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Strip Tillage in Wheat Cultivation: A Wind of Change in Production, Greenhouse Gas Emission and Energy Use

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ABSTRACT

The experiment was conducted at the Paba MLT site, Rajshahi during the year of 2016-17, 2017-18 and 2018-19 in High Ganges River Flood Plain Soil (AEZ-11) to evaluate the performance of Strip tillage (ST) and to estimate the change in input-output energy and GHG emission as compared to conventional tillage (CT).The production program was done in a compact two hectares' block. Seeding was done in the half of the land with the help of a power tiller operated strip tillage machine and other half by conventional tillage (power tiller) system. The yield was significantly different between ST and CT.The average three years yield was 4264kgha^{-1} in ST which was 9.6% higher than CT (3892 kgha^{-1}).The strip tillage (ST) emitted 52.3% lower (210 kg CO_2eqha^{-1}) greenhouse gas (GHG) in crop residue management sector than CT (440kg CO_2eqha^{-1}).The ST liberated 43.3% (170kg CO_2eqha^{-1}) less GHG in the fuel use sector compared to CT (300 kg CO_2eqha^{-1}). In case of total emission, ST reduced16.8% total GHG emission (1749kg CO_2eqha^{-1}) compared to CT (2099kg CO_2eqha^{-1}) during wheat production period. ST liberated 24.1% lower GHG (0.41kg CO_2eqkg^{-1} product) to produce per kilogram product compare to CT (0.54kg CO_2eqkg^{-1} product).The total energy input requirement of wheat was 14.6% lower in ST (16692 MJ ha^{-1}) than CT (19553 MJ ha^{-1}).The total output energy is8.56% higher in ST (164132 MJ ha^{-1}) than CT (151196 MJ ha^{-1}). The energy efficiency or energy ratio in wheat production was found higher in ST (9.83) than CT (7.73). Specific energy was found maximum in CT (5.02 MJ kg^{-1}) as compared to ST (3.92 MJ kg^{-1}). The energy productivity was found 30% higher in ST (0.26 kg MJ^{-1}) than CT (0.20 kg MJ^{-1}). Thus, ST increased grain and energy productivity, reduced GHG emission and utilized lower input energy to produce higher output energy than CT to bring wheat production closer to sustainability in Bangladesh.

1. Introduction

Intensive tillage and imbalance use of fertilizers have substantially increased the production cost and energy use in conventional crop production system. In conventional system, wheat crop is generally sown after harvest of preceding T. Aman rice crop. Land was prepared by Two-wheel tractor (power tiller) following 3-4 passes of ploughing which consume more time and input cost which also added another delay period with previous one. The wheat crop losses its potential yield due to these cumulating delay inseeding. The conventional tillage system decreased soil fertility, reduces resource use efficiencies, degraded soil ecosystem service and bio-diversity (Choudhury and Behera 2014; Jat et al., 2019) and it is also an input inefficient practices (Parihar et al., 2018). To offset the production cost, reduces input energy use and reduce greenhouse gas emission (Environmental footprints), the conservation agriculture (CA) has been introduced and adopted for climate resilient sustainable production of the crop (Jat et al.,2019).Minimum soil disturbance, crop residues retention on soil, and profitable diversified crop rotation for economic of farmers are the principles of CA. Conservation agriculture can reduce the field preparation and crop establishment cost up to 30%. Strip tillage (ST) machine is a unique minimum tillage device for less disturbance of soil in CA system during

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seeding. ST lies in the middle of conventional tillage (CT) and no-till. It creates slender strips for planting crops in rows, leaving the crop residue and soil in between the strips undisturbed. Bangladesh Agricultural Research Institute (BARI) has developed this power tiller operated strip till seeder for sowing wheat seed by reducing turnaround time and ensures less disturbance of soil.This ST will increase productivity by reducing input energy use and GHG emission compared to conventional tillage system.

Globally, agriculture is a major contributor to anthropogenic greenhouse gas emission. It ranges from 10-12% (Smith et al., 2007) and in some studies it become up to 15% (EPA 2004) and through extension and intensification of agriculture, this contribution is rising. Agriculture is predicted to be one of the biggest sources of GHG emission in Bangladesh releasing 78 Tegagram (Tg) carbon-di-oxide (CO2) eq in 2016, to which rice production provides almost 30% of total GHG emissions from agriculture (FAOSTAT 2018). Bangladesh is regarded as one of the global most vulnerable countries to climate change because of its socioeconomic condition and geographic position (Islam and Nursey-Bray, 2017). It is essential to pay attention to its mitigation. ST system in wheat production can reduce GHG emission as compared to CT system in wheat production.

Energy is consumed and produced by agriculture itself in the form of bioenergy (Ramachandra and Nagarathna, 2001). Intensive agriculture in Bangladesh requires high amount of energy for successful and sustainable crop production. The productivity and profitability (Alam et al., 2005) and also crop yield is directly proportional to input (Srivastava 1982). There are two types of energy are available in agriculture ie; commercial and non-commercial. Commercial energy includes seed, chemical fertilizers, pesticides, human labor, animal labor, machinery, fuel and electricity. The non-commercial energy is natural energy like solar and wind energy etc.In Bangladesh, energy use in agriculture increased due to increase in cereal production (MOF,2012) and energy input increased faster than energy output (Alam et al., 2005). On the other hand, commercial input cost for agriculture is increasing and fuel reserves also declining that warn the scientist to develop energy efficient technologies. The efficient and optimum use of input energy can increase yield up to 30% (Choudhury et al., 2006) and contribute to agricultural sustainability (Singh et al., 2002; Ozkan et al., 2004). This ST may save more energy than CT without reducing the yield of crops. In this part of the study, input-output and energy use efficiency of ST and CT were compared. Many studies have been carried out in Bangladesh, related to crop yield in ST system; however, a few studies have assessed the GHG emission and energy aspects. Hence, the present study was conducted to evaluate the yield performance of wheat in ST and to estimate the change in input-output energy,energy use efficiency and GHG emission in ST as compared to CT.

2. Materials and Methods

2.1. Study Site

The trial was managed at the Paba MLT site, Rajshahi during the year of 2016-17, 2017-18 and 2018-19 in High Ganges River Flood Plain Soil (AEZ-11) to estimate the change in input-output energy and GHG emission in ST as compared to Conventional tillage (CT). The location is situated at 24.436617° N, 88.599847° E. The altitude is 24 m from the sea level of the trial area. The climatic features of the study area are the sub-tropical monsoon and unimodal (uneven) rainfall round the year. May to September received most of the rainfall and the rest of the monthsobtained a lesser amount of rainfall. The total rainfall from November to Marchof the succeeding three years was 45.7 mm, 46 mm and 132.4 mm, respectively and average monthly maximum and minimum temperature reduced up to January and then increased up to dry summer (Fig. 1).

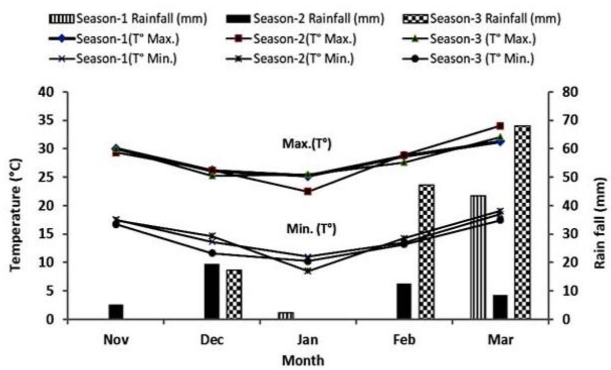

Figure 1. Monthly (crop season only) average maximum and minimum temperature, and rainfall during the period from 2016-17 (season 1), 2017-18 (season 2), and 2018-19 (season 3)

2.2. Experimental Details

The production program was done in a compact twohectares' block. Seeding was done in the half of land with the help of power tiller operated Strip tillage machine and other half by conventional tillage (power tiller) system. Recommended fertilizer doseswere applied just before only one pass of Strip tillage (ST) operation. Strip tillage is an agricultural tillagesystem that includes tilling only a narrow strip of soil where seeds will be sown, while leaving between the rows untilled.Strip tillage covers minimum tilling in the direction of row, seeding and laddering in a single machine pass. But in Conventional Tillage (CT), the land was cultivated well with three ploughing followed by laddering. At the last stage of field preparation, the recommended fertilizers dosages were applied.In both cases, land was fertilized with 5 tons of cow dung and inorganic fertilizers @100-26-50-20-1.5 kg ha^{-1} NPKS and B respectively. Entire amount of P, K, S and B fertilizers with two third of nitrogen were applied as basal and rest one third of N (urea) was top dressed at CRI stage (18-21 DAS) after 1^{st}irrigation. Affinity was sprayed after 5 days of 1st irrigation for the control of broad leaves weed. Seeding was doneat 22 November, 24 November and 25 November in the year 2016, 2017 and 2018 respectively. The wheat variety was BARI Gom-30. The seed rate was 120 kg $ha^{-1}$and 150 Kg ha^{-1}in ST and CT respectively. Crop was harvested on 23 March, 25 March and 28 March in 2017, 2018 and 2019 respectively. All necessary data were collected and yield data of ST and CT were analyzed statistically with t-test. A P-value <0.05 was treated as significant variation between them. The sustainable yield index (SYI) was calculated by the following formula suggested by Krishana and Reddy (1997).

$$YSI = \frac{Ymean - SD}{Ymax} \times 100$$

Where, Y_{mean} = Mean yield from a treatment over years, SD = Standard deviation of the treatment, and Y_{max} = Maximum yield obtained in the treatment.

2.3. Cool Farm Tool

Cool Farm Tool Beta-3 (CFT) was used to determine total greenhouse gas (GHG) emission in wheat production systemunder ST and CT.The tool is farmer-focused and records information about on-farm activities that the farmer is familiar with or can quickly determine while in the field.

The most of the data on input variables of different Cool Farm emission factors were collected from field during experimentation and some are collected direct contact with farmers and other stakeholders. The considered input variables, emission factors and outputs unitof CFT are shown in Table 1.

2.4. Input-output energy calculation

In energy calculation, seed sowing (in CT), fertilizers and pesticides application, irrigation application, different intercultural operations, harvesting and drying are stated as human labour. On the other hand, seed, seed sowing (in ST), fertilizers, pesticides and fuel use for land preparation (in CT), seed sowing (in ST), irrigation and threshing were estimated. The energy used from non-commercial sources was excluded due to they were coming from natural sources. The energy output was also calculated from the amount of grain (product) and straw (by-product) of wheat produced from both tillage options. The total input and output energy of different tillage options of wheat were calculated by using the energy co-efficient (Table 2) of different input and output items as suggested by many scientists (Eusuf et al., 1987; Mittal and Dhawan, 1988; Hassan and Ahmed,1990; Argiro et al., 2006 and Alam,1991). The energy input and output were calculated as Mega Joule (MJ) by following formula.

1) Energy input = $E_{hl} + E_{pr} + E_{mt}$

Where, E_{hl}= Energy from labour (Human labour), E_{pr}= Energy from power and E_{mt}= Energy from materials (fertilizers, Seed, and pesticidesetc).

2) Energy output = $E_{mp} + E_{bp}$

Where, E_{mp}= Energy from main product and E_{bp}= Energy from by- product.

2.5. Input-output energy analysis

After calculation of input and output energy, the input and output energy analysis was carried out to examine the quantity of energy yielded by the tillage options compared to the energy expenditure. The analysis of energy was done by the following energy indices equations.

3) Net energy (MJ) = *Energy output- Total energy input*

4) Energetic efficiency or Energy ratio = $\frac{Output\ energy}{Input\ energy}$

5) Specific energy (MJ/kg) = $\frac{Input\ energy\ (MJ)}{Crop\ yield\ (kg)}$

6) Energy productivity (kg/MJ) = $\frac{Crop\ yield\ (Kg)}{Input\ energy\ (MJ)}$

3. Results

3.1. Yield and yield sustainable index

The result showed that the grain yield was significantly different between the tillage options in the year of 2016-17, 2017-18 and 2018-19. The yield was significantly higher (Table 3) in strip tillage in every year than conventional system. The wheat yield was 4164 $kgha^{-1}$, 4334 $kgha^{-1}$ and 4294 $kgha^{-1}$ in strip tillage in the year of 2016-17, 2017-18 and 2018-19 respectively. On the other hand, the wheat yield was 3292 $kgha^{-1}$, 4142 $kgha^{-1}$ and 4042 $kgha^{-1}$ in the year of 2016-17, 2017-18 and 2018-19 in conventional tillage system which were significantly lower than ST. The average three years yield was 4264 $kgha^{-1}$ in ST which was 9.6% higher than CT (3892 $kgha^{-1}$). In case of yield sustainable index (YSI), the ST system (96%) was more sustainable than CT (85%). The straw produced in ST was always higher than CT.

3.2. Greenhouse gas emission

Greenhouse gas emission in different sectors during wheat production in strip tillage (ST) and conventional tillage (CT) was presented in Table 4. The strip tillage (ST) produced 210 kg CO_2eqha^{-1} greenhouse gas in crop residue management sector during the crop season where CT produced 440kg CO_2eqha^{-1} GHG.Thus, ST emitted 52.3% lower GHG than CT in crop residue management sector. Soil and fertilizers sector produced 1280 kg CO_2eqha^{-1} GHG in ST and 1270 kg CO_2eqha^{-1} GHG in CT. The ST liberated 43.3% lower (170kg $CO_2eq\ ha^{-1}$) in fuel use sector where CT produced 300 kg CO_2eqha^{-1} GHG. Crop protection and off farm transport sectors produced the same amount of GHG in both the tillage systems. In case of total emission, ST emitted 16.8% (1749kg CO_2eqha^{-1}) lower GHG than CT (2099 kg CO_2eqha^{-1}) during wheat production period. ST liberated 24.1% lower GHG (0.41kg CO_2eqkg^{-1} product) to produce per kilogram product compare to CT (0.54 kg CO_2eqkg^{-1} product).

3.3. Input-output energy and energy analysis

Energy input in seed, fertilizers and manure, pesticides, fuel and labor are shown in Table 5. The input energy used for the production of wheat was influenced by ST and CT tillage techniques. In this study, fertilizers and manure (11904 MJ) accounted for a major share of energy input in ST followed by seed (1764 MJ ha^{-1}), fuel (1520 MJ ha^{-1}), labor and pesticides. On the other hand, fertilizers and manure (11904 MJ) accounted for a major share of energy input in CT followed by fuel (3705 MJ ha^{-1}), seed (2205 MJ ha^{-1}), labor and pesticides. STconsumed 20%, 59% and 16% lower input energy than CT in the sectors of seed, fuel and labor respectively.The total energy input requirement of wheat was minimum in ST (16692 MJ ha-

[1]) and maximum in CT (19553 MJ ha^{-1}). ST spent overall 14.6% lower total energy input than CT. The total energy output from grain (main product) and Straw (by-product) of wheat was computed and presented in Table 6. The by-product of wheat contributed the higher output energy than grain output energy in both the tillage options.The higher grain (62682 MJ ha^{-1}) and straw (101450 MJ ha^{-1}) output energy were found in ST where the CT produced the lower grain (57212 MJ ha^{-1}) and straw (93984 MJ ha^{-1}) output energy. The higher total output energy was calculated in ST (164132 MJ ha^{-1}) which was 8.56% higher than CT (151196 MJ ha^{-1}). The net energy was also 12% higher in ST (147440MJ ha^{-1}) than CT (131643 MJ ha^{-1}). The energy ratio or energy efficiency in wheat cultivation was found higher in ST (9.83) than CT (7.73). Specific energy was found maximum in CT (5.02 MJ kg^{-1}) and minimum in ST (3.92 MJ kg^{-1}). The energy productivity was found 30 % higher in ST (0.26 kg MJ^{-1}) than CT (0.20 kg MJ^{-1}).

3.4. Economic analysis

Strip tillage (ST) minimized land operation cost due to one pass of Strip tillage is equivalent to three pass with one laddering of CT tillage. Economic analysis (Table 7) also revealed that total variable cost minimized due to the reduction of the land operation cost in ST (Tk. 35285 ha^{-1}) compared to CT (Tk. 38175 ha^{-1}). The higher gross margin was produced by ST (Tk. 71317.5 ha^{-1}) than CT (Tk. 59125 ha^{-1}).

Table 1. Considered emission factors, input variables and cool farm tools (CFT) output

Emission factors	Input variables	CFT output
Crop residue management	Amount of residue, management practice	Kg CO_2 e/ha, Kg CO_2 e/kg product
Soil and fertilizers	Soil texture, soil PH, soil moisture, soil drainage, fertilizer type, fertilizer origin, application rate	Kg CO_2 e/ha, Kg CO_2 e /kg product
Crop protection (Pesticides)	Application rate, number of application	Kg CO_2 e/ha, Kg CO_2 e/kg product
Energy use (Diesel)	Types, Liters used	Kg CO_2 e/ha, Kg CO_2 e/kg product
Off farm transport	Fuel type, liters used, vehicle type, goods weight, distance	Kg CO_2 e/ha, Kg CO_2 e /kg product

Table 2. Energy co-efficient of different input and output during wheat cultivation

Input		Output	
Input name	Co-efficient (MJ kg^{-1})	Output Name	Co-efficient (MJ kg^{-1})
1. seed	14.70	1. wheat grain	14.70
2. Fertilizer		2. wheat straw	18.90
a. N	60.10		
b. P	11.10		
c. K	11.10		
d. Manure	1.0		
3. Pesticides			
a. Insecticides	145.0		
b. Herbicides	200.0		
4. Diesel	56.31		
5. Human labor	1.96		

Table 3. Yield and Yield Sustainable Index (YSI) of wheat in Strip Tillage (ST) and Conventional Tillage (CT) at Paba, Rajshahi during 2016-19

Tillage options	Yield (kg ha^{-1})								Yield increased over CT (%)	Yield Sustainable index (%)
	Year: 2016-17		Year: 2017-18		Year: 2018-19		Average			
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw		
ST	4164	5168	4334	5493	4294	5443	4264	5368	9.6	96
CT	3492	4473	4142	5273	4042	5173	3892	4973	-	85
P-Value	0.0	0.0	0.0	0.0	0.0	0.0	-	-	-	-
Sig. level	**	**	**	**	**	**	-	-	-	-

Table 4. Sector wise Greenhouse Gas (GHG) emission in Strip tillage (ST) and conventional tillage (CT) system

Sectors	Greenhouse gas (GHG) emission (kg CO_2 e/ha)		GHG emission reduced/ increased in ST over CT (%)
	Strip tillage (ST)	Conventional tillage (CT)	
Crop residue management	210	440	52.3
Soil and fertilizers	1280	1270	(0.80)
Crop protection (Pesticides)	82	82	0
Energy use (Diesel)	170	300	43.3
Off farm transport	7	7	0
Total emission/ha	1749	2099	16.8
Emission/kg product	0.41	0.54	24.1

The figure in the parentheses indicates the % increase in ST system

Table 5. Sector wise energy input in Strip tillage (ST) and Conventional tillage (CT) options

Tillage options	Energy input (MJ ha^{-1})					Total Energy input (MJ ha^{-1})
	Seed	Fertilizers & Manure	Pesticides	Fuel	labor	
ST	1764 (20%)	11904	269	1520 (59%)	1235 (16%)	16692 (14.6%)
CT	2205	11904	269	3705	1470	19553

CT: conventional tillage, ST: strip tillage; figures in parentheses indicate the % of decreased input energy use in ST than CT

Table 6. Input-Output energy and energy analysis in Strip tillage (ST) and Conventional tillage (CT) options

Tillage options	Total Energy Input ($MJha^{-1}$)	Energy output ($MJha^{-1}$)		Total Energy output ($MJha^{-1}$)	Energy Analysis			
		Grain	Straw		Net Energy ($MJha^{-1}$)	Energy efficiency	Specific Energy (MJ kg^{-1})	Energy productivity (Kg MJ^{-1})
ST	16692	62682	101450	164132 (8.56%)	147440 (12%)	9.83	3.92	0.26 (30%)
CT	19553	57212	93984	151196	131643	7.73	5.02	0.20

Figures in parentheses show the percentage of increased output energy, net energy and energy productivity in ST than CT

Table 7. Cost and return analysis of wheat crop under Strip tillage (ST) and CT at Paba, Rajshahi during 2016-19

Tillage option	Yield (kg ha^{-1})	Gross income (Tk. ha^{-1})	Total variable cost (Tk. ha^{-1})	Gross margin (Tk. ha^{-1})	BCR
Strip tillage (ST)	4264	106600	35285	71315	3.02
CT	3892	97300	38175	59125	2.55

NB : Wheat @ 25 Tk/kg and Wheat Seed @ 50 Tk/kg, Urea @ 16Tk/kg, TSP @ 22 Tk/kg, MOP @ 15 Tk/kg, Gypsum @ 7 Tk/kg, Boric Acid @ 350 Tk/kg, Labour wage @ 400 Tk/day and Power tiller 2250 Tk ha^{-1}/pass, Strip tillage: 3750 Tk/ha

4. Discussions

In the experiment, the field observations and comparisons with conventional tillage (CT), the strip tillage (ST) produced the higher yield of wheat during the studied period of consecutive three years. The incretion of yield in ST that may be due to the proper placement and distribution of seed, good germination and plant establishment (Ganesh, 1999) and also crop residue used as mulch preserve soil moisture and resist weed seeds to grow for proper growth and development of wheat. Hossain et al. (2005)stated that ST produced higher spikes m^{-2} and yield in wheat than CT. The higher gross margin was achieved in ST due to the higher yield and less variable cost than CT. The lower variable cost incurred in ST due to lower seeding cost, less seed and labor requirement and less fuel consumption. Hossain et al, (2005) stated similar observationsin their study in Bangladesh.Wang et al. (2024) also reported that ST increased maize yield by 9.7%. The higher sustainable yield index was also achieved in ST indicating that amore suitable grain yield was achieved in ST compare to CT system.

In greenhouse gas emission, the soil tillage system is one of the greatest significant contributors to CO_2 emissions in agriculture. ST liberated 16.8% reduced amount of total GHG than CT. It may be due to the effect of minimum tillage, residue management and less fuel use in ST than CT. Crop residue management sector in the present study, ST emitted 52.3% less GHG than CT. Burning of residues in wheat fields liberated more GHG in CT system where as incorporation of residues in fields reduced the same in ST system. Urban Cordeirs et al. (2024) reported that incorporation of crop residues into the soil is better for the environment than burning them because it reduces greenhouse gas emissions and helps the soil. Wang et al. (2024) also reported that ST significantly decreased GHG releases by 8.5% compared to CT.

ST reduced 43.3% GHG emission in the fuel consumption sector than CT system in the study dueto the less fuel use in land preparation and seeding in ST system. Stajnko et al (2009) reported that fuel consumption was higher under CT than reduced tillage in corn silage. Jaskulska and Jaskulski (2020) also reported that the ST reduced 20-30 L ha^{-1} of fuel use than CT.

Irrespective of tillage practices, the energy input was higher in CT system over ST due to the higher fuel consumption, seed and labour requirement in CT. ST practice reduced the energy input due to saving of energy in tillage practice where seed, fuel and labour were also saved compare to CT system. In this study, ST reduced 14.6% of total energy input than CT system. Choudhury and Behara (2014) reported that the adoption of zero tillage practice saved on an average 22% input energy consumption in maize and Stajnko et al (2009) also added that the CT require higher energy input. The total energy output from wheat grain and straw was higher in ST system than CT due to the higher grain and straw productivity in ST. The energy ratio or energy efficiency was higher in ST due to the utilization of lower input energy and achieved better yield to produce higher output energy as compare to CT. Specific energy requirement was higher in CT indicated that CT method utilized more input energy in wheat production and produced less yield as compared to ST. The energy productivity was higher in ST indicated that one Mega Joule (MJ) input energy produced maximum grain as compared to CT. It may be due to the lower input energy produced higher wheat yield in ST. All these energy analyses were also supported by Choudhury et al (2020) in zero tillage maize production.

5. Conclusion

This study provides an inclusive and quantitative assessment of ST and CT effects on wheat yield, GHG emissions and energy use in AEZ-11 during wheat production period. It is revealed that ST changed wheat yield, GHG emissions and energy use patterns in wheat production. Crop residue management, soil and fertilizers and fuel use sectors are the highest contributors of GHG emission and management of those sectors are the possible pathway to reduce GHG emission in wheat production. In general, ST reduced16.8% total GHG emission and 14.6% total input energy with a simultaneous increase in wheat yield of 9.6% and showed higher energy productivity than CT. Energy analysis quantifies the amount of energy needed for crop production. It can also be applied to optimize energy efficiency consumption to bring agriculture closer to sustainability in Bangladesh. Future ST studies should include additional field data for the entire cropping pattern of a year as this could more accurately represent the full expression of GHG emission and energy use variations between ST and CT.

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Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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