusted to 14% moisture content, whereas the stover yield was expressed on an oven-dry basis.

2.9.3 Rice

Rice was harvested on 9 November 2018 and 28 October 2019 at full maturity. The data collection procedure for rice was done by following the same procedure as wheat.

2.10 Rice Equivalent Yield (REY)

After rice-based two cropping patterns were completed for two years, mean system productivity was calculated as summation of individual crop yield of each cropping cycle. The productivity of different crops (grain) sequences was compared by calculating their economic rice equivalent yield (REY) using the below equation given by Ahlawat and Sharma (1993):

$$REY\ (t\ ha-1)\ =\frac{Yield\ of\ each\ crop\ (t\ ha-1)\ x\ Economic\ value\ of\ respective\ crop\ (Tk\ t-1)}{Price\ of\ rice\ grain\ (Tk\ t-1)}$$

Where the REY of component crops lentil, maize, and potato was computed according to the above formula:

2.11Statistical Analysis

The mean comparisons were tested by Duncan’s Multiple Range Test (DMRT) using the statistical package Statistix 10 at a 5% level of significance.

3. RESULTS

3.1 Soil Properties

3.1.1 Bulk density

In 2017, the initial soil (0-15 cm) showed a bulk density of 1.45 g cm^{-3} (Table 3). In 2019, tillage significantly influenced the soil bulk density. Strip planting and zero tillage significantly decreased BD (1.41 g cm^{-3}) relative to CT (1.46 g cm^{-3}). On the other hand, Bed planting and PTOS also had significantly lower BD (1.43 g cm^{-3}) (Table 3).

Table 3. Bulk density of the field during 2017 and 2019

Factors & treatments		BD (g cm^{-3})	BD (g cm^{-3})
		2017	2019
Depth	0-15 cm	1.45	1.43
Tillage	CT	-	1.46
	Bed	-	1.43
	PTOS	-	1.43
	Zero	-	1.41
	Strip	-	1.41
LSD (0.05)		-	0.02

3.1.2 Soil pH

In 2017, surface soil (0-30 cm) showed a lower pH (6.93) (Table 5). In 2019, tillage significantly influenced soil pH, TOC, total N, and extractable P, S, B, Fe, and Zn (Table 6). Soil pH was significantly higher in CA (7.02-7.06) than in CT (6.94) (Table 6).

Table 4. The initial soil pH, OC, total N, extractable P, S, B, Fe and Zn content in soils under 0-30 cm depths in 2017

Soil depth (cm)	Sand (gkg^{-1})	Silt (gkg^{-1})	Clay (gkg^{-1})	Texture class	pH	TOC (%)	TN (%)	P (mg kg^{-1})	K meq 100^{-1} g soil	S (mg kg^{-1})	Fe (mg kg^{-1})	B (mg kg^{-1})	Zn (mg kg^{-1})
2017	298	509	193	Silt loam	6.93	0.453	0.110	20.6	0.212	15.6	58.3	0.58	1.50

Table 5. Final soil pH, TOC, total N, extractable P, S, B, Fe, and Zn content in soils under different tillage in 2019

Factors & treatments	**PH**	**TOC (%)**	**Total N (%)**	**Available P (mg kg^{-1})**	**Exchangeable K (meq 100 g^{-1} soil**	**Available S (mg kg^{-1})**	**Available B (mg kg^{-1})**	**Available Fe (mg kg^{-1})**	**Available Zn (mg kg^{-1})**
T_1	7.03	0.87	0.13	27.9	0.21	20.2	0.92	65.4	2.16
T2	7.04	0.77	0.13	25.7	0.20	18.5	0.78	60.7	1.81
T3	7.02	0.83	0.12	25.8	0.21	18.8	0.79	62.0	1.60
T4	7.06	0.87	0.13	25.1	0.21	18.6	0.79	66.0	1.61
T5	6.94	0.64	0.11	21.3	0.19	16.6	0.63	50.7	0.98
LSD (0.05)	0.07	0.12	0.01	3.41	0.01	2.16	0.16	9.17	0.61
Level of significance	*	*	*	*	*	*	*	*	*

(T_1) = strip planting + 30% crop residue; (T_2) = power tiller-operated seeder (PTOS) + 30% crop residue; (T_3) = zero planting + 30% crop residue; (T_4) = bed planting + 30% crop residue; and (T_5) CT =conventional tillage practices.

3.1.3 Total organic carbon (TOC) of soil

The initial soil TOC was 0.453% in 2017 (Table 4). In 2019, soil organic carbon was significantly higher in CA (0.775-0.873%) than that in CT (0.642%) (Table 5).

3.1.4 Total N

In 2017, surface soil TN was 0.110% (Table 4), while in 2019, soil TN was significantly higher in CA (0.123-0.128%) than in CT (0.114%) (Table 5).

3.1.5 Extractable P

In 2017, 20.6 mg kg^{-1} of P was found in the soil (depth 0–30 cm) (Table 4). 2019 saw a considerable increase in the soil extractable P in CA (25.1–27.9 mg kg^{-1}) compared to CT (21.3 mg kg^{-1}). (See Table 5).

3.1.6 Extractable K

The K content of the soil (depth 0–30 cm) in 2017 was 0.212 mg kg^{-1} (Table 4). Extractable K in 2019 was substantially higher in CA (0.203-0.205 mg kg^{-1}) compared to CT (0.193 mg kg^{-1}) (Table 5).

3.1.7 Extractable S

In 2017, 15.6 mg kg^{-1} was found in the soil at a depth of 0–30 cm (Table 4). Table 5 shows that in 2019, Extractable S was substantially greater in CA (18.5-20.2 mg kg^{-1}) compared to CT (16.6 mg kg^{-1}).

3.1.8 Extractable Fe

58.3 mg kg^{-1} of soil initial Fe was found in 2017 at a depth of 0–30 cm (Table 4). 2019 saw a significant rise in extractable Fe in CA (60.0–63.0 mg kg^{-1}) compared to CT (50.7 mg kg^{-1}) (Table 5).

3.1.9 Extractable B

B 0.58 mg kg^{-1} was found in the soil (depth 0–30 cm) in 2017 (Table 4). In 2019, Extractable B was notably greater in CA (0.778–0.920 mg kg^{-1}) compared to CT (0.625 mg kg^{-1}) (Table 5).

3.1.10 Extractable Zn

At 0–30 cm depth, the initial zinc status was recorded in 2017 at 1.50 mg kg^{-1} (Table 4). 2019 saw a considerable increase in extractable zinc levels in CA (1.60–2.16 kg^{-1}) compared to CT (0.98 mg kg^{-1}) (Table 5).

3.2 Effect Conservation Agricultural Practices on Yield-Contributing Characters and Yield

3.2.1 Wheat

Conservation agriculture significantly influenced the yield and yield-contributing parameters of wheat. Data on yield contributing parameters are presented in Table 6. All the yield-contributing parameters like spike m^{-2}, panicle length, grain spike^{-1}, and 1000 grain weight were numerically higher in machinery-based tillage systems than in conventional practice (Table 6). Similarly, grain as well as straw yield was comparatively high in the CA-based tillage option (Table 9). In 2017, the wheat yield was about 12.8%, 11.6%, 9.8%, and 4.9% higher in Strip, PTOS, Bed, and Zero, respectively, than in CT (farmer’s current practice) (Table 9). On the other hand, the wheat yield was about 12.4%, 11.9%, 11%, and 10.8% higher in Bed, Strip, PTOS, and Zero, respectively, than in CT (farmer’s current practice) in 2018 (Table 9). Meanwhile, the two-year average yield of wheat was about 12.5%, 11.6%, and 8.7% higher in Strip, PTOS, Bed, and Zero, respectively, than in CT (Table 9). A similar trend was observed in straw yield and wheat grain yield. Here, the yield of straw is higher in conservation agriculture than in conventional methods (Table 9).

3.2.2 Mungbean

Yield and yield contributing characteristics of mungbean were significantly influenced by conservation agriculture. Consequently, pod/plant, seeds/pod, 1000 seed weight and seed yield were influenced significantly (Table 7). The maximum pods/plant was recorded in CA systems with 30% straw retention, statistically identical to each other’s with 30% straw retention. The minimum pods/plant was found from conventional with no straw retention. Similarly, maximum seeds/pod, 1000 seed weight, and seed yield were recorded from CA systems with 30% straw retention. Mungbean yield in conservation agriculture was 17.5–22.2% higher in 2017 and 11.3-20% higher in 2018 than conventional methods (Table 9). It was specifically observed that the yield of mungbean was statistically different, but all were similar in conservation agriculture practices. The two-year average yield of mungbean also had the same trend, i.e., the yield in conservation agriculture was 14.9-22.3% higher than the conventional method (Table 9). A similar trend was found in straw and grain yields (Table 9).

Table 6. Yield contributing characters of wheat as influenced by tillage

Factors & treatments	Plant height (cm)			Plant population m^{-2}			Spike length (cm)			Grain panicle^{-2}			TGW		
	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean
Strip + 30% residue	92.9	97.9	95.4	302	296	299	9.48	10.2	9.85	45.6	56.9	51.2	46.3	48.7	47.6
PTOS + 30% residue	92.9	98.6	95.8	330	295	312	9.35	10.0	9.70	46.4	57.0	51.7	46.6	48.9	47.8
Zero + 30% residue	91.8	96.5	94.1	305	304	304	9.33	9.23	9.30	44.5	51.6	48.0	46.1	48.9	47.5
Bed + 30% residue	94.6	98.1	96.3	303	303	303	9.62	10.2	9.90	46.9	57.0	51.9	47.6	49.2	48.4
CT	91.6	98.4	95.0	303	305	304	9.23	8.83	9.03	43.9	45.0	44.5	45.8	48.0	46.9
LSD (0.05)	0.40	1.38	0.78	10.2	6.33	7.74	0.08	0.36	0.17	0.86	0.48	0.67	0.34	0.76	0.43
Level of significance	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

Table 7. Yield contributing characters of mungbean as influenced by tillage

Factors & treatments	Plant height (cm)			Plant population m^{-2}			Pod plant^{-2}			Grain panicle^{-2}			TGW		
	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean
Strip + 30% residue	54.0	56.4	55.2	28.1	36.3	32.2	18.7	19.3	19.0	10.9	9.90	10.4	47.4	48.7	48.1
PTOS + 30% residue	54.9	56.3	55.6	28.5	35.5	32.1	18.8	19.0	18.9	11.0	9.92	10.5	47.5	48.9	48.2
Zero + 30% residue	52.7	54.2	53.5	27.1	31.0	29.1	18.9	18.2	18.6	10.7	9.52	10.1	47.3	48.5	47.9
Bed + 30% residue	55.0	56.6	55.8	29.3	35.5	32.4	19.2	19.5	19.4	10.7	10.2	10.5	48.4	49.2	48.9
CT	51.7	55.5	53.6	24.8	26.7	25.8	18.5	17.2	17.9	9.9	9.43	9.65	47.2	48.1	47.7
LSD (0.05)	2.15	1.55	1.24	2.58	3.89	1.25	0.58	0.83	0.64	0.75	0.51	0.44	0.83	0.44	0.46
Level of significance	*	*	*	*	*	*	ns	*	*	*	*	*	*	*	*

Table 8. Yield contributing characters of T. aman rice as influenced by tillage

Factors & treatments	Plant height (cm)			Plant m^{-2}			Panicle length (cm)			Grai panicle^{-2}			TGW		
	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean
Strip + 30% residue	128	128	128	238	244	241	25.0	25.5	25.3	138	145	142	23.5	23.9	23.8
PTOS + 30% residue	128	128	128	245	245	245	24.9	25.4	25.2	138	145	142	23.4	24.0	23.7
Zero + 30% residue	126	127	127	237	244	240	24.6	24.4	24.5	137	143	140	24.5	23.7	24.1
Bed + 30% residue	129	129	129	240	248	244	24.8	25.5	25.2	137	145	141	23.0	24.1	23.6
CT	128	130	129	242	248	245	24.6	25.1	24.9	136	143	140	27.1	24.0	25.6
LSD (0.05)	2.01	2.28	1.82	8.48	3.61	4.95	0.45	1.14	0.62	4.55	4.00	2.48	5.04	0.38	2.53
Level of significance	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

Table 9. Grain and straw yields of wheat, mungbean and T. aman rice as influenced by tillage

Factors & treatments	Wheat grain (t ha^{-1})			Wheat straw (t ha^{-1})			Mungbean grain (t ha^{-1})			Mungbean straw (t ha^{-1})			T. Aman grain (t ha^{-1})			T. Aman straw (t ha^{-1})		
	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean
Strip + 30% residue	3.69	4.05	3.88	5.42	4.61	5.00	1.54	1.36	1.46	2.34	2.98	2.68	4.57	4.67	4.60	5.52	5.03	5.30
PTOS + 30% residue	3.65	4.02	3.85	5.34	4.72	5.03	1.54	1.33	1.45	2.49	2.97	2.73	4.61	4.67	4.63	5.78	5.02	5.43
Zero + 30% residue	3.43	4.01	3.75	5.02	4.59	4.83	1.48	1.28	1.39	2.40	2.93	2.66	4.54	4.53	4.53	5.58	4.99	5.30
Bed + 30% residue	3.59	4.07	3.85	4.89	4.67	4.78	1.54	1.38	1.48	2.27	3.02	2.64	4.54	4.72	4.63	5.44	5.08	5.25
CT	3.27	3.62	3.45	4.39	4.34	4.38	1.26	1.15	1.21	2.06	2.60	2.31	4.54	4.70	4.63	5.38	5.45	5.40
LSD (0.05)	0.30	0.31	0.16	0.58	0.25	0.27	0.11	0.13	0.06	0.23	0.25	0.14	0.18	0.38	0.21	0.59	0.42	0.25
Level of significance	*	*	*	*	*	*	*	*	*	*	*	*	ns	ns	ns	ns	ns	ns

Table 10. System productivity of Wheat - Mungbean - T. aman rice system as influenced by tillage treatments

Factors & treatments	Wheat REY (t ha^{-1})			Mungbean REY (t ha^{-1})			T. Aman yield (t ha^{-1})			Systems REY (t ha^{-1})		
	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean
Strip + 30% residue	5.42	4.61	5.00	3.41	3.02	3.23	4.53	4.67	4.60	13.4	12.3	12.8
PTOS + 30% residue	5.34	4.72	5.03	3.43	2.96	3.18	4.52	4.67	4.58	13.3	12.3	12.8
Zero + 30% residue	5.02	4.59	4.83	3.28	2.85	3.05	4.56	4.53	4.55	12.9	12.0	12.4
Bed + 30% residue	4.89	4.67	4.78	3.43	3.13	3.25	4.49	4.72	4.60	12.8	12.5	12.7
CT	4.39	4.34	4.38	2.80	2.62	2.73	4.50	4.70	4.60	11.7	11.6	11.7
LSD (0.05)	0.58	0.25	0.27	0.25	0.18	0.13	0.39	0.38	0.31	0.56	0.58	0.48
Level of significance	*	*	*	*	*	*	ns	ns	ns	*	*	*

Table 11. Profitability of Wheat-Mungbean-T. Aman production under different tillage practices during 2018-19

Factors and treatments	Gross return (Tk ha^{-1})			Total variable cost (Tk ha^{-1})			Gross margin (Tk ha^{-1})			BCR		
	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean
Strip + 30% residue	303320	314270	314315	194845	186079	190462	108475	128191	123853	1.56	1.69	1.65
PTOS + 30% residue	301990	311810	312680	193525	186300	189913	108465	125510	122767	1.56	1.67	1.65
Zero + 30% residue	293570	304870	304800	194845	185931	190388	98725	118939	114412	1.51	1.64	1.60
Bed + 30% residue	299290	317380	313775	196165	185458	190812	103125	131922	122963	1.53	1.71	1.64
CT	274240	292240	288620	194680	194368	194524	79560	97872	94096	1.41	1.50	1.48

Input: Urea: 22 Tk kg^{-1}, TSP: 27 Tk kg^{-1}, MoP: 20 Tk kg^{-1}, gypsum: 10 Tk kg^{-1}, zinc sulphate: 220 Tk kg^{-1}, boric acid: 150 Tk kg^{-1}, tillage cost:10000 Tk ha^{-1}, irrigation (1 time): 1000 Tk ha^{-1} and labour: 500 Tk day^{-1} (8 hours), wheat seed: 55 Tk kg$^{-1;}$ Output: wheat grain: 25Tk kg^{-1}, wheat stover: 1 Tk kg^{-1}, mungbean: 60Tk kg^{-1}, Rice grain: 25Tk kg^{-1}, Rice strawr 2Tk kg$^{-1,}$

3.2.3 T. aman rice

It was revealed that there was no significant difference among the treatments regarding crop yield and yield parameters. However, rice responded well to tillage machinery-based seeding systems over conventional ones. All the yield-contributing parameters, like spike m^{-2}, panicle length, grain spike^{-1}, and grain weight, were numerically more or less equal in machinery-based tillage systems and conventional practice (Table 8). Similarly, grain and straw yield were also more or less equal in the seeder-based tillage option and CT. Among the seeding machinery, in 2017, the PTOS system produced the highest grain yield (4.61 t ha^{-1}), followed by the Strip system (4.57 t ha^{-1}), the Bed Planting System (4.54 t ha^{-1}), the Zero system (4.54 t ha^{-1}), and conventional practice (4.54 t ha^{-1}) (Table 9). It was identical with each other's tillage options. In 2018, the bed planting system produced the highest grain yield (4.72 t ha^{-1}), followed by the strip system (4.67 t ha^{-1}), the PTOS system (4.67 t ha^{-1}), the zero system (4.53 t ha^{-1}), and conventional practice (4.70 t ha^{-1}). These tillage options were also identical to each other. In terms of average yield, the PTOS system produced the highest grain yield (4.63 t ha^{-1}), followed by the bed planting system (4.63 t ha^{-1}), the strip system (4.60 t ha^{-1}), the zero system (4.53 t ha^{-1}), and conventional practice (4.63 t ha^{-1}), which were identical to each other's tillage options (Table 9). There was no difference in yield or other parameters between conservation agriculture and conventional methods for rice. Statistically, all methods yielded similar results, although mathematically, the yield was different (Table 9).

3.3 Relative Equivalent Yield (REY) and System Productivity

3.3.1 Wheat REY

Different tillage options significantly affected wheat REY for both the years and their mean (Table 10). The highest and identical Wheat REY was obtained from CA (Strip +30% residue, PTOS +30 % residue, Zero +30 % residue and Bed planting +30 % residue) treatments than CT in both the years and their mean (Table 10).

3.3.2 Mungbean REY

From the results presented, it appears that the mean and individual year REY of mungbean varied significantly due to different tillage (Table 10). About 17.1% to 22.4% mean mungbean yield was increased considerably by CA over CT in 2018. Whereas 8.6% to 19.4% mungbean REY increased in CA compared to CT in 2019 (Table 10). The Mean REY of mungbean for two years also showed a similar trend as in 2018 and 2019; here, a significantly higher mean mungbean REY was obtained from CA than CT (Table 10).

3.3.3 System productivity

The system productivity of the wheat-mungbean-T. Aman rice pattern has been expressed as rice equivalent yield (REY). In the cropping patterns of wheat- mungbean- rice, REY increased significantly under the conservation agriculture system compared to the conventional system (Table 10). Here, conservation agriculture yields were 9.7 to 14.4% higher than conventional methods in 2018 and 2.7 to 7.4% higher in conservative agriculture in 2019 than conventional methods. The two-year average rice equivalent yield increased by 6.3 to 9.9% under conservation agriculture compared to conventional methods. The REY followed the increasing order of Strip planting> PTOS > Bed planting > Zero planting> CT (Table 10).

3.4 Economic Analysis

Like yield and yield parameters, higher economic return was achieved from mechanized cultivation with reduced cultivation cost, contributing to a higher gross margin and BCR than the conventional system (Table 11). Many opportunities from BARI seeding machinery, like tilling, seeding, and seed covering at a single pass, reduced the operational cost tremendously. However, the cost and return analysis of the whole cropping pattern showed that the height gross return (303320 Tk.), gross margin (123853 Tk), and benefit-cost ratio (1.83) were obtained from the treatment strip tillage option during the 2017-18 and 2018-19. All CA treatments like Strip, PTOS, Zero, and Bed planting+30% crop residue showed more or less equal gross return, gross margin, and BCR compared to CT. Regarding the parameters mentioned above, the economic performance of the conventional tillage option was found to be lower than others (Table 11).

4. DISCUSSION

The grain yields of wheat and mungbean increased by 13% and 9% in SP compared to

CT, respectively. Wheat straw and mungbean stover yields showed similar trends, whereas straw yields of rice were insignificant in SP and CT. This is consistent with the findings of Hossain et al. (2019), who showed that upland crops like mungbean (1.25 t ha^{-1} in SP and 1.02 t ha^{-1} in CT) and Salahin et al. (2017) for wheat (4.61 t ha^{-1} in SP and 4.33 t ha^{-1} in CT), who found that minimum tillage provided higher yields than CT. This may be due to improved soil structure and better use of nutrients and water suitable soil temperature and moisture conditions and minimum soil disturbance. Also, the SP system can increase nutrient uptake by row sowing, which optimizes conditions suitable for root uptake of fertilizer-supplied nutrients, resulting in higher crop yields. Gathala et al. (2015) also reported that CT provided a higher rice yield (mean 4.67 t ha^{-1} in 4 years) compared to SP (4.62 t ha^{-1}), although the difference was not significant.

In this study, CA provided 9%, 6%, and 11% higher grain yields of wheat, mungbean, and rice than CT, while biomass yield followed the same trend. This finding is supported by the findings of Rashid et al. (2019), Rashid et al. (2019) reported a higher mungbean yield of 1.30 t ha^{-1} from plots treated with 100% residue retention compared to 50% residue retention (1.23 t ha^{-1}) during the third cropping cycle. They also showed that 100% residue retention gave better rice yield (5.56 t ha^{-1} and 5.83 t ha^{-1}) than SP and CT with 50% residue (5.12 t ha^{-1} SP and 5.63 t ha^{-1}), respectively. done) from CT. A similar trend of increased grain and residue yields was observed by Salahin et al. (2017a), who found that three component crops containing 30% residues of rice (17–23%), mungbean (1–3%), and wheat (8–97%) did not increase yield or incorporation compared to one to two crop residues. Retention of crop residues enhances decomposition and mineralization by microorganisms that convert crop residues into organic matter-stable humus (Salas et al., 2003). Also, residue addition improves soil fertility and water availability and creates a suitable rooting environment by improving soil structure that facilitates better crop establishment.

The present study showed that the mean system REY of the pattern was increased by 3% by SP compared to CT, although the difference was not significant in the second year. Also, the REY of the system was about 8% higher in CA retention than in CT. These findings were consistent with those of Salahin et al. (2021. Salahin et al. (2021) showed that the three-year mean REY was highest (20.4 t ha^{-1}) in SP and lowest (16.9 t ha-1) in CT, where HR retained 0.5 t ha^{-1} more REY than LR retained rice-lentil. Provided a wheat-jute system. Rashid et al. (2019) also showed that, with full residue incorporation, SP provided a higher system REY (20.8 t ha^{-1}) than CT (19.7 t ha^{-1}) from the third cropping cycle of the maize-mung bean-rice pattern. They found higher system REY in both SP and CT systems than in plots that included 50% of the residue and in plots that included full residue. According to Jat et al. (2021), minimal soil disturbance (permanent bed + residue) increased 3-year system crop yield (4.3 t ha^{-1}, rainfed and mustard over CT without residue retention (3.9 t ha^{-1}).

A two-year experiment significantly affected the REY system of the wheat-mungbean-rice system. In this study, Tillage practices, such as reduced tillage and CT, also had significant effects ($p > 0.05$) on wheat yield and system REY but not on rice yield and were found to be higher in SP than CT. Memon et al. (2018) found similar results in their study. They found that tillage practices, such as reduced tillage and CT, had no significant effect ($p > 0.05$) on grain yield during the rice growing season. Mahajan et al. (2002) reported that CT and ZT produced similar crops if weeds were controlled, and crop stands were equal. A similar result was reported by Singh and Kaur (2012) that crop yield under ZT may be equivalent or slightly lower than that under CT but not significantly different; therefore, ZT practices had lower tillage costs, and crops under ZT compared to CT can be sown earlier than this.

Rice grain yield increased up to 12% with the long-term practice of CA (Bell et al., 2019). Haque et al. (2016) conducted an experiment over three years comparing non-puddle and puddle rice in two locations of the Rajshahi region in monsoon season. They found that non-puddle planting did not reduce rice yield compared to puddle planting. Sharma et al. (2005) compared rice transplanted after one pass in wet soil to rice transplanted after full soil pudding, involving different tillage operations and yielding similar rice yields. Islam et al. (2014) showed that grain yield in MT-untreated rice seedlings was similar to puddle transplanting CT, indicating that tillage intensity can be reduced to establish seedling rice without sacrificing yield. Memon et al. (2018) reported that the highest average yield was recorded in reduced tillage with 60% wheat straw addition (8274 kg ha^{-1})

and the lowest in CT with no straw (7172 kg ha^{-1}). In Tillage systems, such as CA and CT, the rice yield is slightly higher or equal in CT than CA but significantly higher REY of wheat and mungbean in CA than in CT. However, the system recorded significantly higher REY in CA systems than in CT. Naudin et al. (2010) reported that NT and residue mulching effectively increase crop yield. Follett et al. (2005) found that increased SOM under ZT promoted higher crop production. Steiner (2002) found that conservation tillage improves soil fertility, water use efficiency, and timely planting to increase yields. Similar results obtained by Mandal et al. (2004) found that the addition of rice straw to organic manure improved soil moisture, increased microbial activity, and increased wheat grain yield compared to results from residue removal or burning. Singh (2010) found similar crop yields with permanent residue retention under ZT compared to CT with and without mulching (Singh et al. 2005).

Increased residue retention relative to farmers ‘current practice, in combination with CA (Conservation Agriculture), increased soil fertility status over two years (after six crops). The increase in soil fertility can be attributed to increasing the conversion of plant roots and residues to SOC due to the decrease in soil disturbance by CA. It was found that increased residue retention with minimum tillage significantly improved soil BD at 0-15 cm depth. Alam et al*.* (2018) found that the lowest BD at this site was in the HR retention and varied among the different tillages. The lowest BD (1.37 g cm-3) was found in SP HR, and the highest was in CT LR (1.49 cm-3) after 14 crops. A similar trend we also found after six crops the lowest BD (1.41-143 g cm-3) was in CA and the highest was in CT (1.46 g cm-3). Ghuman and Sur (2001) reported the bulk density in the surface layer (0-10 cm) was significantly lower by 0.05 g cm-3 in minimum tillage with residue retention compared to minimum and conventional tillage without residue.

Minimum soil disturbance showed significantly higher soil pH after six crops. Alam et al. (2018) found that the pH at this site was higher than in the current study and unaffected by residue and tillage after 14 crops, but the increasing trend was similar. On the other hand, SOC and TN were higher in SP than in CT, respectively, after 6 crops. The tillage practices and residue retention levels affected the SOC content in the soils of this site, and the SPHR treatment had a significantly higher SOC content than the other treatment combinations after 14 crops (Alam et al*.,* 2018).

The frequency and intensity of tillage had a significant influence on the disintegration and decomposition of organic matter, including residues (Singh and Ladha, 2004). Minimum soil disturbance resulted in higher SOC content in surface layers with residue incorporation. Minimum soil disturbance had 3.86-31% higher organic matter than conventional tillage (Balota et al*.,* 2004). Significantly higher SOM in 0-10 cm soil depth was found under minimum soil disturbance compared to the conventional tillage system in Uzbekistan (Jat et al*.,* 2012). Generally, in no-till, reduced till and strip-till systems where soil destruction is reduced, and residues are present on the surface or near the surface results in higher SOM than the residue incorporated into the soil as in the case of conventional tillage (Marahatta et al*.,* 2014).

Among the tillage practices, SP had the greatest improvement on the TN status than CT and HR retention improved the TN status compared to the LR retention, and the TN values ranged from 0.049 to 0.075% after 14 crops (Alam et al*.,* 2018) in these soils. The current study found a similar increasing trend but higher TN status after 30 crops where SP showed significantly higher TN than CT. Thomas et al*.,* (2007) recorded that the TN of 10 cm depth under minimum tillage was 21% higher than for conventional tillage. Compared to initial year, TN content (0-30 cm) improved by 21.3% on minimum soil disturbance with straw cover while it decreased by 11.9% on traditional tillage with straw removal after 15 years of experiment (Wang, 2008).

It was observed that available P, Zn, B and Fe were significantly influenced by CA where CA showed significantly higher available nutrients than CT. After 16 years of experimentation, the available P under minimum soil disturbance with straw retention (NTSC) was 97.5% higher than under conventional tillage with straw removal (TTSR) in the 0-5 cm soil layer (Wang, 2008). The topsoil accumulation of P in NTSC is attributed to the limited downward movement of particle-bound P in minimum tillage soils and the upward movement of nutrients from deeper layers through nutrient uptake by roots (Urioste et al*.,* 2006). Duiker and Beegle (2006) reported higher extractable P levels in minimum tillage than in conventionally tilled soil, and this is due to reduced mixing of the fertilizer P with the soil, leading to lower P-fixation (Marahatta et al*.,* 2014). The present study found that exchangeable K was significantly influenced by CA systems where CA showed significantly higher exchangeable K than CT. Minimum tillage with residue retention had increased K availability on the surface soil where the density of crop roots was higher (Franzluebbers and Hons, 1996).

5. CONCLUSION

The yield of component crops in an intensive wheat-mungbean-rice cropping pattern was achieved under different tillage options with 30% straw retention. From a two-year study, it was revealed that strip tillage systems, power tiller operated seeder (PTOS), zero tillage, and raised bed with 30% straw retention were affected in terms of yield and yield components for all three crops, ultimately producing maximum yield due to their increased photosynthesis and border effect. For the sustainable yield and benefit of residue retention in intensified R-W systems in Bangladesh, the CA machinery is very effective, so it needs a massive extension. Despite the many advantages of seeding machinery, some efforts should still be taken before its dissemination to a new area. The availability of parts, the development of local service providers, the skillfulness of the operators, and the positive mindset of the people should be considered for expansion in a new area.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

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

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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