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***Corresponding author**

M Mobarak Hossain, Department of Agronomy, Bangladesh Agricultural University, Bangladesh

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Research Article

Higher Profitability of Wheat-Mungbean-Rice System Through Conservation Agriculture Practice in Sub-Tropical Climate of Bangladesh

M Mobarak Hossain[1]*, Mahfuza Begum[1] and Richard W Bell[2]

[1]*Department of Agronomy, Bangladesh Agricultural University, Bangladesh*

[2]*Agricultural Sciences, Murdoch University, Australia*

Abstract

Two-Wheel Tractor (2WT) operated plow tillage and crop residue exclusion practices in the rice-wheat system are costly, labor-intensive, soil destructive, and non-ecofriendly. In recent years, pursuits of healthy food production through sustaining the productive capacity of soils, and environmental quality, have raised concerns to adopt Conservation Agriculture (CA) worldwide. Single-Pass Tillage (SPT) combined with herbicides and crop residue retention principles of CA is being developed in Bangladesh. Between 2014 and 2016, we conducted a two-year on-farm experiment under the wheat-mungbean-rice system in Bangladesh. These crops were grown under two crop establishment methods; T1: Plow Tillage (PT) + three times manual weeding by hand, and T2: Pre-plant knockdown herbicide (PRE) + SPT + Pre-emergence herbicide (PE) + Post-emergence herbicide (PO). Treatments were combined with two levels of crop residues, R0: zero residues and R50: 50% anchored residue. The PT was accomplished with two primary tillage operations performed by a 2WT, whereas SPT was completed by a single-pass process using a Versatile Multi-crop Planter machine. The PRE: glyphosate, PE: pendimethalin for all crops, and PO: carfentrazone-ethyl+isoproturon, fenoxaprop-p-ethyl, and ethoxysulfuron-ethyl for wheat, mungbean, and rice, respectively, were applied at the prescribed dosage and time. Data reveal that, relative to traditional practice (PT+3HW without residue), the CA practice (PRE + SPT + PE + PO with 50% residue) resulted in 30, 39, and 15% higher yield and 37, 29, and 22% higher economic returns in wheat, mungbean, and rice, respectively. The productivity of the wheat-mungbean-rice system was 41% higher than that of the wheat-rice system.

Introduction

Almost all crops in Bangladesh are grown using intensive plowing after the complete removal of earlier crops. The rice field is habitually puddled before manual transplanting. Wheat, mungbean, and other non-rice crops are produced on severely pulverized dry soils. These conventional methods raise questions about agricultural production's sustainability. Intensive plowing damages soil structure, depletes the Soil Organic Matter (SOM), and increases farm labor and fuel needs for plowing and the total cost of production [1]. Additionally, it retards the establishment of subsequent crops, resulting in lower yields. Additionally, there is rising worry over agricultural labor shortage due to lower profits and migration from rural to urban regions inside and outside nations [2]. As a result, labor and other input-efficient alternative systems that produce more at a lower cost are in high demand. Without a new and more sustained improvement in agricultural productivity, agricultural supply would struggle to keep up with fast-expanding demand due to population expansion and changing consumer tastes as income grows. Conservation Agriculture (CA) may be one strategy for addressing these issues.

The CA stands on the fundamental concepts of little or no soil plowing with herbicides, residue retention from previous crops, and prudent crop rotation [3]. Reduced tillage combined with residue retention may enhance the soil's physical, chemical, and physical qualities, promote timely planting, save labor, fuel, and equipment expenses, and maintain profitability [4]. However, evidence of global data revealed that CA technology might help Bangladesh's agriculture to address human resources and energy shortages.

The "rice-wheat (R-W)" is the dominant farming pattern in the South Asian continent, which occupies around 13.5 million hectares of the Indo-Gangetic Plains (IGP), including 0.8 million hectares in Bangladesh [5]. Rice is cultivated during the warm rainy season (July-October), and then wheat is grown in the dry winter seasons (November–March). The field remains fallow for two months in April and May. There is the possibility to cultivate a crop with a short life cycle of 60-65 days, such as mungbean, in a wheat-mungbean-rice (W-M-R) combination, therefore contributing significantly to nutrition security. At the same time, the potential for R-W-M systems employing the benefits of CA principles has garnered substantial interest in Bangladesh.

In CA, numerous solutions for minimal soil disturbance exist, including Single-Pass Tillage (SPT), which disturbs the soil surface by 15-25% with a plow ridge of 6 × 4 cm depth and width [6]. Farmers are interested in using SPT to produce crops since it lowers cultivation expenses, prevents soil deterioration, and conserves water without sacrificing production. However, the SPT has been rebuked for its ineffective weed management. By contrast, typical heavy tillage efficiently reduces present weeds by smothering them and their seeds in the soil [7]. In SPT, to eradicate existing weeds and their viable seeds, a non-selective herbicide in a pre- and post-emergence herbicide sequence must be applied [8].

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Farmers increasingly use 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 [9]. Previous research established that herbicide applications guaranteed continuous and effective weed control and resulted in a higher yield when compared to hand weeding [10]. However, repeated use of herbicides with the same molecule may develop weed tolerance to herbicides that increase weed control's difficulty [11]. Furthermore, herbicide longevity in the soil and their toxicity on the subsequent crop(s) are significant problems. The decreased availability of appropriate herbicide molecules due to rising prices and environmental concerns highlight the importance of implementing an integrated approach to managing weeds to ensure a sustainable SPT. Crop residues and more intensive farming are two agronomic options that have already been talked about for weed control in SPT [12].

Previous studies demonstrate that crop residue retention and intensification stimulate nutrient cycling, enhance crop availability of nutrients, enhance OM content, control weeds, enhance soil water content, and decrease irrigation water needs by lowering soil evaporation [13]. Residue retention may also be crucial R-W systems, which are typically removed from the fields. Compared to rice-rice (R-R) systems, R-W systems extract more nitrogen, phosphorus, and potassium. Additionally, by including mungbean and keeping its leftovers, the nitrogen economy of the next cereal crop may be enhanced. Although multiple studies have been conducted on the impacts of SPT and residue mulching on the productivity of various cropping systems, no large-scale research has been conducted in Bangladesh on this technique under the W-M-R system. Thus, the present two-year research used W-M-R systems in conjunction with different tillage and residue management practices in order to determine Bangladesh's most productive and lucrative possibilities.

Materials and Methods

The experimental site, time, soil, and climate

During 2014-15 and 2015-16 consecutive years, a two-year crop sequence experiment under wheat-mungbean-rice pattern was done in a farmers' field in Mymensingh district of Bangladesh (N: 24 75' and E:90 50').

The land was flood-free medium-high with a sandy clay loam soil texture (sand, silt, and clay @ 50, 23, and 27%, respectively). The composition of pH (6.69), total nitrogen (0.11%), available phosphorus (16.2 ppm), exchangeable potassium (0.31 ppm), and available sulfur (14 ppm) denotes a dark grey non-calcareous alluvium nature of the soil.

The average annual rainfall in the region is 172 mm, with around 95% falling between May and September (Figure 1). Total rain was most significant 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. March, October, and November had the highest sunshine hours in both years.

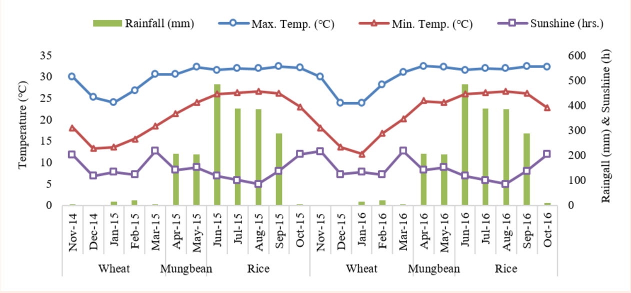

Figure 1: Weather condition of experimental site during 2014-2016.

Experimental materials, treatments, and design

A Rabi (mid-November–March) season wheat *(Triticum aestivum* L.)-Kharif 1 (April–May) season mungbean *(Vigna radiata* L. *Wilczek)*-monsoon (June–mid-November) rice *(Oryza sativa* L.) were grown on the same plots for two successive years. The following treatments were assembled in a randomized complete block design and replicated four times.

Component A: Crop establishment method

a) Traditional practice, T1: Plow Tillage (PT) with three times hand weeding (HW): PT + 3 HW

b) CA practice, T2: Pre-plant herbicide (PRE) prior to Single-Pass Tillage (SPT), afterwards Pre- (PE) and Post-emergence herbicide (PO) : PRE + SPT + PE + PO

Component B: Crop residue retention

a) Traditional practice, R0: Zero-residue

b) CA practice, R50: 50% anchored residue

Tillage and planting practice

PT had completed four plowings and cross plowings in each 9 × 5 m plot, followed by two days of sun drying, flooding, and leveling with a Two-Wheel Tractor (2WT). A Versatile Multi-crop Planter (VMP) in one pass completed the STP. At the row spacing of the respected crop, the VMP constructed each row of 6 × 5 cm width and depth.

Wheat (cv. BARI Wheat 26) and mungbean (cv. BARI Mung 6) seeds were planted in lines on the same day using VMP in ST and manually in CT. For rice (cv. BRRI hybrid dhan6), the final field was prepared by flooding and levelling in CT. Following ST, the field was flooded with 3-5 cm of water after ST operation and one day before transplanting to soften the strips sufficiently to transplant rice seedlings. The seedlings were then transplanted in the elevated furrows (single seedling hill^{-1}). Table 1 shows the glimpse of cultural activities for different crops and were the same in both ST and CT in both years.

Table 1: Different activities performed in traditional and CA practice.

Activities	Wheat		Mungbean		Rice	
	2014-15	2015-16	2015	2016	2015	2016
Seed rate (kg ha^{-1})	120	120	25	25	10	10
Date of seeding	20 Nov.	20 Nov.	30 Mar.	30 Mar.	05 Jun.	05 Jun.
Date of transplanting	-	-	-	-	30 Jun.	30 Jun.
Row Spacing	Continuous seeding at 20 cm apart lines				25 cm × 15 cm	
Date of harvest	26 Mar.	26 Mar.	28-May	28-May	10 Oct.	10 Oct.

Crop residue retention

Planting was done without keeping previous crop residues in the no-residue method. Rice, wheat, and mungbean were harvested using a 50% residue practice, leaving 50% of the plant standing in the individual plots.

Weed control

We performed three HWs in CT at 25, 45, and 65 days after planting. In SPT, herbicides of various groups (Table 2) were applied using a hand-operated knapsack sprayer. Only ethoxysulfuron-ethyl was sprayed in water logging conditions, and the rest were applied at field capacity moisture level. PRE was applied three days before of ST operation. The PE and PO were applied three and 25 days after planting, respectively.

Table 2: Different herbicides and their rates of application.

Herbicide group and name	Apply rate (ha^{-1})		
	Wheat	Mungbean	Rice
Pre-plant: Glyphosate	3.7 L		
Pre-emergence: Pendimethalin	2.5 L		
Post-emergence: Carfentrazone-ethyl	1.25 kg	-	-
Fenoxaprop-p-ethyl	-	650 ml	-
Ethoxysulfuron-ethyl	-	-	100 g

Intercultural operations

The nitrogen (N) @100, 20, and 80, phosphorus (P) @ 26, 20, and 22, potassium (K) @ 33, 15, and 35 and sulfur (S) @20, 10, and 11 kg ha-1 were applied in wheat, mungbean, and rice, respectively. Before planting in all crops, the entire P, K, and S were broadcasted. N was applied in three splits at 15, 30, and 45 days after rice transplant. In wheat, two-thirds of the N were used at final plowing and the rest 21 Days after Seeding (DAS). In mungbean, the full amount of N was applied at final plowing.

Rice did not require additional irrigation due to adequate rainfall. At 20, 55, and 80 DAS, three irrigations were used in wheat. Two irrigations with good drainage were performed on the mungbean at 25 and 45 DAS. Adequate plant protection measures were implemented following the guidelines throughout the crop growing season.

Measurements and analysis

Yield contributing characters of wheat (Table 3), mungbean (Table 4), and rice (Table 5) have been transcribed from randomly selected ten plants at maturity. Mungbean pods were picked twice at 55 and 70 DAE. The crops were harvested from the three × 1m area from 3 spots of each plot. The yield (t ha^{-1}) was calculated at 14% moisture content. Total pattern productivity was estimated by calculating rice equivalent yield (REY).

$$REY = Y_x\left(\frac{P_x}{P_r}\right)$$

where Y_x is the yield of non-rice crops (t ha^{-1}), Px and Pr are the price (US\$ h^{-1}) of non-rice crops and rice, respectively.

Table 3: Treatment effect on the mungbean yield.

Treatments		Plants m^{-2} (no.)	Pods plant^{-1} (no.)	Seeds pod^{-1} (no.)	1000-grain weight (g)	Seed yield (t ha^{-1})
PT + 3 HW	R0	60	41c	10	40.6	1.33cd
	R50	62	40c	10	40.8	1.41c
PRE + SPT + PE + PO	R0	62	44b	10	41.1	1.73b
	R50	63	48a	11	41.3	1.82a
Least significant difference at p ≤ 0.05		15.25	3.24	0.56	0.89	0.21

The means with similar letters do not differ significantly at p ≤ 0.05.

Table 4: Treatment effect on the rice yield.

Treatments		Hills m^{-2} (no.)	Tillers m^{-2} (no.)	Grains panicle^{-1} (no.)	Sterile spikelets panicle^{-1} (no.)	1000-grain weight (g)	Grain yield (t ha^{-1})
PT + 3 HW	R0	27	234d	147c	36	29.6	5.37c
	R50	27	246c	163b	33	30.23	5.50b
PRE + SPT + PE + PO	R0	27	289b	195a	33	32.1	6.05ab
	R50	27	298a	198a	21	32.48	6.20a
Least significant difference at p ≤ 0.05		1.93	6.68	8.52	3.66	3.4	0.17

The means with similar letters do not differ significantly at p ≤ 0.05.

Table 5: Treatment effect on the productivity of wheat-mungbean-rice pattern.

Treatments Wheat		Yield of			REY of wheat-mungbean-rice system
		Wheat	Mungbean	Rice	
PT + 3 HW	R0	3.56d	1.33cd	5.37c	13.80d
	R50	3.63c	1.41c	5.50b	14.30c
PRE + SPT + PE + PO	R0	4.31b	1.73b	6.05ab	16.60ab
	R50	4.64a	1.82a	6.20a	17.50a
Least significant difference at p ≤ 0.05		0.14	0.21	0.17	0.88

The means with similar letters do not differ significantly at p ≤ 0.05. The market price of wheat, mungbean, and rice @ 270.58, 588.23, and 205.89 US\$ ha^{-1}, respectively. 1

US\$ = 84.52 BDT on 01 June 2021.

Crop production economics were calculated using a partial budgeting methodology. The variable costs were determined by the labor required for planting, weeding, harvesting, threshing, irrigation, and fertilization and the cost of all other inputs such as seed, residues, fertilizer, and irrigation. The gross profit margin was determined using market prices for grain and by-products. The Benefit-Cost Ratio (BCR) was computed by dividing gross revenues by expenses.

Analysis of variance was constructed to analyze data, and Duncans' Multiple Range Test was performed to separate treatment means at a p ≤ 0.05 level of significance using the STAR software.

Results

Treatment effect on the wheat yield

Except for the plant population and 1000-grains weight, the mean results from the two-year research demonstrated that establishing procedures had a significant (p ≤ 0.05) influence on the number of spikes m^{-2}, grains spike^{-1}, and grain yield of wheat (Table 6). The maximum average grain yield was determined using the CA method followed by the traditional method. The yield was about 30% higher in PRE + SPT + PE + PO with 50% residue than PT + 3 HW without residue.

Table 6: Treatment effect on wheat yield.

Treatments		Plants m^{-2} (no.)	Spikes m^{-2} (no.)	Grains spike^{-1} (no.)	1000-grains weight (g)	Grain yield (t ha^{-1})
PT + 3 HW	R0	162	290cd	33bc	44.76	3.56d
	R50	167	295c	35b	45.92	3.63c
PRE + SPT + PE + PO	R0	157	309b	38ab	45.46	4.31b
	R50	166	323a	44a	46.73	4.64a
Least significant difference at p ≤ 0.05		15.25	5.52	5.54	2.5	0.14

The means with similar letters do not differ significantly at p ≤ 0.05.

Treatment effect on the mungbean yield

The number of pods per plant^{-1} and seed yield (t ha^{-1}) were significantly affected (p ≤ 0.05) but resulted in a statistically non-significant increase in the number of plants m^{-2}, seeds pod^{-1}, and 1000-seeds weight (Table 3). The PRE + SPT + PE + PO with 50% residue was found to have the highest pod plant^{-1}, followed by the same treatment without residue. The lowest value was obtained with PT + 3 HW either without or with 50% residue. PRE + SPT + PE + PO with 50% residue produced the best seed production, followed by the same treatment without residue. Simultaneously, the lowest yield was obtained with PT + 3 HW devoid of residue, followed by PT + 3 HW devoid of 50% residue. There was a yield increase of about 39% in PRE + SPT+ PE + PO with 50% residue than PT + 3 HW retained zero-residue.

Treatment effect on the mungbean yield on the rice yield

The combination of treatments had a significant effect (p ≤ 0.05) on the number of productive tillers m^{-2}, grains panicle^{-1}, and grain yield (t ha^{-1}), although the number of hills m^{-2}, sterile spikelets panicle^{-1}, and 1000-grain weight were not impacted significantly (Table 4). PRE + SPT + PE + PO with 50% residue produced the most productive tillers m^{-2} and grains panicle^{-1}, followed by the same treatment without residue. In contrast, the lowest value was obtained in PT + 3 HW without residue, followed by PT + 3 HW with 50% residue. We discovered that PRE + SPT + PE + PO combined 50% residue yielded about 15% more than PT + 3 HW without residue.

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Treatment effect on the benefit-cost ratio (BCR) of wheat, mungbean, and rice

The maximum average BCR had been transcribed from the PRE + SPT + PE + PO with 50% residue in all three crops, followed by the same treatment without residue. At the same time, the PT + 3 HW without residue produced the lowest BCR, followed by the same treatment with 50% residue (Figure 2). We recorded about 37, 30, and 22% higher BCR in PRE + SPT + PE + PO than PT + 3 HW in wheat, mungbean, and rice. Solely, the 50% residue earned about 6% higher BCR in all the crops.

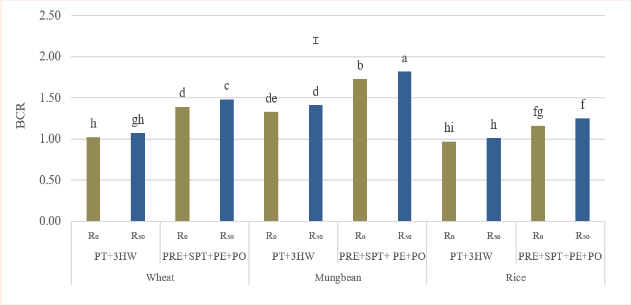

Figure 2: Treatment effect on the BCR of wheat, mungbean and rice.

Treatment effect on the productivity of wheat-mungbean-rice pattern

The results indicated that PRE + SPT + PE + PO and 50% residue boosted productivity by 21% and 4%, respectively, compared to PT + 3 HW and zero-residue (Table 5). The addition of mungbean boosted the productivity of the wheat-mungbean-rice system by 41% when compared to the wheat-rice system.

Discussion

The yield differences across treatments might be related to differences in yield-contributing characteristics of crops such as the number of spikes m^{-2} and grains $spike^{-1}$ in wheat, the number of pods $plant^{-1}$ in mungbean, and the number of effective tillers m^{-2} and grains $panicle^{-1}$ in rice. The greater yield in SPT in the current study accords with the research results of the previous study [14]. The author discovered that the greater wheat yield in Minimal Tillage (MT) than Plow Tillage (PT) might be attributable to the change in soil parameters owing to the favorable influence of MT on grain production. Higher overall porosity and improved soil moisture conservation aided root development, while nutrient absorption enhanced grain production [15]. The SPT has a more favorable physical soil environment for agricultural development than PT [16]. The extensive pulverization of the surface soil may have resulted in less steady crop production in PT than SPT [17]. The mechanical pressure of tractors on the grown layer under the PT causes discontinuity of the conducting pores and compaction of the soil below the cultivated layer.

Furthermore, Zheng et al. [18] discovered that increasing crop production in SPT may enhance soil fertility by saving soil and water and sequestering organic carbon in farmed soils, reducing the extremes of waterlogging and drought than PT. Alam et al. [19] indicated that increased SPT output might be connected with enhanced soil structure and stability, allowing for greater drainage and water holding capacity. Higher infiltration rates and favorable moisture dynamics enabled up to a 30% increase in maize production [20] due to increased soil organic carbon, total soil nitrogen, and phosphorus in the SPT than PT by 25, 18, and 7%, respectively [21]. These results have implications for understanding how conservation tillage methods improve soil quality and sustainability in SPT of CA practice.

Physical shock or disruption in the average growth of agricultural plants happened while hand weeding PT, which may inhibit crop development for short periods and, eventually, production may be reduced [22,23]. Herbicides, on the other hand, did not affect crops. Herbicides administered at field rates have a hormetic influence on crop growth and development, which may have led to higher crop yields in this research [24]. The author concluded that glyphosate might stimulate plant growth, cause shikimic acid build-up, boost photosynthesis, and open stomata, all of which contribute to enhanced seed production by shortening the plant life cycle. However, Velini et al. [25] demonstrated that glyphosate might prevent rust infections in wheat, increasing grain yield. The findings of glyphosate, when combined with pendimethalin, may cause a 25% increase in total biomass growth in crop plants [26]. At the same time, carfentrazone-ethyl contributed to total biomass in wheat, resulting in a more significant number of tillers per m^{-2} area and a greater yield [27]. The effect mentioned above of PRE, PE, and PO herbicides may have resulted in more significant grain production of rice, mungbean, and wheat in SPT than PT in the current research.

In this research, crop residue retention of 50% boosted wheat, mungbean, and rice grain production by 3–4% compared to zero residues, which might be related to agricultural residues' favorable influence on soil fertility, linked to increased crop output. This finding is in line with the results of a study conducted in China [28] recorded residue returns significantly increased the average crop yield by 5% compared to no-straw treatment. Mungbean yield was increased by 5% in 50% residue over no-residue in Bangladesh [29]. In another study, the 3% higher rice yield [30] and 4% higher wheat yield [31] was discovered in 50% stubble mulch than no-stubble. Increased crop residue retention enhances soil porosity, reduces soil compaction and bulk density, and improves soil aeration and water status productivity [32]. Crop residues enhance the organic matter, accessible minerals, fulvic acid, and humic acid levels of the soil and facilitate the release of slow-acting potassium [33]. Additionally, it lowers the need for artificial fertilizers [34], improves the soil environment [35], increases the leaf area of plants, and enhances photosynthetic material transfer to the grain [36], thus increasing crop production and quality [37]. As a carbon source, the organic matter in crop residues could help bacteria grow and improve soil fertility [38]. Additionally, it may encourage earthworm reproduction, increase the variety of soil arbuscular mycorrhizal fungi, and increase crop yield. [39,40]. In this research, relative to zero-residue, 50% residue produced the higher numbers of spikes m^{-2} and grains $spike^{-1}$ of wheat, pods $plant^{-1}$ of mungbean, tillers m^{-2} and grains $panicle^{-1}$ of rice could have attributed to the beneficial effect of crop residues and resulted in better wheat, mungbean, and rice yield. Around 7% greater profit in 50% residue might be attributed to about 5-9% greater grain production in all crops of the wheat-mungbean-rice system than in zero-residue.

According to an economic study, PRE + SPT + PE + PO with 50% residue made the maximum profit over PT + 3 HW without residue. The disparity in BCR might be ascribed to differences in grain output and cultivation costs in PT and SPT. Savings in the PRE + SPT + PE + PO over PT + 3 HW may be attributable to tillage operations (56, 45, 67%), weeding expenses (21, 40, and 58%), and labor needs (25, 29, and 22%) in wheat, mungbean, and rice, respectively (Table 7). This estimate is consistent with prior research that estimated 70 % [41] and 49% [42] savings in land preparation in SPT over PT. Due to the reduction of tillage intensity and fuel usage, the SPT had the lowest plowing cost (ranging from US\$32.541–33.25 ha^{-1}), while the PT had the highest price (ranging from US\$88.2–110.29 ha^{-1}). This finding is in line with a previous study where around 67% savings on land preparation costs in reduced tillage, RT (US\$ 35.8 ha^{-1}) than the conventional one (US\$190.8 ha^{-1}) owing to single plowing and lesser amount of fuel usage relative to PT [43]. Due to fewer tillage operations and TSP fertilizer applied with VMP during tillage, SPT lowered fuel and labor needs in field preparation and fertilizer application. Inundating the field, laborers had little problem transplanting plants in ST due to soil softness. Wheat and mungbean were seeded at the same time by the VMP during the SPT operation.

Table 7: Effect of crop establishment method on inputs requirements in wheat, mungbean, and rice.

Crops	Treatments	Tillage practice		Weed control		Labor requirement	
		Costs	Savings (%)	Costs	Savings (%)	Number	Savings (%)
Wheat	PT + 3 HW	81.2	-	124	-	167	-
	PRE + SPT + PE + PO	35.3	56	97.2	21	125	25
Mungbean	PT+3 HW	65	-	80	-	150	-
	PRE + SPT + PE + PO	35.3	45	48	40	106	29
Rice	PT + 3 HW	108.2	-	309	-	175	-
	PRE + SPT + PE + PO	35.3	67	131	58	136	22

Costs are in US\$, 1 US\$ = 84.52 BDT on 01 June 2021.

Herbicide weed control gave greater net advantages in ST than manual three times hand weeding in PT in this research. This result is consistent with the previous research, which found that herbicidal weed treatment saves 37–73% more than hand weeding [44]. In addition, previous studies found that manual weeding costs more money than herbicide-based weed management, which costs less to do. The use of an adequate herbicide may effectively replace hand weeding [45,46].

Furthermore, utilizing herbicides to manage weeds under SPT resulted in more significant net benefits than three hand weeding operations under PT. Three times manual weeding was needed in PT, costing US$124, 80, and 309 ha^{-1} in wheat, rice, and mungbean, respectively. By contrast, all herbicides incurred only US$97.2, 48, and 131 ha^{-1}, respectively. Consequently, herbicides saved 21, 40, and 58% cost, respectively, compared to manual weeding in PT. The prices of manual weeding were also higher than those of herbicides in previous studies [47,48]. Moreover, in the PT practice, 167, 150, and 175 person-days ha^{-1} of labor were needed for wheat, mungbean, and rice cultivation (from seeding to seed storage). By comparison, 125, 106, and 136 person-days in SPT. As a result, SPT lowered labor requirements relative to PT by 25, 29, and 22%, respectively. This reduction allowed SPT to earn a higher return than PT in this report. Our observation is consistent with previous research indicating that one-third of labor is savage in SPT practices compared to PT [49-51].

Wheat-mungbean-rice pattern productivity was about 41% more than wheat-fallow-rice pattern production. Incorporating mungbean, which produces an average yield of 1.57 t ha^{-1}, into the wheat-fallow-rice rotation may boost the practice. This result is consistent with previous research indicating that including one or more short-duration crops into established cropping patterns stimulates system production [52-54]. So, the researchers thought that crop cultivation using CA principles: single-pass tillage, which sequentially applied a pre-plant herbicide, then a pre- and post-emergence herbicide, and kept 50% of the crop residue, might have been more profitable than current crop cultivation practices.

Conclusion

Conservation Agriculture is an innovative technique to cultivate crops with fewer inputs. When combined with efficient herbicides and residue mulching, single-pass tillage was a lucrative alternative to the traditional laborious crop cultivation practice by saving tillage operations costs (56, 45, 67%), weeding expenditures (21, 40, and 58%), and labor requirements (25, 29, and 22%) in wheat, mungbean, and rice, respectively. Additionally, this strategy increased crop yield by about 4% and the BCR by 37, 30, and 22% higher, respectively, in wheat, mungbean, and rice. Moreover, the practice of the wheat-mungbean-rice system was 41% higher profit than the wheat-rice system. In the present study, the method of conservation agriculture principles under the wheat-mungbean-rice system was suitable over the existing traditional practice of crop cultivation in the wheat-rice system.

Declaratory Statement

The authors disclosed no possible conflicts of interest.

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