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RESEARCH ARTICLE

Land Use, Productivity, and Profitability of Traditional Rice–Wheat System Could be Improved by Conservation Agriculture

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Abstract: Power tiller-driven plow tillage and crop residue exclusionary Traditional Agriculture practices are expensive, labor demanding, soil damaging, and eco-unfriendly. Over the last several years, pursuits of crop production through sustaining the productive capacity of soils, and environmental quality, have raised concern to adopt Conservation Agriculture worldwide. Single tillage combined with herbicides and crop residue retention principles of Conservation Agriculture are being developed. Between 2016–2017 and 2017–2018, a two-year on-farm experiment was done in Bangladesh. We practiced two crop establishment methods; Traditional Agriculture: Plow tillage followed by three manual weeding without residue preservation of previous crop and Conservation Agriculture: Pre-plant herbicide + single tillage + pre-emergence herbicide + post-emergence herbicide; under rice–wheat and rice–wheat–mungbean systems. Data reveal that the Conservation Agriculture was more cost-effective crop establishment technique than Traditional Agriculture in rice, wheat, and mungbean by increasing the ratio of benefit to costs by 24.3%, 35.7% and 48.8%, respectively, with a savings in tillage operations (66.3%, 58.1%, and 57.6%, respectively), weeding expenditures (59.2%, 24.5%, and 42.2%, respectively), and manpower requirements (25.1%, 27.2%, and 31.3%, respectively). This has resulted in an increase of 32% productivity of rice–wheat–mungbean systems with the yield advantage of 16%, 31% and 37% in rice, wheat and mungbean, respectively. When mungbean was added, the rice–wheat system's productivity rose by 43%. The rice–wheat–mungbean system under Traditional Agriculture had the highest land utilization efficiency (99.45%), followed by Conservation Agriculture (92.05%), which expanded the scope to include additional crops into rice–wheat–mungbean system. Moreover, the Conservation Agriculture had a 59.7% greater production efficiency than Traditional Agriculture, where the rice–wheat–mungbean system having the highest production efficiency (53.00 kg^{-1} ha^{-1} day^{-1}), followed by the rice–wheat system (45.57 kg^{-1} ha^{-1} day^{-1}).

Keywords: Plow tillage; Single tillage; Herbicides; Crop residues; Land utilization efficiency; Production efficiency; Rice equivalent yield

1. Introduction

Rice–Wheat (R–W) is the predominant cropping pattern in Bangladesh, occupying around 0.8 million hectares of land [1]. In this system, rice is cultivated during the rainy

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season (July~October) while wheat is cultivated during the dry season (November~March). In April and May, the land sits fallow for two months. It has been shown that cereal–cereal sequences such as rice–wheat are more stressful on soil resources than cereal–legume sequences [2]. It is also suggested that the R–W system decreases system output owing to decreasing soil organic matter, reduced soil fertility, the development of nutrient imbalances, and ineffective fertilization techniques [3]. The R–W system is reported to extract more nitrogen, phosphorus, and potassium than rice–rice (R–R) system. It is possible to plant a crop with a short life cycle of 60~65 days, such as mungbean, in rice–wheat–mungbean (R–W–M) combination, therefore making a substantial contribution to food and nutrition security [4]. Additionally, by including mungbean (M), the nitrogen economy of the succeeding cereal crop may be enhanced in traditional R–W system.

Traditionally in Bangladesh, almost all crops are cultivated via intensive plowing after the complete removal of previous crop. Prior to manual transplantation, the rice field is traditionally saturated. On the other hand, non-rice crops e.g., wheat, mungbean etc. are grown on heavily pulverized dry soil. The sustainability of agricultural output is called into doubt by these traditional practices. Intensive plowing degrades soil structure, depletes soil organic matter (SOM), and increases agricultural labor and fuel requirements for plowing, as well as the overall production cost. In addition, it delays the establishment of subsequent crops, resulting in decreased yields [5]. Also, there are more worries about a lack of farm workers because of lower salaries and people moving to cities [6]. Because of this, there is a lot of demand for labor and other low-input systems that can produce more for less capital. Without a new and more long-lasting improvement in agricultural productivity, the supply of food would have a hard time keeping up with the fast-growing demand caused by a fast-growing population. Conservation Agriculture (CA) could be a way to deal with of these problems [6]. The CA is founded on the core principles of minimal soil plowing with herbicides, residue retention from prior crops, and judicious crop rotation [7]. Combining single tillage with crop residues may enhance the physical, chemical, and biological properties of the soil, promote timely planting, save labor, fuel, and equipment costs, and preserve profitability [8]. However, global statistics indicate that technology may be able to assist Bangladesh's agriculture in addressing labor and energy problems.

In CA, numerous solutions for minimal soil disturbance exist, including single tillage (ST), which disturbs the soil surface by 15~25% with a plow ridge of 6 cm × 4 cm depth and width [5]. Farmers are interested in using ST to produce crops since it lowers cultivation expenses, prevents soil deterioration, and conserves water without sacrificing production. However, the ST has been rebuked for its ineffective weed management. By contrast, typical heavy tillage efficiently smothers weeds and their seeds deep into the soil [9]. In ST, to eradicate existing weeds and their viable seeds, a non-selective herbicide in a sequence of a pre-emergent and post-emergent herbicide must be applied [10]. Farmers are increasingly using herbicides to manage weeds because of their quicker effectual actions with a cheaper cost to overcome the labor shortage caused by high salaries during peak demand seasons [11]. Earlier study proved that herbicide ensured constant and efficient weed control and resulted in a greater yield as compared to manual weeding [12]. However, weed resistance to herbicides may develop with frequent usage of herbicides with the same chemical that increase weed control's difficulty [13]. Furthermore, herbicide longevity in the soil and their toxicity on the subsequent crop(s) are major problems. Due to growing pricing and environmental concerns, the supply of acceptable herbicide compounds has diminished, and highlight the importance of implementing an integrated approach to managing weeds to ensure a sustainable ST. Residues of previous crops and crop intensification have already been highlighted as agronomic options for weed control in ST practice integrated with herbicides [14].

Previous research has shown that crop residue preservation accelerates system productivity through improving soil health and controlling weeds [13]. Hence, it crucial to preserve resides of previous crops under R–W systems, which are typically removed from the fields. Although multiple studies have been done on the combined impacts of ST and crop residues to enhance the system productivity, no large-scale study has been conducted in Bangladesh on this technique under the R–W–M system. The potential for R–W–M systems using the advantages of CA principles has generated considerable attention in Bangladesh. Thus, the present two-year research used R–W–M systems in conjunction with the low and single tillage and preserving residues to determine a sustainable crop production practice.

2. Methodology

2.1 Location and Tenure

The site of this on-farm experiment located at the Bhungnamary village of Gouripur sub-district under Mymensingh district in Bangladesh (24.4514°N, 90.2411°E) (Figure 1). This two-years longer experiment was conducted during 2016–2017 and 2017–2018 successive years.

Figure 1. Site of the on-farm experimentations

2.2 Soil and Climate

The field was a medium-high piece of land that was free of flooding and had a sandy clay loam soil texture (sand: silt: clay@52: 20: 28). The pH of the soil was 6.81 with N, P, K, and S content of 1100 ppm, 16.3 ppm, 0.32 ppm and 14.1 ppm, respectively.

The average annual rainfall in the region is 172 mm, with around 95% falling between May and September (Figure 2). Total rain was extreme during June~October and lowest during November~March in both years. The highest temperature in April~May was sometimes over 33 °C, while the low temperature in January was about 12 °C. In both years, the months of October~November and March had the highest number of sunshine hours.

2.3 Experimental Materials, Treatments, and Design

Rice, wheat and mungbean were grown during the time of June~October, December~March, November~January and April~May, respectively in two successive years. The following two crop establishment methods under two cropping sequence were imposed in RCBD manner and were replicated four times.

(A) Crop establishment methods

i. Traditional Agriculture (TA): Plow tillage (PT) followed by three manual weeding (at 25 days, 45 days, and 65 days after planting) without residue preservation of previous crop;

ii. Conservation Agriculture (CA): Pre-plant herbicide (PPH) prior to single tillage (ST), followed by pre-emergence (PEH) and post-emergence herbicides (POH) with 50% anchored residue of previous crop (height basis).

Here, we used glyphosate (3.7 L) and pendimethalin (2.5 L) as PPH and PEH for all crops, while, ethoxysulfuron-ethyl (100 g), carfentrazone-ethyl+isoproturon (1.25 kg), and fenoxaprop-p-ethyl (650 mL) as POH for rice, wheat, and mungbean, respectively. The rate of herbicides application was active ingredient per hectare basis. The PPH was applied three days before in ST operation. The PEH and POH were applied three and 25 days after planting. Only ethoxysulfuron-ethyl was sprayed in water logging conditions, and the rest were applied at field capacity moisture level. Herbicides were applied using a hand-operated knapsack sprayer.

Planting was done without keeping previous crop residues in the TA treatment. Rice, wheat, and mungbean were harvested at 50% height of plant anchored from the ground label in CA.

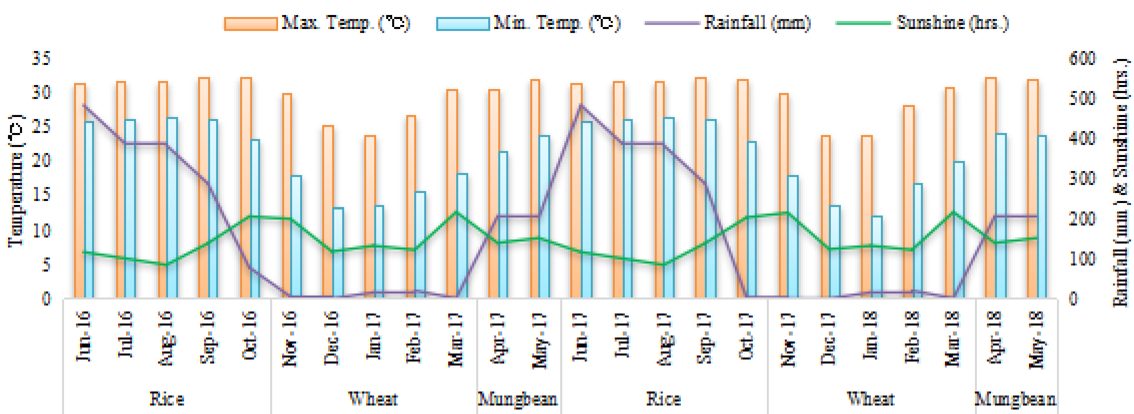

Figure 2. Weather conditions of the experimental site

(B) Cropping systems

i. Traditional Agriculture (TA): Rice–Wheat (R–W) system;

ii. Conservation Agriculture (CA): Rice–Wheat–Mungbean (R–W–M) system.

2.4 Tillage and Planting Practice

The PT had finished with four plowings and cross plowings in each 9 m × 5 m plot, done by a two-wheel tractor (2WT). A Versatile Multi-crop Planter (VMP) machine finished the ST. Here, each row of 6 cm × 5 cm width and depth was made at the row spacing of the respective crop.

Summer rice (BRRI hybrid dhan6) seedlings were transplanted in the dully prepared puddled land in PT. Whereas, in ST, after the VMP operation, the field was flooded with about 5 cm of water for 24 hours to soften the strips enough to transplant single rice seedlings per hill. Line seeding of wheat (BARI Gom 26), and mungbean (BARI Mung 6) was done using VMP in CA and by manually in TA on the same day.

2.5 Intercultural Operations

We applied N, P, K, S and Zn fertilizers in the form of prilled-urea, triple super phosphate, muriate of potash, gypsum and zinc sulphate monohydrate the crop field at the rate presented in the Table 1. Prior to planting in all crops, the whole P, K, and S were broadcast. At 2, 4, and 6 weeks after rice transplantation, N was administered in three splits. In wheat, two-thirds of the nitrogen was applied during final plowing and the remainder during the 3 weeks after seeding (WAS). Mungbean was sown with the full dose of N.

Table 1. Fertilizers used in the experimentations

Crops	Fertilizers (kg ha^{-1})				
	N	P	K	S	Zn
Rice	120	22	35	11	3
Wheat	90	26	33	20	2
Mungbean	20	20	15	10	1

Rice did not require additional irrigation due to adequate rainfall. Three irrigations at 3 WAS, 8 WAS, 11 WAS were used in wheat. Two irrigations with adequate drainage were performed on the mungbean at 4 WAS. Appropriate plant protection measures were undertaken throughout the crop growing season in accordance with the requirements [15,16].

2.6 Measurements and Analysis

2.6.1 Yield Attributes and Yield

Prescribed data on rice, wheat and mungbean have been transcribed from randomly selected ten plants at 80% maturity. All crops were reaped from a three-by-one meter space in three different locations within each plot. At a moisture level of 14%, the yield (t ha^{-1}) was computed.

2.6.2 Rice Equivalent Yield (REY)

The REY was computed to compare system performance by converting non-rice crop yields to rice equivalent yield on a pricing basis using the Equation (1). The REY of all individual crops was summed together to calculate system productivity [17].

$$REY = \sum Yx\left(\frac{Px}{Pr}\right) \quad (1)$$

Here, *Yx* and *Px* denote the yield (t ha^{-1}) and price (US\$ t^{-1}) of crop 'x', respectively, while *Pr* is the price (US\$ t^{-1}) of rice.

2.6.3 Land Utilization Efficiency (LUE)

The LUE was calculated as the sum of the growth duration days of all crops in the cropping sequence by 365 days [18] as of Equation (2).

$$LUE = \frac{\sum Dc}{365} \times 100 \quad (2)$$

Here, ∑Dc denotes the sum duration (days) of all crops in the system.

2.6.4 Production Efficiency (PE)

The PE was computed by dividing the overall economic yield on a rice equivalent basis by sum of the growth duration days of all crops [18] as of Equation (3).

$$PE = \frac{REY}{\sum Dc} \quad (3)$$

Here, the REY and ∑Dc denote the rice equivalent yield and the sum duration of all crops in the system

2.6.5 Economics

The gross return, gross margin, and benefit cost ratios were calculated using the partial budgeting approach [19]. The data on crop measurement parameters for each year were analyzed statistically using the International Rice Research Institute developed STAR (Statistical Tool for Agricultural Research) software [20], and mean comparisons were done using DMRT at the 5% level [21].

3. Results

3.1 Effect of Crop Establishment Methods on the Yield Traits and Yield of Rice

Data revealed that CA significantly yielded about 16% more paddy than TA, which might be influenced by the 21% and 37% higher number of tillers m^{-2} and grains panicle^{-1}, respectively in CA although the number of hills m^{-2}, sterile spikelets panicle^{-1}, and 1000-grain weight were not impacted (Table 2). It was also showed that rice cultivation under CA boosted the profit (BCR) by 24% than the TA.

3.2 Effect of Crop Establishment Methods on the Yield Traits and Yield of Wheat

Data presented in the Table 3 showed that about 11% higher number of heads m^{-2} and 27% higher grains head^{-1} in CA boosted 31% higher grain yield in CA (4.74 t ha^{-1}) relative to the TA (3.61 t ha^{-1}), while the plant population and 1000-grains weight were not influenced by the crop establishment methods. Moreover, the CA earned 36% higher profit over the TA.

3.3 Effect of Crop Establishment Methods on the Yield Traits and Yield of Mungbean

We found 17% higher number of pods plant^{-1} and a yield increase of about 37% in CA compared to TA (Table 4). There was no significant influence of CA and TA on the number of plants m^{-2} and seeds pod^{-1}, and 1000-seeds weight. Data also disclosed that mungbean cultivation under CA boosted the profit by 49% than the TA.

3.4 Effect of Crop Establishment Methods on the System Productivity, Land Usage Efficiency (LUE) and Production Efficiency (PE)

The CA method increased the productivity of the R–W and R–W–M systems by 27% and 32%, respectively than the TA (Table 5). When mungbean was included, the productivity of the R–W system increased its production by 43%. The R–W–M system under TA had the greatest LUE (99.45%), followed by the same system under CA (92.05%), and the R–W system under TA (81.91%), while the R–W system under CA had the lowest LUE (76.71%).

Additionally, data indicated that the R–W–M system in CA had the greatest PE (53 kg^{-1} ha^{-1} day^{-1}), followed by the R–W system in CA (45.57 kg^{-1} ha^{-1} day^{-1}) and the R–W–M system in TA (45.57 kg^{-1} ha^{-1} day^{-1}). While the R–W system with the lowest PE (33.14 kg^{-1} ha^{-1} day^{-1}) was discovered under TA. CA's PE was, on average, was 60% more than TA's.

3.5 Effect of Crop Establishment Methods on the Economics of Crop Production

Data presented in the Table 6 revealed that the TA and CA method exerted a significant influence on the costs of crop production. The CA was the most cost-efficient method where savings were attributable to tillage operations (66.3%, 58.1%, 57.6%), weeding expenses (59.2%, 24.5%, and 42.2%), and labor needs (25.1%, 27.2%, and 31.3%) in rice, wheat, and mungbean, respectively.

Table 2. Treatment effect on the yield traits and yield of rice

Treatments	Hills m^{-2} (no.)	Tillers m^{-2} (no.)	Grains panicle^{-1} (no.)	Sterile spikelets panicle^{-1} (no.)	1000-grains weight (g)	Grain yield (t ha^{-1})	BCR
TA	26	239b	145b	35	29.60	5.41b	1.07b
CA	26	288a	199a	26	32.48	6.23a	1.33a
LSD ($p \leq 0.05$)	1.93	6.68	8.52	3.66	3.40	0.17	0.11

TA: Traditional Agriculture, CA: Conservation Agriculture, BCR: Befit Cost Ratio, LSD: Least Significant Difference. The means with similar letters do not differ significantly at 5% level of significance

Table 3. Treatment effect on yield traits and yield of wheat

Treatments	Plants m^{-2} (no.)	Heads m^{-2} (no.)	Grains head^{-1} (no.)	1000-grains weight (g)	Grain yield (t ha^{-1})	BCR
TA	164	293b	31b	44.87	3.61b	1.12b
CA	167	324a	39a	46.13	4.74a	1.52a
LSD ($p \leq 0.05$)	15.25	5.52	4.54	2.50	0.14	0.11

TA: Traditional Agriculture, CA: Conservation Agriculture, BCR: Befit Cost Ratio, LSD: Least Significant Difference. The means with similar letters do not differ significantly at 5% level of significance

Table 4. Treatment effect on the mungbean yield

Treatments	Plants m^{-2} (no.)	Pods $plant^{-1}$ (no.)	Seeds pod^{-1} (no.)	1000-seeds weight (g)	Seed yield ($t\ ha^{-1}$)	BCR
TA	60	42b	10	40.6	1.30b	1.23b
CA	63	49a	11	41.3	1.79a	1.83a
LSD ($p \leq 0.05$)	15.25	3.24	0.56	0.89	0.21	0.07

TA: Traditional Agriculture, CA: Conservation Agriculture, BCR: Befit Cost Ratio, LSD: Least Significant Difference. The means with similar letters do not differ significantly at 5% level of significance

Table 5. Effect of crop establishment methods on the REY, LUE) and PE

Treatments	Cropping system	REY ($t\ ha^{-1}$)	Growth duration (days)				LUE (%)	PE ($kg^{-1}\ ha^{-1}\ day^{-1}$)
			R	W	M	Total		
TA	R–W	9.91d	153	146	-	299	81.91c	33.14d
	R–W–M	13.57b	153	150	60	363	99.45a	37.38c
CA	R–W	12.76bc	142	139	-	280	76.71d	45.57b
	R–W–M	17.81a	142	139	54	337	92.05b	53.00a
LSD ($p \leq 0.05$)		0.91					4.07	3.96

TA: Traditional Agriculture, CA: Conservation Agriculture, REY: Rice Equivalent Yield, R: Rice, W: Wheat, M: Mungbean, LUE: Land Utilization Efficiency, PE: Production Efficiency, LSD: Least Significant Difference at 5% level of significant. The means with similar letters do not differ significantly at $p \leq 0.05$. The market price of wheat, mungbean, and rice @ 271.14, 589.71, and 209.50 US\$ ha^{-1}, respectively. 1 US\$ = 86.42 BDT on 05 April 2022.

Table 6. Effect of crop establishment method on the major inputs requirements in rice, wheat, and mungbean

Crops & treatments	Tillage			Weed control			Labors		
	TA	CA	% Cost savings in CA	TA	CA	% Cost savings in CA	TA	CA	% Cost savings in CA
Rice	117.9	39.8	66.3	336.8	137.6	59.2	191	143	25.1
Wheat	88.5	36.4	58.1	135.2	102.1	24.5	182	132	27.2
Mungbean	70.9	30.1	57.6	87.2	50.4	42.2	164	112	31.3

Costs are in US\$ per ha basis, 1 US\$ = 86.42 BDT on 05 April 2022. TA: Traditional Agriculture, CA: Conservation Agriculture

4. Discussion

In the present study, CA increased the productivity of rice–wheat–mungbean system than the TA. The production gaps between these two practices might be explained by variations in yield and yield-contributing characters of individual crops such as the number of effective tillers m^{-2} and grains $panicle^{-1}$ of rice; the number of heads m^{-2} and grains $head^{-1}$ of wheat; and the number of pods $plant^{-1}$ of mungbean. The higher output in CA is consistent with prior research [14], which revealed that the higher crops yield in minimum tillage (MT) compared to plow tillage (PT) might be attributed to changes in soil characteristics caused by MT's beneficial effect on grain production. Increased soil porosity and greater moisture conservation supported root growth, whereas increased nutrient absorption boosted grain production [22]. The CA's physical soil environment is more favorable to crop production than the PT's [23]. Additionally, it was reported that the lower crop yields in TA than CA were caused by the formation of the surface crust in PT [24], which resulted in the loss of structure and homogenization of the cultivated soil layer. It results in discontinuity of the nutrient and water conducting pores and compaction of the soil beneath the cultivated layer due to mechanical pressure from tractors.

Moreover, one previous study observed that increasing crop yield in CA may be influenced by the improve soil fertility by conserving soil and water and sequestering organic carbon in farmed soils, hence lowering extremes of waterlogging and drought [25]. Furthermore, the higher production in CA might be related to improved soil structure and stability, which would allow for better drainage and water holding capacity [26]. Increased infiltration rates and favorable moisture dynamics permitted a 30% improvement in maize production [27], due to a 25%, 18%, and 7% increase in soil organic carbon, total soil nitrogen, and phosphorus accumulation in the ST in CA compared to the PT in TA, respectively [28]. These findings have implications for a better understanding of how conservation tillage improves soil quality and sustainability in CA practice.

While hand weeding TA, physical shock or interruption in the normal growth of agricultural plants occurred, which may temporarily impair crop development and, subsequently, output may be lowered [29,30]. On the other hand, herbicides applied in CA had little impact on crops. Herbicides applied at field rates have a hormetic effect on crop growth and development, which may have resulted in increased crop yields in this study [31]. The author found that glyphosate may accelerate plant growth, induce the accumulation of shikimic acid, increase photosynthesis, and open stomata, all of which led to increased seed production by shortening the plant life cycle. However, that glyphosate may help prevent wheat rust infections, hence improving grain production [32]. Glyphosate has been shown to boost total biomass growth by 25% when paired with pendimethalin in crop plants [33], while carfentrazone-ethyl+isoproturon has been shown to improve total biomass growth in wheat, resulting in a higher number of tillers per m^2 area and a higher yield [34]. The favorable impact of the herbicides employed may have resulted in more rice, mungbean, and wheat grain output in CA than in TA in the present investigation.

Furthermore, the higher productivity in CA might be related to the residues' positive contribution on soil fertility, which is linked to increased crop output. This result is congruent with the results of a study conducted in China [35], which showed that recorded residue returns increased average crop output by roughly 5% as compared to no-straw treatment. Another study found that applying 50% stubble mulch increased rice production by 3% [36] and wheat yield by 4% [37]. Increased crop residue retention enhances soil porosity, decreases compaction and bulk density, and improves soil aeration and productivity under dry circumstances [38]. Crop leftover increases the organic matter, accessible minerals, fulvic acid, and humic acid levels in the soil, as well as the rate of potassium release. Furthermore, it lowers the requirement for synthetic fertilizers, improves the soil environment, increases plant leaf area, and enhances photosynthetic material transfer to grain, all of which increase crop yield and quality [39,40]. Crop residues are high in organic matter, which can serve as a carbon source for soil microorganisms, stimulate microbial activity, improve soil fertility, promote earthworm reproduction, and increase the diversity of soil arbuscular mycorrhizal fungi [41], all of which contribute to increased crop yield. In this research, 50% residue generated more rice tillers m^{-2} and grains $panicle^{-1}$, wheat heads m^{-2} and grains $head^{-1}$, and mungbean pods $plant^{-1}$, which could be linked to agricultural residues' favorable impact and resulted in enhanced rice, wheat, and mungbean yields, and ultimately system productivity.

According to the economic assessment of this study, CA profited the most over TA. The differential in BCR might be attributed to disparities in grain yield and cultivation expenses in TA and CA, respectively, in PT and ST. Savings may be attributed to tillage, weeding, and labor expenditures required in all crops (Table 7). This conclusion is consistent with previous study, which predicted 70% [42] and 49% [43] savings in land preparation in ST and PT, respectively. The ST had the lower plowing cost (ranging from US$30.1~39.8 ha^{-1}) due to reduced tillage intensity and fuel use, whereas the PT had the higher price (ranging from US$70.9~117.9 ha^{-1}). This conclusion is consistent with prior research that found a 67% reduction on land preparation expenses in reduced tillage, RT (US$ 36 ha^{-1}) over conventional tillage (US$ 191 ha^{-1}) due to single plowing and fewer fuel use compared to PT [44]. ST reduced fuel and labor requirements in field preparation and fertilizer application due to fewer tillage operations and TSP fertilizer applied with VMP during tillage. Due to the softness of the soil in ST, employees had minimal difficulty transplanting plants by inundating the area. The VMP sowed wheat and mungbean at the same time during the ST operation in the CA technique. Moreover, herbicidal weed control provided better net benefits in CA than manual three-times hand weeding in TA. This finding is consistent with prior studies, which found that herbicide weed treatment saves 100% more than manual weeding [45]. Furthermore, past research has demonstrated that the higher weeding costs associated with human weeding are economically unproductive when compared to herbicidal weed treatment. Hand weeding may be efficiently replaced by the application of an appropriate herbicide [46].

Furthermore, using herbicides to control weeds under CA yielded larger net benefits than three manual weeding procedures under TA. Manual weeding was required three times in TA, costing US$336.7 ha^{-1}, US$58.1 ha^{-1}, and US$87.2 ha^{-1} in rice, wheat, and mungbean, respectively. All herbicides, on the other hand, cost just US$137.6 ha^{-1}, US$102.1 ha^{-1}, and US$50.4 ha^{-1}, respectively. As a result, herbicides saved 59.2%, 24.5%, and 50.4% of the cost of hand weeding in TA, respectively. Findings of past research corroborate our findings by showing that the greater expenses associated with manual weeding are unprofitable when compared to herbicidal weed management [47,48]. Furthermore, rice, wheat, and mungbean production (from sowing to seed storage) in the PT needed 191, 182, and 164 person-days ha^{-1} of work, respectively. In CA, the figures were 143 person-days, 132 person-days, and 112 person-days, respectively. Therefore, CA reduced labor needs by 25.1%, 27.2%, and 31.3%, respectively, as compared to TA. In this research, this reduction enabled CA to generate larger economic returns than TA. Our findings are consistent with prior studies demonstrating that one-third of work in CA procedures is harsh compared to TA [49,50].

Result found that the productivity of the rice–wheat–mungbean system was about 43% higher than that of the rice–wheat system. Incorporating mungbean into the rice–wheat system, which generates an average yield of 1.23 t ha^{-1} in TA and 1.60 t ha^{-1} in CA, may increase productivity. This finding is consistent with prior studies, which found that including one or more short-duration crops into established cropping patterns increases system production efficiency [51-53]. Cropping sequence intensification using mungbean as a grain legume in the current R–W system resulted in the largest land use and production efficiency of sequence. This conclusion backs up the results of previous study, who observed that including blackgram and mungbean into the wheat–rice cropping sequence boosted system productivity, gross return, gross margin, benefit-cost ratio, and production efficiency. This farming series provided 57% greater wheat equivalent yield than the prior wheat–rice system [54].

Every year, the wheat–rice agricultural method produces a significant number of crop residues. Wheat and rice straw have traditionally been harvested from fields for use as cow fodder and a variety of other applications such as animal bedding, home thatching, and fuel [55]. It has been established that including legume crops into the system as green manure or grain legumes is more beneficial than keeping a rice–wheat sequence [6]. Legume crops may help cereal-based farming systems sustain long-term productivity by fixing atmospheric nitrogen, improving soil fertility, and improving soil fertility. It is well known that the rice–wheat cropping system may be modified by replacing grain legumes such as mungbean for rice [7]. Differences in efficiencies in the land use and production might be a result of the variations in crop growth length (days). Crops that grow more rapidly in the CA system than in the TA system have a lower LUE and PE. It has extended the scope to incorporate other crops with a growth period of roughly 30 days, such as leafy vegetables: *Amaranthus gangeticus* L., *Spinacia oleracea* L., and others, by adjusting the planting dates of rice, wheat, and mungbean in the R–W–M system. Such improvements have attributed a significant productivity with a better sustainable profit, land utilization efficiency, and production efficiency of the rice–wheat–mungbean cropping system under conservation agriculture practice: single tillage, which sequentially applied a pre-plant herbicide, then a pre- and post-emergence herbicide, and retained 50% crop residue than the current traditional agriculture practice under rice–wheat system.

5. Conclusions

Conservation Agriculture is an innovative technique to cultivate crops with less inputs. When combined with efficient herbicides and residue recycling, single tillage was a lucrative alternative to the traditional laborious crop cultivation practice by increasing the yield of rice, wheat and mungbean by 15.2%, 31.3% and 37.6% and the BCR by 24.3%, 35.7% and 38.8% higher profit, respectively. Moreover, practice of rice–wheat–mungbean system was 43% more profitable over rice–wheat system. In the present study, the practice of conservation agriculture under rice–wheat–mungbean system was expedient over the existing traditional agriculture practice of rice–wheat system. Because the rice–wheat–mungbean system utilized the land more efficiently with the maximum crop production efficiency. This practice has also extended the scope to incorporate other leafy vegetable crops with a growth period of roughly 30 days. To validate this result, it is recommended to practice conservation agriculture under the diversified cropping system across the country.

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Conflict of Interest

The authors disclosed no possible conflicts of interest.

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