Designing an Energy Use Analysis and Life Cycle Assessment of the Environmental Sustainability of Conservation Agriculture Wheat Farming in Bangladesh

Md Mashiur Rahman ⬤, Md Sumon Miah, Md Aminur Rahman, Mukaddasul Islam Riad, Naznin Sultana, Monira Yasmin, Fouzia Sultana Shikha, and Md Manjurul Kadir

Abstract The agricultural sector in Bangladesh is an ongoing societal expectation of reducing environmental impacts and increasing crop productivity to provide food security for its growing population. Introducing life cycle assessment is a systematic approach for establishing how sustainable a crop may become and the potential impacts of complete life cycle wheat farming on the environment and input resource conservation. This innovative field study focuses on conservation agriculture wheat farming to increase energy use efficiency (EUE) and environmental sustainability by decreasing greenhouse gas (GHG) emissions through comparing different conservation tillage practices to conventional tillage. Furthermore, the study estimated the net

M. M. Rahman (✉)
Agricultural Engineering Division, Regional Agricultural Research Station, Bangladesh Agricultural Research Institute, Jamalpur 2000, Bangladesh

M. S. Miah
Scientific Officer, Farm Machinery and Postharvest Process Engineering Division, Bangladesh Agricultural Research Institute, Gazipur 1701, Bangladesh

M. A. Rahman
Agricultural Engineering Division, Regional Agricultural Research Station, Bangladesh Agricultural Research Institute, Rahmatpur, Barisal, Bangladesh

M. I. Riad
Farm Division, Regional Agricultural Research Station, Bangladesh Agricultural Research Institute, Jamalpur 2000, Bangladesh

N. Sultana
Entomology Division, Bangladesh Sugarcrop Research Institute, Ishwardi, Pabna 6620, Bangladesh

M. Yasmin · F. S. Shikha
Soil Science Division, Regional Agricultural Research Station, Bangladesh Agricultural Research Institute, Jamalpur 2000, Bangladesh

M. M. Kadir
Chief Scientific Officer, Regional Agricultural Research Station, Bangladesh Agricultural Research Institute, Jamalpur 2000, Bangladesh

carbon footprint (CF) of wheat farming, taking into account the additional contribution of soil carbon sequestration and offered a model of the environmental sustainability for wheat farming. The FEAT tool was used to assess energy use analysis, life cycle GHG emissions, and CF during the life cycle (CF) wheat farming. The introduced strip tillage (ST), minimum tillage (MT), and conventional tillage (CT) were predicted by utilizing input enegy of 18,764.29, 18,728.78, and 20,564.32 MJ ha^{-1} in wheat farming, respectively, with the EUE of 8.46, 8.65, and 6.25%. Among the tillage practices, MT is the most effective practice option in the wheat farming production process. The net life cycle GHG emissions were observed to be 1.968, 1.977, and 2.023 kgCO$_2$eq ha^{-1} for ST, MT and CT, respectively, where the CF was estimated to be 0.013, 0.012, and 0.014 kgCO$_2$ MJ^{-1}. As a result, CA-based ST and MT practices to be the most effective life cycle GHG mitigation options for wheat farming in Bangladesh.

Keywords Conservation Agriculture · Conservation tillage · Life cycle assessment · Energy footprint · Greenhouse gas emission · Carbon footprint

Highlights

1. Strip tillage (ST), Minimum tillage (MT), and conventional tillage (CT) were introduced.
2. Conservation tillage affected carbon footprint through soil organic carbon accumulation and yield.
3. MT practice had the lowest energy input calculated in 18,728.78 MJha^{-1}.
4. Minimum net life cycle GHG emissions was 1.968 kgCO$_2$eqha^{-1} for ST practice.
5. The carbon footprint was estimated as 0.012 kgCO$_2$MJ^{-1} of energy output for MT practice.

1 Introduction

The agriculture sector in Bangladesh is expecting to increase the crop production through a sustainable management practices for overcoming ongoing increasing food security due to growing its population of 164.7 million currently [72] and awaited to reach 205 million by 2050 [10], while need to reduce energy inputs to secure agriculture profitability and also ensure environmental sustainability in term of greenhouse gas (GHG) emissions [11, 58, 60]. Emerging conservation agriculture (CA) can be suggested as one of the solutions in sustainable crop management practices which consisting of minimal soil disturbance, crop residue retention, and diverse crop rotations for the possibility to obtain higher crop productivity, increasing energy use efficiency (EUE), improving soil quality and also reducing GHG emissions [17, 18, 39, 79], which is practiced over 3.9 Mha area of South Asia [38]. Being implemented CA practice through management of minimum soil disturbance using

conservation tillage practices (CTP) and covering stable crop residue has grown in importance seeking to improve EUE and reduce life cycle GHG emissions of agricultural farming, as well as increasing crop productivity [30, 69, 70]. These benefits have identical advantages to increasing adoption of CA practices worldwide [73, 77].

CA-based CTP is a tillage system of minimizing soil disturbance which creates a suitable soil environment for growing crops by way of conserving soil, water, and energy resources, mainly through reduction of the intensity of tillage passes and a minimum of 30% of the topsoil covered with the stable crop residues [61]. With this, CTP has a significant influence on soil physical and chemical properties for maintaining soil health due to tilling soil with a minimal; other main benefits of CTP are including—reduce soil erosion, decreased labor and energy inputs, increased availability of water for crop production [20]. Moreover, covering stable crop residue also benefits a sustainable crop production system that increases soil organic carbon (SOC), controls weeds, and improves soil structure that helps to reduce energy inputs, anchoring soil and adding carbon deep in the soil profile via roots [20].

Different tillage practices, including CTP such as minimum tillage (MT), strip tillage (ST), and conventional tillage (CT), are such crop management options based on the principles of CA [53], and this has been identified for mitigating GHG emissions in wheat farming [1, 12, 26, 37, 44, 52, 53]. Among these, ST and MT might be a good options for reducing GHG emissions and enhancing the SOC in the top layer of soil [21]. By adopting CTPs, GHG emissions can be reduced significantly in wheat farming by increasing SOC accumulation in soil [11]. On the contrary, soil tillage practices are an essential part of the agriculture production process, which has adverse effects on physicochemical properties of soil and environmental impacts [4]. Nonetheless, immense tillage practice has led to higher aeration that causes SOC breakdown and also increases GHG emissions [5]. The researcher reported that the CT and reduced tillage affected soil losses of about 207.7 and 111.5 Mg ha^{-1} [6].

Energy input is a crucial parameter used in the agricultural sector for producing food grains, although it is one of the main contributors to adverse environmental impacts for emitting GHG emissions [34, 76]. Agriculture has an energy use of 5% share globally [9]. Among these, the most energy sources come from non-renewable sources, leading to enormous GHG emissions. Various energy sources are utilized in the agriculture sector like human, renewable, coal, fossil fuel, solar, wind, and hydro, etc. Among these, fossil (diesel) fuel is used in higher amounts in developing countries for different machinery uses in agricultural farming operations [56]. Higher energy inputs, especially non-renewable energy inputs, reduce EUE in agriculture farming. In addition, many indirect energy inputs are used in agriculture farming, such as mineral or synthesis fertilizers, chemical pesticides, insecticides, and herbicides. For this, current energy consumptions in the agricultural production process need to be minimized for undertaking use of optimum level, which is the first assumption seeking to optimize any farming activities in terms of production cost to gain farm profitability and achieve agricultural sustainability [45, 62]. Therefore, analysis of energy use needs to be assessed to determine the EUE and environmental impacts for achieving the energy footprint of wheat farming. According to the Paris agreement on the climate change management strategy, the primary emphasis has been given

on reducing GHG emissions. Therefore, the ongoing agriculture farming requires to turn into the practice by adopting climate-smart agriculture. Hence, the different environmental footprints such as carbon and energy footprint are needed to assess environmental sustainability of crops.

However, recent agriculture and agricultural practices in Bangladesh have emitted GHG emissions of 37% among all sectors, where the combined share of agriculture and agricultural land use emitted 47.2%. In contrast, world agriculture and related land use contribute 19.79% of GHG emissions [24]. United Nations Environment Programme (UNEP) emissions gap report revealed that about one-third of the GHG emissions attributed is from agriculture and related land use [67]. It also reported that agriculture is one of the main four sectors contributing to GHG emissions and has proven to reduce GHG emissions. The report underlined that promoting CA practices in agriculture should play the proper role in reducing GHG emissions. That is why there is still hope for minimizing GHG emissions from the agriculture sector by applying conservation tillage practices [24, 58]. The agricultural sector has contributed to emitting more GHG concentrations into the atmosphere in recent decades. Improper soil management and the use of high amounts of energy (direct and indirect) inputs contribute significantly to these emissions [21].

All about it, life cycle GHG emissions is one of the global-scale climate change indicators to determine the environmental sustainability of any crop farming [29]. The amount of life cycle GHG emissions of crop or food production or services product is commonly expressed as carbon footprint (CF) [31, 54], where CF is a sustainability indicator to assess global warming potential (GWP) with a solid scientific basis, and it is measured as of carbon dioxide equivalents (CO_2eq) [71]. Recently, life cycle assessment (LCA) is the most employed approach to quantify different environmental footprints on life cycle farming activities. To assess the environmental impacts, use the term CF using the amount of GHG emissions per kilogram/ton of food or grains produced throughout the entire production process in all stages of a crop like tillage operation, application of fertilizers and pesticides, harvesting, processing, transport, storage, and consumption in the end during its life cycle [14]. Data of GHG emissions can be measured with the field measurement instruments or calculations based on emission factors (EF) given by IPCC [46]. The application of LCA analysis in wheat farming is not a new technolgoy and several international studies have investigated its importance as a user-friendly tool to evaluate sustainability within agricultural farming. In this study, the LCA approach was employed to assess the potential environmental footprint of wheat farming associated with the combination of different tillage practices, including CT practices and synthetic fertilizer, which was not investigated in the past.

Regard as mentioned above, this field study has been undertaken which has a special significance. In most of the studies, a higher share of energy inputs comes from agricultural machinery and synthetic chemical fertilizers, and the inputs energy consumption is also differed by different tillage practices. CTP, including ST and MT, is related to the lower fuels and energy inputs. In contrast, a CT practice is coupled with higher fuels and energy inputs. For this, a fundamental problem is the impact

assessment of different tillage practices on EUE and different environmental foot-prints in agroecosystems. Therefore, considering preliminary study in agroecosystem of conservation tillage wheat farming, this field experiment was conducted for the different tillage practices associated with the stable crop residue retention (20 cm) to evaluate the EUE, life cycle GHG emissions, and its impacts on the environmental footprint including energy and carbon footprint. In addition, this study investigated the performance comparison of energy use analysis and environmental footprint for the different tillage practices (ST, MT, and CT). Finally, a systematic LCA approach proposed a suitable model for sustainable wheat farming.

2 Materials and Methods

2.1 Study Site, Design, and Soil Sampling

The conducted field study was located in the research field at the Regional Agriculture Research Station (RARS), Jamalpur, Bangladesh, in the rabi season during 2019–21 and the site details are shown in Table 1. The experimental soil is in agro-ecological zone (AEZ) 8 and 9 of the young & old Brahmaputra and Jamuna floodplain of Bangladesh. The climatic condition was represented by semi-arid monsoon and sub-tropical within a variation of rainfall during the entire year. The crop was Wheat (*Triticum aestivum* L.)—BARI Gom 28 used in wheat farming. The unit area of experimental plots was 15 m × 13 m alongside a 2-m buffer distance among the experimental plots. The field experiment was performed in the same management practices followed by the same layout. The design of the experiment was adopted by a randomized complete block (RCB) design with four replications. The study treatments were based on different tillage practices and stable crop residue retention (20 cm), shown in Table 2. At the starting of the experiment, each plot was divided from the other according to the layout. The respective tillage practices were done by tillage machinery and stable crop residue retention was maintained with the previous crop of rice used in farmer's practice.

Table 1 Characteristics of the study field in wheat farming

Parameters	Details
Location	Regional Agricultural Research Station (RARS), Jamalpur, Bangladesh
Soil type	Silt clay loam
Location	24°56′32.3″ N latitude, 89°55′37.8″ E longitude, and altitude of 16.46 m
Rainfall	1549.45 mm, medium level Average rainfall (during November–March), 440 mm, concentrated in monsoon season (June–September)
Drainage	Moderate
Temperature	Maximum, 32 °C and minimum, 20 °C (avg.)

Table 2 Experimental treatment of wheat farming

Crop	Conservation tillage practices	Residue management
Wheat	T_1 = Strip tillage (ST), no disturbances of the soil	Stable crop residue management (20 cm)
	T_2 = Minimum Tillage (MT); single tillage	
	T_3 = Conventional Tillage (CT), farmer's practice	

At the pre-sowing and post-harvesting stages, soil samples from 0 to 20 cm deep were collected employing a soil auger. Nine soil samples from each treatment were collected, and the physicochemical properties of soils were determined the procedure delineated by the United States Department of Agriculture (USDA), National Soil Survey Center [14].

Table 3 shows the findings of the soil property study prior to land preparation. Soil carbon sequestration is a continuous process in soil activities to accumulate the soil organic carbon (SOC), which is applied to estimate carbon accounting, as the amount of SOC accumulation for CA formation during the initial soil condition and after crop harvesting differs. The SOC content in soil was determined using the wet oxidation technique. [36].

2.2   Soil Tillage and Agronomic Management Practices

Figure 1 shows the flowsheet of the wheat production process with the account to the LCA system boundary. Five days before planting, tillage practice was done in different treatments according to the design. The previous stable rice crop residue was left on the soil (20 cm) and pulverized during the tillage process. A power tiller-operated BARI inclined seeder was employed for land preparation and seed sowing in both strip tillage (ST) and minimum tillage (MT) practices [32]. For ST practice, the tine setting of the BARI inclined seeder was modified to 12 tines for tilling purposes at each journey and seed sowing was done in six rows with a 20 cm line to line spacing. Thus, the soil was ploughed to a depth of 6–7 cm, and the wheat seed was sown in lines at a specific distance using a seed metering device at a seed rate of 120 kg ha^{-1}. The seed rate was calibrated following the BARI's standard seed rate [19]. One machine operator and one labor were only needed to perform tilling and sowing operations. Soil tilling practice was maintained to a minimum level under the MT practice. The primary goal of MT pracitce is to pulverize the soil, along with the crop residue and weeds. This method was used to incorporate crop residue and weeds into the topsoil, increasing the SOC in the soil. A power tiller-operated BARI inclined seeder with 48 tines was used to till the soil surface, and the seed planting operation was carried out, using the same approach as ST practice. The only difference between these two tillage methods is that tillage practice; ST was followed for tilling in lines

Table 3 Initial soil analysis results in wheat farming

(a) Physical characteristics of soil

Soil depth (cm)	Particle density (g/cm³)	Bulk density (g/cm³)	Porosity (%)	Infiltration (mm/hr)	Field capacity (%)	Soil texture
0–20	2.62	1.40	46.81	8.50	29.41	Silt clay loam

(b) Chemical characteristics of soil

Sample	pH	SOM (%)	SOC (%)	Ca	Mg	K	Total N (%)	P	S	B	Cu	Fe	Mn	Zn
				m_{eq} 100 g^{-1}				μg g^{-1}						
Mean	6.5	2	1.16	6	1.9	0.12	0.1	4.81	8.76	0.32	2.4	24	4	1.22
Critical level	–	–	–	2	0.5	0.12	–	10	10	0.2	0.2	4	1	0.6
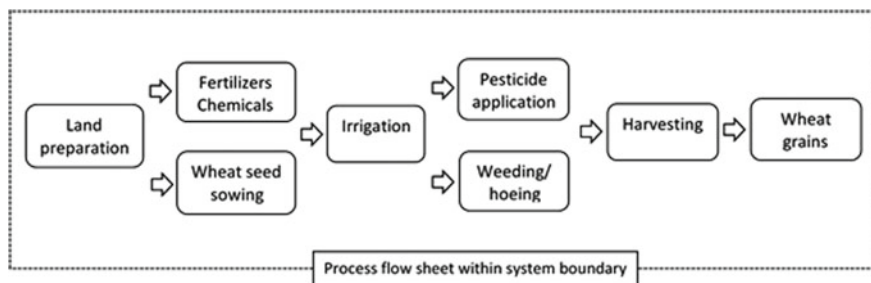
Fig. 1 Wheat production flow sheet in the LCA system boundary

where line outside soils were untilled, and MT was followed for tilling all over the soil up to 6–7 cm depth. One operator and one labor were needed to perform tilling and sowing operations in MT practice. Both ST and MT practices can save a significant amount of time and fuel compared to the conventional tillage (CT) practice [60]. CT practice, known as commonly farmer tillage practice, is used for intensive operations in Bangladesh. Tillage was performed with a power tiller up to 16 cm, pulverizing the soil 4–5 times, while removing exposed weeds from the topsoil. The seed sowing operation was performed manually by broadcasting. This operation took a long time and more fuel was consumed in the tilling operation, resulting in higher energy inputs. In these circumstances, an adverse soil environment was created when higher soil tillage was performed for land preparation, which was unfavorable for growing the beneficial soil microorganisms that are responsible for biomass decomposition and recirculation of biogenic elements that makes nutrients available to plants and growth of SOC concentration [27].

The application rate of chemical fertilizers for the first year was $N_{120}P_{108}K_{80}S_{85}Zn_{10}B_{5.2}$ based on the initial soil test in order to higher yield goal [7] and for the second year, the fertilizer application rate was $N_{60}P_{52}K_{40}S_{85}Zn_{10}B_{5.2}$ to minimize the environmental effects. At land preparation time, urea (one-third) was mixed with triple superphosphate (TSP), MoP, gypsum, and $ZnSO_4$ and then mixed fertilizers was applied to the soil. Half of the urea from the remaining quantity was applied at 25 days after sowing (DAS) and the remaining urea was applied at 45 DAS. Irrigation was used after each fertilizer application. When necessary, the weeder machinery performed intercultural operations. Weeds in ST plots were partially controlled by spraying a post-emergence selective herbicide, Affinity (Carfentrazone ethyl + Isoproturon) @ 2.5 g/L water at 25 DAS, with just one hand weeding at 28 DAS for complete weed removal. The gravimetric method was used to closely monitor the soil moisture[13]. Wheat seeds were sown in the study field on 15 November 2019. During the whole duration, irrigation activities were carried out three times in a volumetric and regulated manner by the measurement system. Irrigation water was applied based on growth stages and DAS; first irrigation was applied after sowing to supply available moisture in the soil, creating favorable conditions for seed germination; second irrigation at 25 DAS was applied when milk stages emerged; and final irrigation was applied at days of heading (51 DAS). An herbicide

spray was applied at 25 DAS on the same day of irrigation applied. Harvesting operation of wheat farming was done by a combined harvester of 16 hp. Fuel measurement was done during farming activities while taking into account time losses for operator personnel [2]. The following equation (1) was used to compute the production energy for agricultural machinery and harvesters [16]:

$$M_e = GM_{pe}/TW \tag{1}$$

where M_e represents the energy of machine per unit area (MJ/ha^{-1}), G represents the machine mass (kg), M_{pe} represents the machine production energy (MJ kg^{-1}), T represents the economic life (h), and W represents the effective field capacity (hah^{-1}).

2.3 LCA Modeling

The LCA is a useful tool for evaluating the environmental sustainability of a process, product, or system over the course of its entire life cycle [68], which was applied in this study to determine the life cycle GHG emissions as a global warming potential (GWP). This study of wheat farming took into account from cradle to farmgate for considering an LCA analysis of energy and carbon footprint [35]. A farm energy analysis tool (FEAT) was employed as a whole-farm approach within the LCA system boundary to estimate energy and carbon footprint, where FEAT is a static, deterministic, and database tool. The newest version developed in 2018 was used in this analysis, together with the most suitable historical database for this study [15]. This database was selected as the reference library to complete the inventory analysis as it is mainly used to help the agricultural sector improve its practices. An advantage of using the FEAT tool over others is that it can be assimilated with it for its transparency and accuracy of any local data. This program is simple to use, allowing it to be used as a dynamic crop production tool to study life cycle energy usage and GHG emissions. If emission factors (EF) were not accessible for any inputs, they were created using a combination of generic and local data from Bangladesh.

2.3.1 Modeling of Life Cycle Energy Flow

Life cycle energy flow modeling is necessary to determine the optimum use of energy inputs for respective agricultural crop and their impact on improving the EUE from the farming inputs. Based on energy consumption, agriculture input energy is separated into direct and indirect energy [76]. Machinery used in agricultural operations, such as tillage for land preparation, seed sowing, fertilization, irrigation, harvesting, threshing, and transportation, were performed by different agricultural machinery, are known as direct input energy. Human power was adopted in every operation

of wheat farming in Bangladesh. Besides these, other necessary inputs energy was also applied in wheat farming which is called indirect input energy, such as farm machinery, seed, pesticide, and chemical fertilizer. For assessing optimum energy usage in wheat farming, energy balance calculations employing direct (operational) and indirect energy were examined. Many other types of energy, such as renewable energy such as seed and human power, and non-renewable energy such as chemicals, fertilizer, herbicides, diesel fuel, water, and machinery, were also identified.

Life cycle energy input–output usage was determined using different energy inputs and outputs, wheat grain yield, and biomass (wheat residue) output (Table 4). Energy equivalents of different inputs and outputs parameters for conservation agriculture wheat farming were extracted from related studies (Table 5). After then, input and output energy of CA-based wheat farming for different tillage practices were calculated by their respective quantity multiplying with their energy equivalent [34]. Finally, the following equations in Table 6 were used to determine energy indicators such as energy use efficiency/energy yield, energy productivity, specific energy, mechanization index, net energy, and agrochemical energy ratio [40, 57, 74].

2.3.2   Modeling of Life Cycle GHG Emission Analysis

According to ISO 14040 LCA approach, LCA addresses quantitative assessment methods for assessing the environmental aspects of a product or service throughout its entire life cycle stages, which defines four conceptual steps, including goal and scope definition, life cycle inventory (LCI), life cycle impact assessment, and interpreting results [25, 68]. The LCA approach was applied to estimate the global warming impact (GWI) in terms of total GHG emissions of agricultural products, as reported by the recent literature [2, 22, 68]. Then, the net life cycle GHG emissions were determined after subtracting SOC accumulation from overall GHG emissions.

Goal Setting and Scope Definition

The study aims to conduct the GHG emissions assessment of wheat production, distribution of the wheat grain to the storage and end-of-life treatment. A functional unit is a unit of measurement used to calculate the function of a system and its environmental implications, where the functional unit, are commonly defined by the weight or volume of a product, used for this study as one kilogram per ton of wheat grains produced by a CA-based wheat production process (Fig. 1). For this, the LCA system boundary for wheat farming was employed from cradle to farmgate, which has both off-farm and on-farm stages. The system boundary encompasses all inputs used in the production process and releases of all sorts of emissions. This study intended to identify emission impact categories and compare the influence of input energy on environmental sustainability. The inputs were categorized as system inputs, and the product produced along with the release of emission were categorized as system outputs. The detailed agricultural modeling of wheat production farming was not included in the scope of the study; a readily available dataset was applied to include the contribution of wheat farming in the overall process.

Table 4 Energy input-outputs usage in wheat farming

Operations	Input	Unit	Strip tillage (ha)	Minimum tillage (ha)	Conventional tillage (ha)
Land preparation	Power Tiller (PT)	h	–	–	24.7
	PTOS	h	11.2	11.2	–
	Diesel Fuel	l	13.5	13.5	24.7
	Human Labor	h	16.5	16.5	28.0
Planting	Seed	kg	119.8	119.8	164.67
	Human Labor	h	0.0	0.0	16.5
Fertilization	Nitrogen (N)	kg	90.0	90.0	90.0
	Phosphate (P_2O_5)	kg	80.0	80.0	80.0
	Potassium (K_2O)	kg	60.0	60.0	60.0
	Sulfur (S)	kg	85.0	85.0	85.0
	Zinc (Z)	kg	10	10	10
	Boron (B)	kg	5.2	5.2	5.2
	Manure	kg	3750	3750	3750
	Human Labor		16.5	16.5	16.5
Irrigation	Electricity	Kwh	34	34	34
	Irrigation water	m3	2625.8	2625.8	2625.8
	Human Labor	h	49.4	49.4	49.4
Weeding	Human Labor	h	98.8	148.2	115.3
Spraying	herbicide	kg	1.6	1.6	1.6
	Human Labor	h	16.5	24.7	24.7
Harvesting	Combine Harvester	h	2.5	2.5	2.5
	Diesel Fuel	L	17.5	17.5	17.5
	Human labor	h	9.9	9.9	9.9
	Wheat Grains	kg	4014.9	4082.6	3820.5
	Wheat Straws	kg	5356.93	5486.8	5018.3

Table 5 Energy equivalents for different inputs and outputs energy in wheat farming

Operations	Parameters	Unit	Energy equivalent (MJ/unit)	Reference no
A. Inputs				
Tillage	Machinery	h	62.7	[80]
	Human labor	h	1.96	[47]
	Diesel fuel	l	56.31	[23, 76]
Seeding	Seed	kg	14.7	[41]
Fertilization	(a) Nitrogen (N)	kg	64.14	[59]
	(b) Phosphate (P_2O_5)	kg	12.44	[59]
	(c) Potassium (K_2O)	kg	11.15	[59]
	d) Zinc (Z)	kg	5.0	[41]
	e) Sulfur (S)	kg	1.12	[41]
Herbicide	Herbicides	kg	101.2	[51]
	Electricity	kWh	3.6	[41]
	Water for irrigation	m^3	1.02	[41]
B. Output				
	Wheat grain	kg	14.7	[41, 80]
	Wheat biomass	kg	18.6	[41, 42, 55]

Table 6 Equations followed to calculate the energy indicators

Energy use efficiency = Wheat grains yield$(kgha^{-1})$/Input Energy$(MJha^{-1})$	(2)
Energy productivity = Output energy$(MJha^{-1})$/Input Energy$(MJha^{-1})$	(3)
Specific energy = Input Energy$(MJha^{-1})$/Wheat yield$(kgha^{-1})$	(4)
Net energy = Outputenergy$(MJha^{-1})$ − Input Energy$(MJha^{-1})$	(5)
Agrochemical energy ratio(%) = Agrochemicals input Energy$(MJha^{-1})$/Input energy$(MJha^{-1})$	(6)

Life Cycle Inventory (LCI)

In these steps, a systematic approach to LCI is a technique for collecting, analyzing, and assessing total inputs and outputs (including emissions into the air, water, soil, and waste processes) flow of each production process while taking into account a system boundary (Fig. 2) [48]. In this stage, the amount of inputs flow, including material manufacturing and transport to the farm gate, and outputs flow for one functional unit of wheat grains to establish a complete LCI by applying a mass balance approach with LCA system boundary (Table 4) [2]. Here, the GHG emissions consisting of CO_2, CH_4, and N_2O were the negative outputs, and SOC accumulation was the positive outputs considering the LCA system boundary of this study. The GHG emissions observed within the LCI system boundary is mainly from off-firm and on-firm activities.
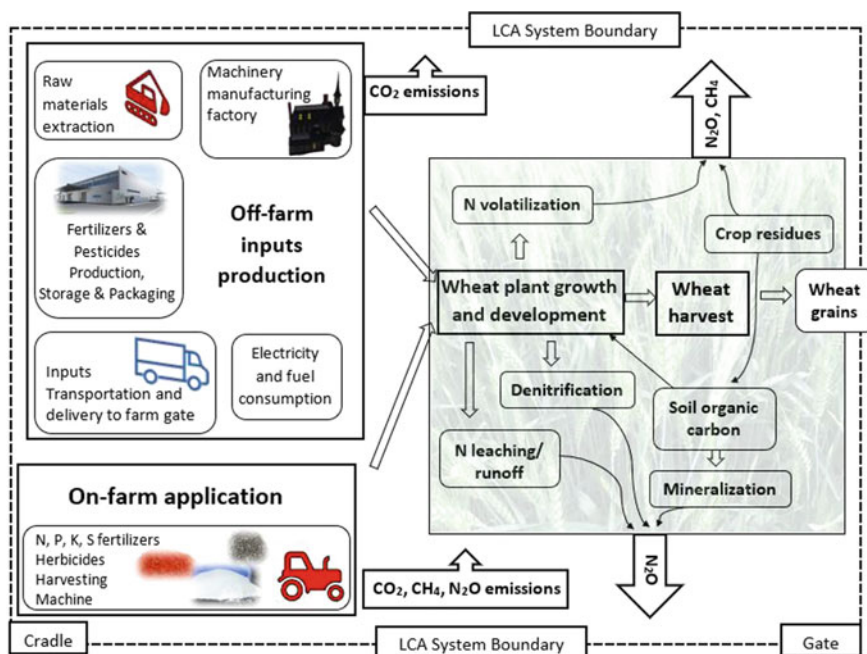
Fig. 2 LCA system boundary including off-firm, on-firm, growth, and development stages and after harvesting activities to analyze environmental aspects of CA wheat farming

Off-farm GHG emissions: Activities of agricultural inputs production and delivery up to farmgate related to GHG emissions were estimated, known as off-farm GHG emissions. The input and output database based on the LCA study for wheat farming was used to determine the farm machinery manufacturing responsible for indirect emissions [66]. The input and output database based on the LCA study for wheat farming was used to determine the farm machinery manufacturing responsible for indirect emissions [66]. Farm machinery's emission factor (EF) was determined by multiplying the machinery production cost for each functional unit, validating the amount provided in the reference [2]. The EFs of chemicals and herbicides used for wheat farming were sourced from the Bangladesh studies [2, 15], and the EFs of imported inputs to Bangladesh were derived from the studies, including fertilizer materials [2], as these data are defined for the local condition in Bangladesh. The GHG emissions data associated with materials transportation for one functional unit of wheat production were used from available databases of EFs of Road Transport [50].

The transportation vehicle for road transport was used in medium-sized trucks of 7 tons and for sea transport was used a medium-size cargo carrier. The GHG emissions associated with the activities of inputs delivery from storage factory to field gate is expressed as ton-kilometers (tkm) for road transport and ton nautical miles (tnm)

for sea transport. The inputs weight is multiplied by the distance between the wheat study field and storage factory for determining tkm and tnm [2, 43, 50, 78].

On-farm GHG emissions: On-farm GHG emissions was related to the on-farm activities for establishing wheat farming. The first emi ssion associated with diesel fuel use by farm machinery is for the preparation of land. Agricultural machinery, such as BARI Seeder, power tiller, and combine harvester, were used for land preparation, seed sowing and harvesting of different treatments of wheat farming. The GHG emissions was assessed for the application of chemicals and weeding in this stage. The fuel used was calculated in standard machinery usage terms (9.35 lha^{-1} for PTOS & BARI Seeder, 25.5 lha^{-1} for power tiller and 1.82–2.11 lton^{-1} for combine harvester). The direct GHG emissions from the soil related to CO_2, CH_4, and N_2O were estimated using the database study owing in FEAT tool. The N_2O emitted directly described in IPCC [65] and also emitted indirectly by ammonia volatilization, runoff of nitrate, crop residue in aboveground and belowground were examined from the database study owing in FEAT software.

Impact Assessment

By multiplying the emission factors (EF) with the associated inputs and outputs in Table 4, the total GHG emissions (CO_2, CH_4, and N_2O) for producing one functional unit of wheat production were determined. This total GHG emissions were converted to CO_2eq GHG emissions using the EF for the respective type of emission or global warming potential (GWP) by applying an IPCC method [65]. The CO_{2eq} GHG emissions for producing each functional unit of wheat production was determined based on GWP value of 100 years accordingly IPCC 2013, where the EFs of 25 and 298 were used for CH_4 and N_2O, respectively [65]. Finally, the following equation (7) was applied to determine net life cycle GHG emissions:

$$NGHG = TGHG - SOCA \tag{7}$$

where

NGHG represents the net life cycle GHG emissions (tonCO$_2$eq ha^{-1})
TGHG represents the total GHG emissions (tonCO$_2$eq ha^{-1}) and
SOCA represents the SOC accumulation in unit of land (kgCO$_2$eq ha^{-1}).

Interpreting Results

The last step of the life cycle GHG emissions methodology is the interpretation of results. The investigated results were interpreted and a suitable model to reduce life cycle GHG emissions was proposed, which is shown in Sect. 3.

2.4 Data Analysis

The different tools and software were employed to analyze the data, which was collected from the experimental field in this study. The STAR statistical analysis software developed by IRRI was employed to analyze yield parameters, where LSD value was assumed to compare means considering a 5% significance level. The FEAT tool was employed to estimate energy use analysis and life cycle GHG emission to determine the energy and carbon footprint.

3 Results and Discussion

3.1 Energy Use Analysis

Table 7 shows the energy use analysis of the different inputs and outputs energy to different tillage practices (ST, MT, and CT). The results show that inputs energy consumption during the lifecycle of wheat farming for ST, MT, and CT practices were 16,268.77, 16,233.26, and 18,068.80 MJ ha^{-1}, respectively. The researcher reported in the previous studies that total energy input has been recorded to be 18,680.8 MJ ha^{-1}, 14,358 MJ ha^{-1}, and 16,000.36 MJ ha^{-1} for wheat farming [16, 49, 59]. In this study, energy consumption for ST and MT practices were relatively low compared to the CT practice because energy inputs of ST practice for land preparation by machinery and diesel fuel used to different management operations were comparatively low. Moreover, wheat grains yield was found to be 4015, 4083, and 3821 kg for ST, MT, and CT practices, accordingly, while the energy output was calculated to be 158,657.40, 162,069.55, and 149,501.58 MJ ha^{-1}, respectively. It is seen that CA-based tillage practices were adopted to reduce the requirement of diesel fuel energy aiming at improving energy use efficiency (EUE). However, CA tillage practices were used to reduce soil microbial activities to decrease CO_2 emissions further, results in increasing agricultural sustainability. For this, conservation tillage practices can be considered an energy-efficient technology and positively minimize energy consumption. Among the energy input of conservation tillage practices and energy output yield, it is shown that MT practice consumes less energy inputs which can be considered one of the sustainable indicators for achieving environmental sustainability.

The table also shows that the most significant part of inputs energy was consumed by synthetic fertilizer of 46.6, 46.71, and 46.96% for ST, MT, and CT, respectively, where N fertilizer share is for 35.48, 35.56, and 31.95%, respectively. The nitrogen fertilizer for all the treatments is the largest energy consumer among the input's energy. Alongside this fertilizer energy, the latter most immense input energy in wheat farming was irrigation water, with 16.46, 16.5, and 14.82% for ZT, MT, and CT practices, respectively. Electricity, human labor, herbicide, and machinery were observed as the minor energy inputs.

The researcher observed that the most significant part of inputs energy consumption among the chemical energy is the N fertilizer which was around 40% of inputs energy [28, 33, 64] because it is an essential element as a moderator in plant growth and biological development and increasing crop yield if applied at the right time. Besides this, N fertilizer has an adverse effect linearly on growth and crop productivity if this fertilizer is not applied in a proper way and right time. This study shows that N fertilizer was the primary input energy consumption in conventional farming, distinguishing between conventional and sustainable agricultural systems. Chemical fertilizer use grew in CT practice, resulting in a higher share of non-renewable energy use, and this matter had seen entirely negative from the philosophy of agroecology consequences adverse impact of CT practice on agricultural sustainability. Therefore, the alternative measured had taken for the renewal or lesser use of N fertilizer. This study shows that renewal was done using cowdung with the use of less N fertilizer (90 kg) than recommended (120 kg) (Table 6), thus input energy consumption was also less with the use of this fertilizers. The energy value of cowdung is equal to 1115 MJ and its equivalent energy of N fertilizer is found from only 17.8 kg, whereas the N fertilizer was applied 90.0 kg per year (avg.). Moreover, the results show that wheat grain productivity was higher in ST and MT practices compared to the CT practice. For this, sustainable fertilizer management had a positive effect to supply more nutrition in soil than chemical fertilizer, getting a more environmental sustainability. As a result, it's worth noting that using manure with biofertilizer in wheat farming can be a viable alternative to reducing energy consumption and developing a sustainable production system that boosts productivity and finally ensures agricultural sustainability. Moreover, CA-based management practices, like composts and stable crop residues management, may increase SOC content and soil health, which will reduce the chemical fertilizer energy demand.

3.2   Energy Indicators in Wheat Farming

Energy indicators in wheat farming were determined by applying the equations in Table 6 for ST, RT, and CT practices (Table 8). The results show that energy use efficiency (EUE) in wheat farming was 9.75, 9.98, and 8.27 for ST, RT, and CT practices, respectively. The EUE is shown in higher in comparison to the stated 2.8 for wheat production systems in Turkey [16], 1.44 in south Panjab in Pakistan [34], 2.9 to 5.2 for wheat production in India [63], and 2.3 in Bangladesh [59]. Comparatively, Lower EUE was observed in CT systems in wheat production due to intake of higher energy inputs than the ST and MT practices, whereas the higher EUE was shown for the MT practice. Energy productivity in wheat farming was calculated as 0.247, 0.251, and 0.211 kg MJ^{-1} for ST, MT, and CT practices, respectively. This corresponds to 247, 251, and 211 g of wheat grain produced per MJ of input energy use for ST, RT, and CT practices, respectively. Previous studies reported that energy productivity in wheat farming was 0.11 kg MJ^{-1} for high inputs and 0.14 kg MJ^{-1} for low inputs usage [75]. Analysis showed that energy productivity is

comparatively higher than previously reported in all the studies in wheat farming. The net energy balance in wheat farming for ST, RT, and CT practices was calculated to be 142,388.63, 145,836.29, and 131,432.77 MJ ha^{-1}, respectively. Energy productivity and net energy per ha in Bangladesh, according to Sanzidur and Kamrul, were 0.2 and 20,595.9 MJ ha^{-1}, respectively [59]. Due to higher yields (grain and straw) with comparatively lower inputs, net energy was found higher in this study than in the previous study for wheat farming. Additionally, energy indices of agrochemical energy, which was found to be 55, 53, and 49% for ST, RT, and CT practices, respectively. This indicator implies that comparatively less agrochemical energy is applied in the ST practice resulted in showing a higher percentage. The modeling of these indicators can be applied in wheat farming systems to use energy efficiently for achieving higher yield, productivity, and sustainability.

Wheat farming in Bangladesh is completely energy efficient in terms of estimated net energy balance and energy ratio, although these indicators can increase further by less inorganic fertilizer. Thus, the sustainability test had been successfully evaluated in terms of energy balance in wheat farming, which indicates that this farming is more energy-efficient and sustainable.

3.3 Assessment of Life Cycle GHG Emission and Carbon Footprint

Figures 3 and 4 show the total life cycle GHG emissions for wheat farming inputs when the LCA system boundary is taken into account. Total GHG emissions for different tillage practices linked with fixed crop residue retention were calculated using a single global warming potential (GWP) allocation in wheat farming. The results show that total GHG emissions for ST, MT, and CT practices were calculated to be 1.987, 1.992, and 2.028 tonCO$_2$eq ha^{-1}, respectively; whereas 0.495, 0.488, and 0.531 tonCO$_2$eq ton^{-1} of wheat grains, respectively. Nitrous oxide (N$_2$O) accounted for the greatest share of total GHG emissions, with about 562 kgCO$_2$eq ha^{-1} of wheat grain accounting for 28.28, 28.21, and 27.71% of total GHG emissions for ST, MT, and CT practices, respectively.

Furthermore, N fertilizer was found to be the second largest contributor in ST, MT, and CT practices, accounting for 24.98, 24.92, and 24.47%, respectively, followed by N$_2$O from aboveground crop residues, nitrous oxide leaching/runoff, diesel fuel, Phosphate, N$_2$O from belowground crop residues, N$_2$O from manure, N$_2$O volatilization, seed, potash, herbicide, input transportation, and electricity. N fertilizer and N$_2$O are the primary consumers of GHG emissions, with some of the nitrogen being dissolved aboveground in the form of volatilization and the rest being applied dissolved into the soil, where it is naturally transformed to N$_2$O by soil microbes. Previous research revealed that wheat cultivation in Pakistan produced 1.118 ton CO$_2$eq ha^{-1} of GHG emissions [34]. According to other research, China's GHG emissions were 2.75 ton CO$_2$eq ton^{-1} of wheat production [78]. According to this

Table 7 The amount of input and output energy utilized in different tillage processes, as well as their percentage share in wheat farming

Input	ST (MJ/ha)	Percentage (%)	MT (MJ/ha)	Percentage (%)	CT (MJ/ha)	Percentage (%)
Human labor	229.15	1.41	193.65	1.19	284.02	1.59
Machinery	860.70	5.21	860.70	5.3	1498.95	8.3
Diesel Fuel	1744.07	11.72	1744.07	10.74	2190.83	12.12
Seed	1760.44	10.82	1760.44	10.84	2420.60	13.4
(a) Nitrogen	5772.60	35.48	5772.60	35.56	5772.60	31.95
(b) Phosphate (P_2O_5)	995.20	6.12	995.20	6.13	995.20	5.51
(c) Potassium (K_2O)	669.00	4.11	669.00	4.12	669.00	3.7
(d) S	95.20	0.59	95.20	0.59	95.20	0.53
(e) Z	50.00	0.31	50.00	0.31	50.00	0.28
(g) Manure	1125	6.92	1125	6.93	1125.0	6.23
Electricity	122.40	0.75	122.40	0.75	122.40	0.68
Irrigation water	2678.36	16.46	2678.36	16.5	2678.36	14.82
Herbicide	166.64	1.02	166.64	1.03	166.64	0.92
Total input energy	16,268.77	100.00	16,233.26	100.00	18,068.80	100.00
Grain	59,018.55	37.20	60,014.25	37.03	56,162.0	37.57
Straw	99,638.85	62.80	102,055.31	62.97	93,339.5	62.43
Total output energy	158,657.40	100.00	162,069.55	100	149,501.58	100

Note ST = Strip tillage practice, MT = Minimum tillage practice, CT = COnvertional tillage practice

study, the use of less nitrogen fertilizer results in a favorable reduction in GHG emissions. Furthermore, as demonstrated by the experiment, stable crop residue retention improved soil structure and increased soil organic carbon (SOC) content by pulverizing it into the soil using conservation tillage practices (CTP), which helped fix atmospheric CO_2 into the soil, resulting in a reduction in total GHG emissions. Soil fertility and environmental quality were significantly improved by implementing CTPs, such as ST and MT practices, and balanced fertilizer management with stable crop residue retention, in order to reduce GHG emissions.

The relative contributions of different tillage treatments at the off-farm stage were nearly similar to GHG emissions for all treatments. The off-farm activities emitted

**Table 8** Results of energy indicators in wheat cultivation using ST, MT, and CT practices

a	Unit	ST	(%)	MT	(%)	CT	(%)
Energy use efficiency/Net energy ratio	kg MJ^{-1}	9.75		9.98		8.27	
Energy productivity	kg MJ^{-1}	0.247		0.251		0.211	
Specific energy	MJ kg^{-1}	3.91		3.84		3.84	
Net energy	MJ ha^{-1}	142,388.63		145,836.29		131,432.77	
Agrochemical energy ratio	(%)	0.55		0.53		0.49	
Mechanization Index	(%)	17.2		17.3		15.5	
Direct energy *	MJ ha^{-1}	4651.59	28.59	4616.08	28.44	5153.21	28.52
Indirect energy **	MJ ha^{-1}	11,617.18	71.41	11,617.18	71.56	12,915.59	71.48
Renewable energy ***	MJ ha^{-1}	4667.95	28.69	4632.45	28.54	5382.98	29.79
Non-renewable energy ****	MJ ha^{-1}	11,600.82	71.31	11,600.82	71.46	12,685.83	70.21

*Note* *Direct energy, **Indirect energy, ***Renewable energy, ****Non-renewable energy

GHGs were approximately 37.97, 37.88, and 38.3% of total GHG emissions for ST, MT, and CT practices, respectively (Fig. 5). A slight increase in emission was observed only for CT practice because wheat seeds and fuels used in this treatment are slightly more. Emission associated with different tillage practices and fixed crop residue retention were not significantly different in off-farm treatment tillage practices.

Analysis in the on-farm stage confirmed that there had not been any CH$_4$ emissions, having the highest GHG emissions from the CT practice than the ST and MT practices, whereas GHG emissions from ST and MT practices were showed similar trends (Fig. 5). The only variation in GHG emissions is from the fuel and biological seed emissions. On-farm GHG emissions can be reduced by reduce use of N fertilizer and increase use of organic fertilizer. Overall, off-farm GHG emissions of wheat farming were much lower than emitted GHG emissions during the on-farm stage because of adopting CA practices.

The GHG intensity or carbon footprint (CF) of wheat grains was determined to be 0.013, 0.012, and 0.014 kgCO$_2$eq MJ^{-1} for ST, MT, and CT practices, respectively. In previous investigations, CF was found to be 0.027 for wheat in the United States [15]. Due to reduce use of N fertilizer and conservation tillage measures, CF was lower in this study. CA practices limit the amount of fuel used in tillage operations,
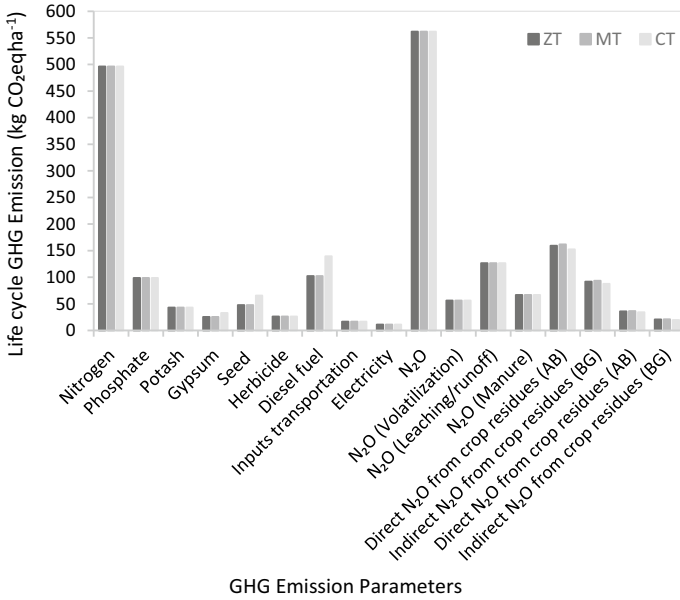
Fig. 3 Life cycle GHG emissions in kg CO_2eqha^{-1} in wheat firming. [*Legend* ZT-Strip tillage; MT-Minimum tillage; CT-Conventional tillage practice]
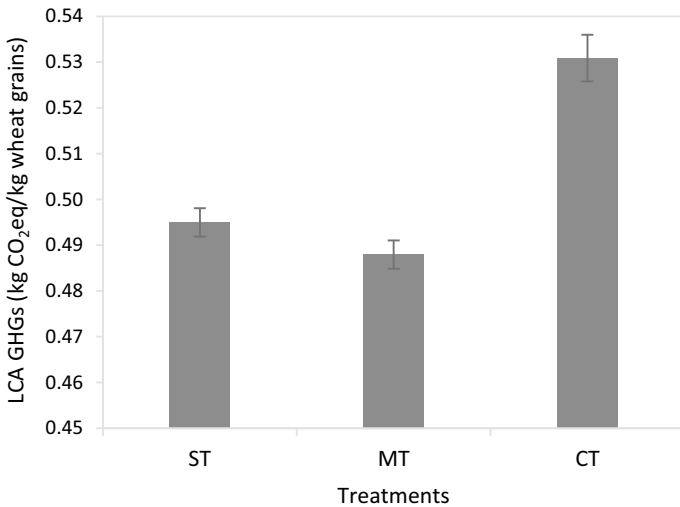
Fig. 4 Total life cycle GHG emissions for one ton of wheat produced per hectare in wheat farming ($p < 0.05$)
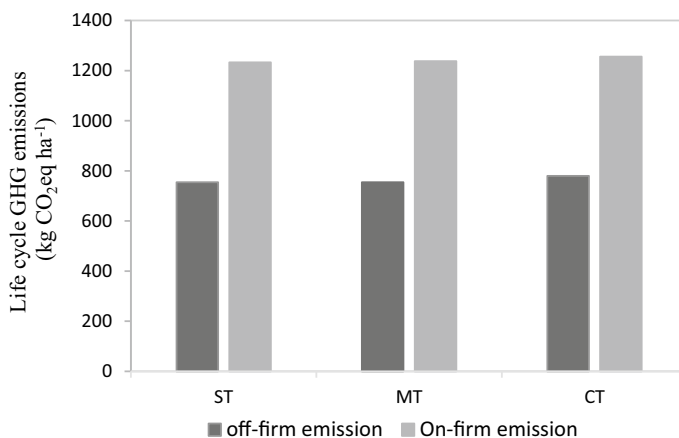
Fig. 5 Life cycle greenhouse gas emissions for one functional unit for off-firm and on-firm activities

resulting in reduced CF and environmental sustainability. The combined effect of improved nitrogen use efficiency, reduced life cycle GHG emissions, and lower CF has been the key result of lowering GHG intensity in wheat farming (Fig. 5).

The net life cycle GHG emissions must be calculated considering SOC accumulation during crop farming, because total life cycle GHG emissions must be accounted for off-farm and on-farm GHG emissions. In agricultural farming, the effects of SOC accumulation on GHG emissions must be recognized; otherwise, life cycle GHG emission results would be misleading. The accumulation of SOC linked with CA-based management practices might take several years to optimize. As a result, when soil characteristics have reached an equilibrium state with the new degree of SOC, the net life cycle GHG emissions of wheat farming using CA-based establishment practices must be estimated and give inceptive results.

3.3.1 Soil Organic Carbon (SOC) Accumulation

The topsoil tends to have the highest concentration of soil organic carbon (SOC) percentage. To determine how much SOC buildup by adopting conservation tillage practices, topsoil up to 20 cm was linked with measurement. Table 9 shows how the SOC accumulation was translated to kilograms of CO_2 equivalent per hectare. For ST, MT, and CT practices, SOC accumulation was 18.94, 14.93, and 5.66 $kgCO_2eq\ ha^{-1}$, respectively. After converting this equivalent SOC accumulation to equivalent CO_2, net GHG emissions for ST, MT, and CT practices were 1.968, 1.977, and 2.023 $kgCO_2eq\ ha^{-1}$, respectively. Although the quantity of SOC per hectare in terms of a kilogram of CO_2 equivalent is modest, this amount of SOC accumulation is only for two years of wheat farming. According to the research, crop residues retention in soil, low soil disturbance, reduced CO_2 emissions, and crop rotation with legume crops can all help to improve SOC content [3, 8]. The study result

Table 9 SOC accumulation and their GHG emissions in wheat farming

Treatment	Total GHG emission (kgCO$_2$eq/ha)	SOC (t/ha)	SOC accumulation (t/ha)	SOC (kgCO$_2$eq/ha)	Net GHG Emissions (kgCO$_2$eq/ha)	Net GHG Emissions (tonCO$_2$eq/ha)
Initial soil		16.240				
ST	1987.22	21.291	5.051	18.94	1968.28	1.968
MT	1992.01	20.221	3.981	14.93	1977.08	1.977
CT	2028.28	17.750	1.510	5.66	2022.62	2.023

implied that CA-based tillage practices and stable crop residue retention enhance SOC in the topsoil.

3.4 Net Life Cycle GHG emission

Net life cycle GHG emissions for different tillage practices were evaluated based on overall GHG emissions for the production of 1 ton of wheat grains after accounting for SOC accumulation. According to the findings, SOC accumulation has a significant impact on lowering net life cycle GHG emissions. The ST practice was also shown to be the best practice for reducing GHG emissions since the highest amount of soil was covered and untilled following during the tillage operation. However, SOC content might reduce GHG emissions in the CT practice to some extent, as heavy tillage in the soil causes intensive soil disturbance and a high level of microbial activity, resulting in less carbon remaining in this practice.

4 Conclusion

The input–output energy balance in wheat farming is a systematic approach to utilize available inputs effectively for increasing overall farming efficiency and environmental sustainability. This study was conducted within the LCA system boundary to evaluate the energy balance of wheat farming using different conservation tillage practices with a stable crop residue retention used in Bangladesh. The analysis of energy use was performed using input and output energy to determine energy use efficiency, net energy, energy productivity, and agrochemical energy ratio for ST, MT, and CT practices, respectively. It is revealed that a lower amount of input energy was related to ST and MT practices, whereas a higher amount was associated with CT practices in wheat farming. Energy use efficiency (EUE) and productivity in wheat farming showed higher value with MT practice (9.98 and 0.251 kg MJ^{-1}) than CT practice (8.27 and 0.211 kg MJ^{-1}). Hence, EUE in wheat farming for different tillage practices kept to the MT > ST > CT sequence. A FEAT tool with LCA system

boundary was employed for estimating life cycle GHG emissions ($tonCO_2eq\ ha^{-1}$) and carbon footprint of wheat farming considering the whole production process, including cradle to farmgate activities. The estimated life cycle GHG emission in wheat farming was 1.968, 1.977, and 2.023 $tonCO_2eq\ ha^{-1}$ for ZT, MT, and CT, respectively. Nitrous oxide (N_2O) direct emission, N fertilizer, N_2O from above-ground crop residues and fuel for machinery operation had the significant suppliers in total GHG emissions. Additionally, the GHG intensity or carbon footprint was 0.013, 0.012, and 0.014 $kgCO_2eq\ MJ^{-1}$ of output energy from wheat farming for ST, MT, and CT practices, respectively, which means the farming system is environmentally more sustainable.

The highest emissions from wheat farming inputs were N fertilizer (41.1% for ST and MT practices, 37.43% for CT practices), followed by irrigation water, diesel, and seed. To address this problem, biofertilizers like manure or cow dung might be suggested to improve soil nutrition and fertility, potentially increasing SOC accumulation and reducing net life cycle GHG emissions. Adopting the conservation agriculture (CA) practice for reducing GHG emissions is also an effective measure. CA-based conservation tillage practices promote SOC accumulation by reducing input energy consumption by taking less fuel and retaining stable crop residue at a certain level. Both these plays a vital role in reducing GHG emissions and achieving long-term environmental sustainability.

References

1. Adhya TK, Mishra SR, Rath AK, Bharati K, Mohanty SR, Ramakrishnan B, Rao VR, Sethunathan N (2000) Methane efflux from rice-based cropping systems under humid tropical conditions of eastern India. Agric Ecosyst Environ. https://doi.org/10.1016/S0167-8809(99)00144-9

2. Alam MK, Bell RW, Biswas WK (2019) Decreasing the carbon footprint of an intensive rice-based cropping system using conservation agriculture on the Eastern Gangetic Plains. J Clean Prod 218:259–272. https://doi.org/10.1016/j.jclepro.2019.01.328

3. Alam MK, Bell RW, Haque ME, Kader MA (2018) Minimal soil disturbance and increased residue retention increase soil carbon in rice-based cropping systems on the Eastern Gangetic Plain. Soil Tillage Res 138:28–41. https://doi.org/10.1016/j.still.2018.05.009

4. Alam MK, Biswas WK, Bell RW (2016) Greenhouse gas implications of novel and conventional rice production technologies in the Eastern-Gangetic plains. J Clean Prod 112:3977–3987. https://doi.org/10.1016/j.jclepro.2015.09.071

5. Alam MK, Islam MM, Salahin N, Hasanuzzaman M (2014) Effect of tillage practices on soil properties and crop productivity in wheat-mungbean-rice cropping system under subtropical climatic conditions. Sci World J 7:1–17. https://doi.org/10.1155/2014/437283

6. Arunrat N, Pumijumnong N, Sereenonchai S, Chareonwong U (2020) Factors controlling soil organic carbon sequestration of highland agricultural areas in the Mae Chaem Basin, northern Thailand. Agronomy 10:305. https://doi.org/10.3390/agronomy10020305

7. Azad AK, Miaruddin M, Wohab MA, Sheikh MHR, Nag BL, Rahman MHH (2020) KRISHI PROJUKTI HATBOI (Handbook on Agro-Technology), 9th edn. Bangladesh Agricultural Research Institute, Gazipur-1701, Bangladesh

8. Baldock JA (2007) Composition and cycling of organic carbon in soil. In: Nutrient cycling in terrestrial ecosystems, pp 1–35. https://doi.org/10.1007/978-3-540-68027-7_1

9. Banerjee A, Jhariya MK, Raj A, Yadav DK, Khan N, Meena RS (2021) Energy and climate footprint towards the environmental sustainability. In: Agroecological footprints management for sustainable food system. https://doi.org/10.1007/978-981-15-9496-0_14

10. Bangladesh Bureau of Statistics (BBS) (2018) Yearbook of agricultural statistics-2017

11. Bell RW, Enamul Haque M, Jahiruddin M, Moshiur Rahman M, Begum M, Monayem Miah MA, Ariful Islam M, Anwar Hossen M, Salahin N, Zahan T, Hossain MM, Alam MK, Mahmud MNH (2019) Conservation agriculture for rice-based intensive cropping by smallholders in the eastern gangetic plain. Agric 9:1–17. https://doi.org/10.3390/agriculture9010005

12. Bhatia A, Sasmal S, Jain N, Pathak H, Kumar R, Singh A (2010) Mitigating nitrous oxide emission from soil under conventional and no-tillage in wheat using nitrification inhibitors. Agric Ecosyst Environ. https://doi.org/10.1016/j.agee.2010.01.004

13. Black CA (1950) Method of soil analysis Part I and II. Am Soc Agron Inc 770

14. Burt R (2014) Soil survey field and laboratory methods manual soil survey investigations report No. 51. United States Dep. Agric. Nat. Resour. Conserv. Serv. version 2

15. Camargo GGT, Ryan MR, Richard TL (2013) Energy use and greenhouse gas emissions from crop production using the farm energy analysis tool. Bioscience 63:263–273. https://doi.org/10.1525/bio.2013.63.4.6

16. Canakci M, Topakci M, Akinci I, Ozmerzi A (2005) Energy use pattern of some field crops and vegetable production: Case study for Antalya Region, Turkey. Energy Convers Manag 46:655–666. https://doi.org/10.1016/j.enconman.2004.04.008

17. Chakrabarti B, Pramanik P, Mina U, Sharma DK, Mittal R (2014) Impact of conservation agricultural practices on soil physic-chemical properties. Int J Agric Sci 5:55–59

18. Chatterjee S, Ghosh S, Pal P (2020) Soil carbon restoration through conservation agriculture. In: Natural resources management and biological sciences. https://doi.org/10.5772/intechopen.93006

19. Chowdhury MAH, Hassan MS (2013) Agricultural technology hand book. Bangladesh Agricultural Research Council, Farmgate, Dhaka-1215

20. Clark A (2007) Managing cover crops in conservation tillage systems, 3rd edn. In: Sustainable Agriculture Research and Education (SARE) program. National Institute of Food and Agriculture, U.S. Department of Agriculture, Maryland, USA

21. Dachraoui M, Sombrero A (2020) Effect of tillage systems and different rates of nitrogen fertilisation on the carbon footprint of irrigated maize in a semiarid area of Castile and Leon, Spain. Soil Tillage Res 196:104472. https://doi.org/10.1016/j.still.2019.104472

22. Denham FC, Biswas WK, Solah VA, Howieson JR (2016) Greenhouse gas emissions from a Western Australian finfish supply chain. J Clean Prod 112:2079–2087. https://doi.org/10.1016/j.jclepro.2014.11.080

23. Erdal G, Esengün K, Erdal H, Gündüz O (2007) Energy use and economical analysis of sugar beet production in Tokat province of Turkey. Energy 32:35–41. https://doi.org/10.1016/j.energy.2006.01.007

24. FAOSTAT (2021) Emiss Shares, Foog Agric. Organ. United Nations. http://www.fao.org/faostat/en/#data/EM/metadata. Accessed 8 Jan 21

25. Finkbeiner M, Inaba A, Tan RBH, Christiansen K, Klüppel HJ (2006) The new international standards for life cycle assessment: ISO 14040 and ISO 14044. Int J Life Cycle Assess. https://doi.org/10.1065/lca2006.02.002

26. Forte A, Fiorentino N, Fagnano M, Fierro A (2017) Mitigation impact of minimum tillage on CO_2 and N_2O emissions from a Mediterranean maize cropped soil under low-water input management. Soil Tillage Res 166:167–178. https://doi.org/10.1016/j.still.2016.09.014

27. Furtak K, Gajda AM (2018) Activity and variety of soil microorganisms depending on the diversity of the soil tillage system. In: Sustainability of agroecosystems, p 45. https://doi.org/10.5772/intechopen.72966

28. Giampietro M, Cerretelli G, Pimentel D (1992) Energy analysis of agricultural ecosystem management: human return and sustainability. Agric Ecosyst Environ 38:219–244. https://doi.org/10.1016/0167-8809(92)90146-3
29. Gómez-Limón JA, Sanchez-Fernandez G (2010) Empirical evaluation of agricultural sustainability using composite indicators. Ecol Econ 69:1062–1075. https://doi.org/10.1016/j.ecolecon.2009.11.027
30. He L, Zhang A, Wang X, Li J, Hussain Q (2019) Effects of different tillage practices on the carbon footprint of wheat and maize production in the Loess Plateau of China. J Clean Prod 234:297–305. https://doi.org/10.1016/j.jclepro.2019.06.161
31. Hillier J, Hawes C, Squire G, Hilton A, Wale S, Smith P (2009) The carbon footprints of food crop production. Int J Agric Sustain 7:107–118. https://doi.org/10.3763/ijas.2009.0419
32. Hossain MI, Sarker M, Haque MA (2015) Status of conservation agriculture based tillage technology for crop production in Bangladesh. Bangladesh J Agric Res 40:235–248. https://doi.org/10.3329/bjar.v40i2.24561
33. Hosseinpanahi F, Kafi M (2012) Assess the energy budget in farm production and productivity of potato (*Solanum tuberosum* L.) in Kurdistan, case study: plain Dehgolan. J Agroecol 4:159–169
34. Imran M, Özçatalbaş O, Bashir MK (2020) Estimation of energy efficiency and greenhouse gas emission of cotton crop in South Punjab, Pakistan. J Saudi Soc Agric Sci 19:216–224. https://doi.org/10.1016/j.jssas.2018.09.007
35. ISO (2016) Environmental management—life cycle assessment—requirements and guidelines ISO 14044:2006). Int Organ Stand. https://www.iso.org/standard/38498.html. Accessed 23 Oct 21
36. Jackson ML (1959) Soil chemical analysis. J Agric Food Chem 7:138. https://doi.org/10.1021/jf60096a605
37. Jain N, Dubey R, Dubey DS, Singh J, Khanna M, Pathak H, Bhatia A (2014) Mitigation of greenhouse gas emission with system of rice intensification in the Indo-Gangetic Plains. Paddy Water Environ. https://doi.org/10.1007/s10333-013-0390-2
38. Jat ML, Saharawat Y, Gupta R (2011) Conservation agriculture in cereal systems of south Asia: nutrient management perspectives. J Agric Sci 24:100–105
39. Jiban S, Subash S, Prasad TK, Amit C, Manoj K, Subina T (2020) Conservation agriculture as an approach towards sustainable crop production : a review. Farming Manag 5:7–15. https://doi.org/10.31830/2456-8724.2020.002
40. Khan S, Khan MA, Hanjra MA, Mu J (2009) Pathways to reduce the environmental footprints of water and energy inputs in food production. Food Policy 34:141–149. https://doi.org/10.1016/j.foodpol.2008.11.002
41. Khosruzzaman S, Asgar MA, Rahman KR, Akbar S (2010) Energy intensity and productivity in relation to agriculture-bangladesh perspective. J Bangladesh Acad Sci 34:59–70. https://doi.org/10.3329/jbas.v34i1.5492
42. Kurkela E, Moilanen A, Nieminen M (1999) CFB gasification of biomass residues for co-combustion in large utility boilers: studies on ash control and gas cleaning. In: Ower production from biomass III: gasification and pyrolysis R&D&D for Industry. VTT Technical Research Centre of Finland. VTT Symposium, No. 192, Espoo, Finland, pp 213–228
43. Lal R (2004) Carbon emission from farm operations. Environ Int. https://doi.org/10.1016/j.envint.2004.03.005
44. Liu C, Wang K, Meng S, Zheng X, Zhou Z, Han S, Chen D, Yang Z (2011) Effects of irrigation, fertilization and crop straw management on nitrous oxide and nitric oxide emissions from a wheat-maize rotation field in northern China. Agric Ecosyst Environ. https://doi.org/10.1016/j.agee.2010.12.009
45. Liu J, Wang H, Rahman S, Sriboonchitta S (2021) Energy efficiency, energy conservation and determinants in the agricultural sector in emerging economies. Agric 11:773. https://doi.org/10.3390/agriculture11080773
46. Mittal R, Chakrabarti B, Jindal T, Tripathi A, Mina U, Dhupper R, Chakraborty D, Jatav RS, Harit RC (2018) Carbon footprint is an indicator of sustainability in rice-wheat cropping system: a review. Chem Sci Rev Lett 7:774–784

47. Mohammadshirazi A, Akram A, Rafiee S, Mousavi Avval SH, Bagheri Kalhor E (2012) An analysis of energy use and relation between energy inputs and yield in tangerine production. Renew Sustain Energy Rev 16:4515–4521. https://doi.org/10.1016/j.rser.2012.04.047
48. Naderi SA, Dehkordi AL, Taki M (2019) Energy and environmental evaluation of greenhouse bell pepper production with life cycle assessment approach. Environ Sustain Indic 3–4:100011. https://doi.org/10.1016/j.indic.2019.100011
49. Nasseri A (2019) Energy use and economic analysis for wheat production by conservation tillage along with sprinkler irrigation. Sci Total Environ 648:450–459. https://doi.org/10.1016/j.scitotenv.2018.08.170
50. Notter B, Keller M, Althaus H, Cox B, Heidt C, Biemann K, Knorr W, Rader D, Jamet M (2020) HBEFA, 2014. Handb Emiss Factors Road Transp (HBEFA). Version HBEFA 4.1. https://www.hbefa.net/e/index.html
51. Ozkan B, Akcaoz H, Fert C (2004) Energy input-output analysis in Turkish agriculture. Renew Energy 29:39–51. https://doi.org/10.1016/S0960-1481(03)00135-6
52. Pandey D, Agrawal M, Bohra JS (2012) Greenhouse gas emissions from rice crop with different tillage permutations in rice-wheat system. Agric Ecosyst Environ. https://doi.org/10.1016/j.agee.2012.07.008
53. Pathak H, Aggarwal PK (2012) Low carbon technologies for agriculture: a study on rice and wheat systems in the indo-gangetic plains. New Delhi, India
54. Pathak H, Jain N, Bhatia A, Patel J, Aggarwal PK (2010) Carbon footprints of Indian food items. Agric Ecosyst Environ 139:66–73. https://doi.org/10.1016/j.agee.2010.07.002
55. Phyllis (2020) Database for biomass and waste. Wheat straw 1995. https://ukerc.rl.ac.uk/DC/cgi-bin/edc_search.pl/?WantComp=85
56. Pimentel D, Cooperstein S, Randell H, Filiberto D, Sorrentino S, Kaye B, Nicklin C, Yagi J, Brian J, O'Hern J, Habas A, Weinstein C (2007) Ecology of increasing diseases: population growth and environmental degradation. Hum Ecol 35:653–668. https://doi.org/10.1007/s10745-007-9128-3
57. Pishgar-Komleh SH, Ghahderijani M, Sefeedpari P (2012) Energy consumption and CO_2 emissions analysis of potato production based on different farm size levels in Iran. J Clean Prod 33:183–191. https://doi.org/10.1016/j.jclepro.2012.04.008
58. Rahman MM, Aravindakshan S, Hoque MA, Rahman MA, Gulandaz MA, Rahman J, Islam MT (2021) Conservation tillage (CT) for climate-smart sustainable intensification: assessing the impact of CT on soil organic carbon accumulation, greenhouse gas emission and water footprint of wheat cultivation in Bangladesh. Environ Sustain Indic 10:100106. https://doi.org/10.1016/j.indic.2021.100106
59. Rahman S, Hasan MK (2014) Energy productivity and efficiency of wheat farming in Bangladesh. Energy 66:107–114. https://doi.org/10.1016/j.energy.2013.12.070
60. Sayed A, Sarker A, Kim JE, Rahman MM, Mahmud MGA (2020) Environmental sustainability and water productivity on conservation tillage of irrigated maize in red brown terrace soil of Bangladesh. J Saudi Soc Agric Sci 19:276–284. https://doi.org/10.1016/j.jssas.2019.03.002
61. Singh BP, Setia R, Wiesmeier M, Kunhikrishnan A (2018) Agricultural management practices and soil organic carbon storage. Soil Carbon Storage: Modulators, Mech Model. https://doi.org/10.1016/B978-0-12-812766-7.00007-X
62. Singh G, Singh S, Singh J (2004) Optimization of energy inputs for wheat crop in Punjab. Energy Convers Manag 45:453–465. https://doi.org/10.1016/S0196-8904(03)00155-9
63. Singh H, Singh AK, Kushwaha HL, Singh A (2007) Energy consumption pattern of wheat production in India. Energy 32:1848–1854. https://doi.org/10.1016/j.energy.2007.03.001
64. Singh S, Singh S, Mittal JP, Pannu CJS (1998) Frontier energy use for the cultivation of wheat crop in punjab. Energy Convers Manag 39:485–491. https://doi.org/10.1016/s0196-8904(96)00234-8
65. Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (2013) IPCC, 2013: climate change 2013: the physical science basis. In: Contribution of working group i to the fifth assessment report of the intergovernmental panel on climate change, IPCC

66. Suh S (2004) Materials and energy flows in industry and ecosystem networks. Int J Life Cycle Assess 9:335–336. https://doi.org/10.1007/bf02979425
67. UNEP (2017) The emissions gap report 2017—a UN environment synthesis report. United Nations Environ Programme (UNEP). https://doi.org/10.1016/j.biocon.2006.04.034
68. Volanti M, Martínez CC, Cespi D, Lopez-Baeza E, Vassura I, Passarini F (2021) Environmental sustainability assessment of organic vineyard practices from a life cycle perspective. Int J Environ Sci Technol. https://doi.org/10.1007/s13762-021-03688-2
69. Wang W, Yuan J, Gao S, Li T, Li Y, Vinay N, Mo F, Liao Y, Wen X (2020) Conservation tillage enhances crop productivity and decreases soil nitrogen losses in a rainfed agroecosystem of the Loess Plateau, China. J Clean Prod. https://doi.org/10.1016/j.jclepro.2020.122854
70. Wang Z, Wang G, Han Y, Feng L, Fan Z, Lei Y, Yang B, Li X, Xiong S, Xing F, Xin M, Du W, Li C, Li Y (2020) Improving cropping systems reduces the carbon footprints of wheat-cotton production under different soil fertility levels. Arch Agron Soil Sci. https://doi.org/10.1080/03650340.2020.1720912
71. Wiedmann T, Minx J (2007) A definition of ' carbon footprint. Science 80-:1–7. https://doi.org/10.1088/978-0-750-31040-6
72. Worldometer (2020) Bangladesh population. https://www.worldometers.info/world-population/bangladesh-population/. Accessed 22 Oct 21
73. Xiao L, Zhao R, Zhang X (2020) Crop cleaner production improvement potential under conservation agriculture in China: a meta-analysis. J Clean Prod. https://doi.org/10.1016/j.jclepro.2020.122262
74. Yousefi M, Damghani AM, Khoramivafa M (2014) Energy consumption, greenhouse gas emissions and assessment of sustainability index in corn agroecosystems of Iran. Sci Total Environ 493:330–335. https://doi.org/10.1016/j.scitotenv.2014.06.004
75. Yousefi M, Mahdavi Damghani A, Khoramivafa M (2016) Comparison greenhouse gas (GHG) emissions and global warming potential (GWP) effect of energy use in different wheat agroecosystems in Iran. Environ Sci Pollut Res 23:7390–7397. https://doi.org/10.1007/s11356-015-5964-7
76. Zangeneh M, Omid M, Akram A (2010) A comparative study on energy use and cost analysis of potato production under different farming technologies in Hamadan province of Iran. Energy 35:2927–2933. https://doi.org/10.1016/j.energy.2010.03.024
77. Zentner RP, Lafond GP, Derksen DA, Nagy CN, Wall DD, May WE (2004) Effects of tillage method and crop rotation on non-renewable energy use efficiency for a thin Black Chernozem in the Canadian Prairies. Soil Tillage Res. 77:125–136. https://doi.org/10.1016/j.still.2003.11.002
78. Zhang D, Shen J, Zhang F, Li Y, Zhang W (2017) Carbon footprint of grain production in China. Sci Rep. https://doi.org/10.1038/s41598-017-04182-x
79. Zhang W, Zheng C, Song Z, Deng A, He Z (2015) Farming systems in China: innovations for sustainable crop production. In: Crop physiology: applications for genetic improvement and agronomy, 2nd edn. https://doi.org/10.1016/B978-0-12-417104-6.00003-0
80. Ziaei SM, Mazloumzadeh SM, Jabbary M (2015) A comparison of energy use and productivity of wheat and barley (case study). J Saudi Soc Agric Sci 14:19–25. https://doi.org/10.1016/j.jssas.2013.04.002