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Research Article

Energy Use and Productivity in Conservation Agriculture

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ABSTRACT

Sustainable agriculture is a viable solution to satisfy the world's increasing demand for food and conservation agriculture (CA) plays a crucial role in achieving this objective. The energy input and output in CA practice is the parameter that indicates the effectiveness of CA for a particular crop. An assessment of the energy requirements of the rice-wheat-mungbean cropping pattern was carried out at the research field of Bangladesh Agricultural University for conventional tillage (CT) and strip tillage (ST) practices. This study focused on assessing energy use and crop production efficiency under different tillage practices in CA. The total input energy in CT was the highest in rice (21003 MJ/ha) followed by wheat (20985 MJ/ha) and mungbean (12376 MJ/ha), while in ST, it was 17174 MJ/ha, 16496 MJ/ha, and 8067 MJ/ha for rice, wheat, and mungbean, respectively. The results show that energy inputs were less for all the three crops in ST compared to CT due to less energy consumption in land preparation. The maximum energy was consumed in terms of chemical fertilizers followed by irrigation, machinery (diesel), plant protection, human labour, and seed for this cropping system. Energy outputs were 154717.5 MJ/ha, 86660 MJ/ha, and 23178 MJ/ha for rice, wheat, and mungbean, respectively in CT and 162085 MJ/ha, 95945 MJ/ha, and 29848 MJ/ha for rice, wheat, and mungbean, respectively in ST. Energy productivities were 0.249 kg/MJ and 0.320 kg/MJ for rice, 0.133 kg/MJ and 0.188 kg/MJ for wheat, and 0.035 kg/MJ and 0.098 kg/MJ for mungbean in CT and ST, respectively. Energy productivity in ST was 22.1%, 29.2%, and 48.6% higher for rice, wheat, and mungbean, respectively, compared to CT due to increased yield in ST. The energy output-input ratio was higher in ST than in CT; 7.3 and 9.4 for rice, 4.12 and 5.81 for wheat, and 1.9 and 3.7 for mungbean in CT and ST, respectively. So, ST is a better option among the two cultivation processes in energy-saving depending on the resource's availability.

Introduction

Agriculture is the driving force of living for human beings as it is the only source of food production. The world's new target is to make hunger-free earth and achieve the goal by 2030. The concept of sustainable agriculture was adopted as a part of sustainable development goal-2 (Mollier et al., 2017; Rickards and Shortis, 2019). Sustainable agriculture is a collaborative scheme of plant and animal production practices with a precise application to satisfy human food and fibre requirements, enhance environmental quality, and make clever use of non-renewable on-farm resources. A successful application of such practices will uphold farm operations' economic feasibility and improve the quality of life for farmers and society over time (Bundy et al., 1990). The practice of conservation agriculture (CA) has been imposed to satisfy the motto of sustainable agriculture by ensuring healthier production with minimum soil disturbance and proper use of natural resources considering environmental effects.

The three vital principles of CA are enduring residue soil cover, minimal soil interference, and crop rotations (Hobbs et al., 2008; FAO, 2015). CA has been demonstrated in agronomic studies as an influential factor in increasing soil moisture conservation, minimizing land degradation and outflow, and enhancing soil structure, health, and bioavailability. Moreover, it allows earlier crop planting (FAO, 2008; Thierfelder and Wall, 2009; Thierfelder et al., 2015, 2017). Subsequent research has indicated that it has the potential to improve the productivity of soil, heat

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and dry phase adaptability, and crop yield (Thierfelder and Wall, 2010; Thierfelder et al., 2015; Steward et al., 2018). Inferring these facts of soil and yield increases, its importance in socioeconomic advantages including labour savings, women's participation, food and nutrition security, and improving rural livelihoods have been pretended to be mainstreamed in CA adoption (Whitfield et al., 2015). There is also an acknowledgment that these advantages do not apply to all people across all locations, and that CA approaches must be tailored to the specific agro-ecological and socioeconomic circumstances (Andersson and Giller, 2012).

Energy and agriculture have a very intimate and enormous interaction. Energy is one of the most valuable inputs in agricultural productivity. Nowadays, energy consumption in agricultural activities has been exaggerated as a result of continuous human population increase, a desire for a higher quality of living, and limited availability of arable land. The usage of energy in agriculture has increased due to the green revolution, which has resulted in increased use of high-yielding crops, fertilizers, and pesticides, as well as fuel and electricity (Hatirli et al., 2006). According to Bockari-Gevao et al. (2005), the largest average operational energy consumption engaged in tillage (1.75 GJ/ha) accounted for approximately 48.6% of total operational energy ingesting (3.6 GJ/ha), followed by harvesting (1.17 GJ/ha, 32.6%) and planting (0.56 GJ/ha, 15.7%) in Malaysia's lowland rice production scheme. Adequate energy usage is one of the prerequisites for agricultural sustainability since it benefits the economy, conserves fossil resources, and protects the environment (Uhlin, 1998). Agriculture's output is dependent on a large combination of inputs, such as power (farm equipment, human labour, animal draft, electricity), better seeds, fertilizers, and irrigation water. Fertilizers and other chemical agricultural inputs have historically been significant in enhancing food production in all parts of the world. Fuel and fertilizers (N and P) account for the majority (>75%) of total energy expenditures in a mixed cropping system (Hetz, 1992). Energy expenditures for agricultural production may be used as the building blocks for life-cycle assessments of agricultural goods, as well as a first step in identifying crop production processes that benefit the most from increased efficiency (Piringer and Steinberg, 2006). Energy monitoring in crop production is required to manage scarce resources for increased agricultural productivity better. The weights for inputs and outputs are predicted to optimize the relative efficacy of crop production for the same unit. It would also analyse the production methods and recommend the most economical production. Therefore, this research work was undertaken to determine the direct and indirect energy consumption of field operations and the contribution of input energies to output energy for rice, wheat, and mungbean production under different tillage practices.

Materials and Methods

Primary data for energy input resources were gathered from the crop production year 2016-17, 2017-18 and 2018-19 to evaluate the situation of energy consumption for rice, wheat, and mungbean by conducting field experiments in the research farm of the Bangladesh Agricultural University (BAU), Mymensingh. The rice-wheat-mungbean cropping pattern was followed for the experiment with three replications. The crop variety selected for rice was BRRI dhan49, wheat BARI Gom 25, and mungbean Binamoog 8. A seasonal activity calendar in Figure 1 shows the time distribution of cultivation of the crops for the experiment. Rice was cultivated from late June to the end of October. After harvesting rice, the land was prepared and wheat was planted in the last week of November. Then mungbean was cultivated starting from the last week of March. This cropping pattern was replicated for two more consecutive years.

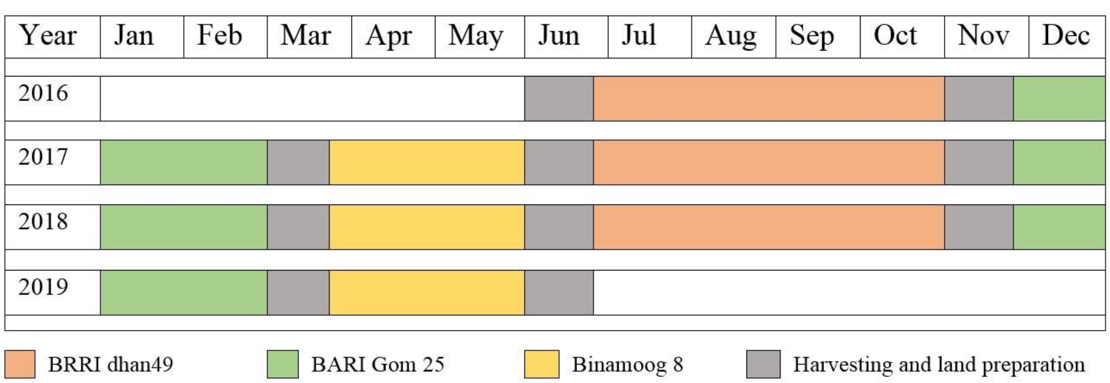

Figure 1. Activity calendar showing the time distribution for rice-wheat-mungbean cropping pattern

The experiment was laid out in a randomized complete block design (RCBD) for the conventional tillage and strip tillage systems. The dimension of the selected field was 78m×50m. The whole experimental field was partitioned into two main blocks, and each block was divided into five equal plots, totalling ten plots in the entire field with a dimension of 24m×15m. A buffer of 0.5m was maintained between two adjacent plots. Five plots were randomly selected for each tillage practice, and the same practice was maintained for each crop in the same cropping year. Different plots were selected randomly for the tillage types for the next cropping years. The layout of the randomized complete block design (RCBD) for the field experiment for the three cropping years is shown in Figure 2.

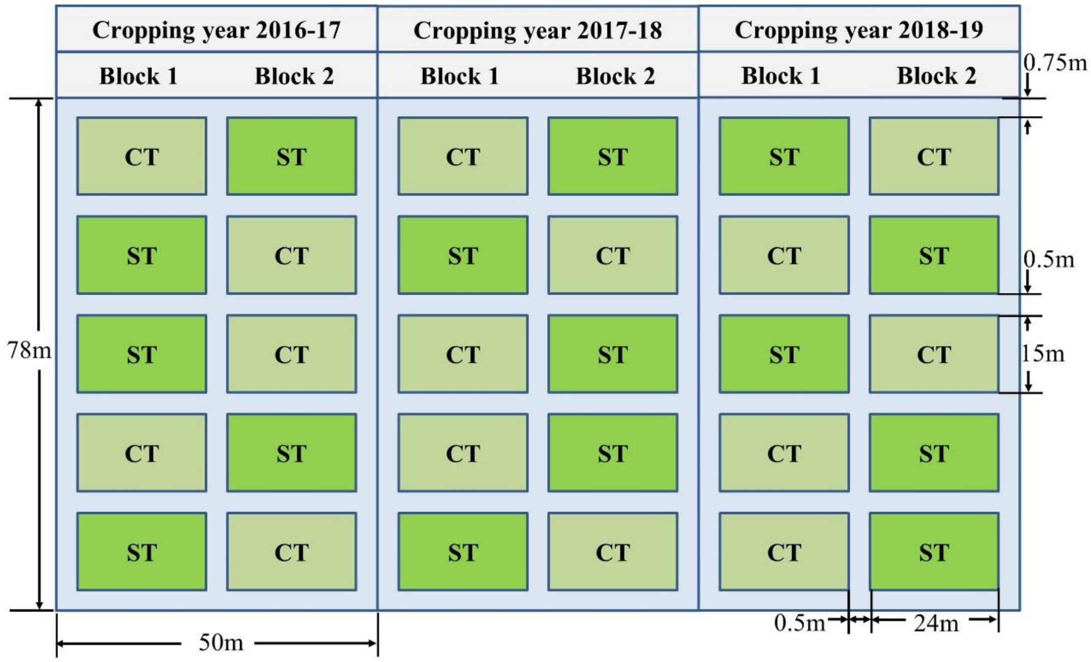

Figure 2. Randomized complete block design (RCBD) layout for the field experiment for 2016-17, 2017-18 and 2018-19 cropping year for conventional tillage (CT) and strip tillage (ST)

Table 1. Energy coefficients used in energy calculation

Particulars	Unit	Energy Equivalents (MJ/Unit)	References
A. Inputs			
1. Human labour	h	1.96	(Rafiee et al., 2010)
2. Machinery	kg	62.70	(Canakci et al., 2005)
3. Diesel fuel	l	56.31	(Erdal et al., 2007)
4. Chemicals			
(i) Herbicides	kg	238.00	(Erdal et al., 2007)
(ii) Pesticides	kg	120	(Canakci et al., 2005)
(iii) Weedicides	kg	101.20	(Erdal et al., 2007)
5. Fertilizer			
(i) Nitrogen	kg	66.14	(Rafiee et al., 2010)
(ii) Phosphate(P_2O_5)	kg	12.44	(Rafiee et al., 2010)
(iii) Potassium(K_2O)	kg	11.15	(Rafiee et al., 2010)
(iv) Sulphur (S)	kg	1.12	(Rafiee et al., 2010)
(v) Zinc (Zn)	kg	8.40	(Pimentel, 1980)
6.Water for irrigation	m^3	1.02	(Rafiee et al., 2010; Acaroglu,1998)
7. Seed (Rice)	kg	14.57	(Bala and Hussain,1992)
8.Seed (Wheat)	kg	14.7	(Khoshroo, 2014)
9.Seed (Mug bean)	kg	14.03	(Gopalan et al., 1978; Binning et al., 1983)
B. Outputs			
1. Grain Paddy	kg	14.57	(Bala and Hussain,1992)
2. Grain Wheat	kg	14.7	(Khoshroo, 2014)
3. Grain Mug bean	kg	14.03	(Gopalan et al., 1978; Binning et al., 1983)
4. Straw	kg	12.50	(Ozkan et al., 2004)

In CT treatment, the land was prepared with two passes tillage by two-wheel tractors (2WT) followed by levelling. Seed and fertilizer were broadcasted by hand in the case of conventional tillage. In the ST method, land preparation, seeding, and fertilizer application were done simultaneously by the versatile multi-crop planter (VMP) in a single pass operation. The input energy was measured at different stages of crop production in the form of labour, diesel, seed, chemical fertilizer, and plant protection (pesticides/ weedicides/ herbicides), and outputs obtained in terms of yield were taken into consideration by appropriate use of energy conversion factors as detailed in Table 1. Human labour and fuel consumption were considered direct energy and the others were considered indirect energy. Both the direct energy (human labour and fuel consumption) and indirect energy (seed, machinery, plant protection, fertilization, and irrigation) were measured. Operation-wise energy was calculated in the form of (i) land preparation, (ii) seeding, (iii) weeding, (iv) fertilizer application, (v) irrigation, (vi) plant protection, and (vii) harvesting and winnowing.

Computation of energy and energy productivity

The energy input, output, energy output-input ratio, and energy productivity in rice, wheat, and mungbean cultivation were calculated following Chamsing et al. (2006) and Islam et al. (2013).

Total energy input (E_i)

Total energy input (MJ/ha) = $E_f + E_s$ .... (i)

where E_f is energy input in farm operations (MJ/ha) and E_s is energy sequestered in machinery (MJ/ha).

Energy input in farm operations (E_f)

Energy input in farm operation (MJ/ha) =
Phy + Chem + Bio .... (ii)

where Phy is physical energy input (MJ/ha), Chem is chemical energy input (MJ/ha), and Bio is biological energy input in farm operation (MJ/ha).

Physical energy inputs (Phy)

Total physical energy input for each farm operation was calculated as the summation of energy inputs from human labour and mechanical power sources.

Physical energy input (MJ/ha) = $E_l + E_m$ .... (iii)

where E_l is labour energy input (MJ/ha) and E_m is mechanical energy input (MJ/ha).

Labour energy input (MJ/ha) = $\frac{L \times W_{dl} \times W_{hl}}{A}$ .... (iv)

where L is number of labours, W_{dl} is number of working days (day), W_{hl} is number of working hours (h/day), and A is planted area (ha).

Mechanical energy input (MJ/ha) =

$$\frac{M_f \times N_m \times W_{dm} \times W_{hm} \times F_{eq}}{A} \text{ .... (v)}$$

where M_f is fuel consumption of machine (L/h), N_m is number of farm machine, W_{dm} is working day of farm machine (day), W_{hm} is working hour for farm machine (h/day), F_{eq} is Energy equivalent of fuel (MJ/L), and A is planted area (ha).

Energy equivalents for labour and fuel are presented in Table 1.

Biological Energy Inputs (Bio)

Seeds were considered as biological energy input resources.

Biological energy input (MJ/ha) = amount of seed applied $\left(\frac{kg}{ha}\right) \times$ energy equivalent of seed $\left(\frac{MJ}{kg}\right)$ .... (vi)

Energy equivalents for seeds of different crops are presented in Table 1 for biological energy input calculation.

Chemical Energy Input (Chem)

Fertilizer and other chemicals (pesticides, herbicides, weedicides, and liquid) were considered as chemical energy input.

Chemical energy input (MJ/ha) =
Fertilizer energy input $\left(\frac{MJ}{ha}\right)$ + Other chemical energy input $\left(\frac{MJ}{ha}\right)$ .... (vii)

Fertilizer energy input (MJ/ha)
= $N \times N_{eqv} + P \times P_{eqv} + K \times K_{eqv} + S \times S_{eqv} + Z \times Z_{eqv}$ .... (viii)

where N, P, K, S, and Z are application rate (kg/ha) of Nitrogen, Phosphate, Potassium, Sulphur, and Zinc, respectively. N_{eqv}, P_{eqv}, K_{eqv}, S_{eqv}, and Z_{eqv} are energy equivalent values (MJ/kg) of Nitrogen, Phosphate, Potassium, Sulphur, and Zinc, respectively.

Other chemical energy input (MJ/ha) =
$Hr \times Hr_{eqv} + Ps \times Ps_{eqv} + Ws \times Ws_{eqv}$ .... (ix)

where Hr, Ps, and Ws is application rate (kg/ha) of herbicide, pesticide, and weedicide, respectively. Hr_{eqv}, Ps_{eqv}, and Ws_{eqv} is energy equivalent (MJ/kg) of herbicide, pesticide, and weedicide, respectively.

Energy equivalents for different fertilizers and other chemicals for unit application are given in Table 1 for total chemical energy calculation.

Energy sequestered in mechanical power sources (E_s)
Energy sequestered (MJ/ha) = M×h .... (x)

where M is energy sequestered in machinery manufacturing (MJ/h) and h is machine working hour (h/ha).

Energy output (E_o)
Energy output (MJ/ha) =
(Yield $\times E_{eqm}$)+(By–product$\times E_{eqb}$).................... (xi)

where E_{eqm} is energy equivalent value of the main product and E_{eqb} is energy equivalent value of by-product.

Energy equivalents used in study are listed in Table 1.

Estimation of input-output energy relation
The input energy parameters for the three crops have a contribution to make an output or production, so the relationship was drawn in the form of a correlation of the input energy variables to the output energy. The ANOVA and Pearson correlation were used to define the contributions that were conducted by IBM SPSS Statistics 25 software (Developer: IBM, Version: 25).

Energy productivity (E_p)
Energy productivity was calculated from crop yield and the total input imposed on the production of crop as

Energy productivity (kg/MJ) =
$$\frac{\text{Crop yield, kg/ha}}{\text{Energy inputs to crop production, MJ/ha}} \text{ .... (xii)}$$

Energy output-input ratio (ER)
It is the ratio of output energy produced to all input energies (total input energy). The energy output-input ratio was calculated as

Energy output-input ratio =
$$\frac{\text{Energy output, MJ/ ha}}{\text{Energy inputs to crop production, MJ/ha}} \text{ ....(xiii)}$$

Results and Discussion

Operation-wise energy distribution
Operational energies for seedling raising, tillage, transplanting, weeding, fertilizing, spraying, harvesting, and winnowing are presented in Table 2.

Table 2. Operation-wise average energy input (MJ/ha) for rice, wheat, and mungbean under conventional tillage (CT) and strip tillage (ST) cultivation

Operations	CT (MJ/ha)	Percentage of total energy (%)	ST (MJ/ha)	Percentage of total energy (%)
Rice (BRRI dhan49)				
Seedling Raising	490	2.3	410	2.4
Land Preparation	8177	38.9	4400	25.6
Transplanting	570	2.7	600	3.5
Fertilizer Application	5754	27.4	5754	33.5
Plant Protection	2548	12.1	2548	14.9
Irrigation	3252	15.5	3252	18.9
Harvesting & Winnowing	212	1	210	1.2
Total	**21003**	**100**	**17174**	**100**
Wheat (BARI Gom 25)				
Land Preparation	8177	39	3949	23.9
Seeding	741	3.5	480	2.9
Weeding	0	0	0	0
Fertilizer Applications	7460	35.6	7460	45.2
Plant Protection	4181	19.9	4181	25.4
Irrigation	0	0	0	0
Harvesting and Winnowing	426	2	426	2.6
Total	**20985**	**100**	**16496**	**100**
Mungbean (Binamoog-8)				
Land Preparation	8109	65.5	4060	50.33
Seeding	740	6	480	6
Weeding	0	0	0	0
Fertilizer Applications	1743.5	14.1	1743.5	21.6
Plant Protection	763.5	6.2	763.5	9.5
Irrigation	0	0	0	0
Harvesting and Winnowing	1020	8.2	1020	12.7
Total	**12376**	**100**	**8067**	**100**

For conventional tillage, CT, of rice, the range of energy required for fertilizer was 27-30%, tillage 30-40%, irrigation 13-20%, and plant protection 10-15% of total energy consumption. In strip tillage, ST, the range of energy required for tillage was 22-28%, fertilizer 30-35%, irrigation 13-20%, and plant protection 12-15% of total energy. For wheat, in CT, the highest energy input was for land preparation (39%), fertilizer ranked second (35.6%), and plant protection third (19.9%), whereas in the ST, fertilizer was the highest energy input (45.2%) followed by plant protection (25.4%). The operation-wise energy was 21% higher in CT than in ST for wheat cultivation. In CT, the energy associated with tillage was 60-66%, fertilizer 10-15%, and harvesting 8-12% of total energy consumption. For mungbean, the highest energy required was in land preparation for both CT (65.5%) and ST (50.3%), followed by fertilizer application (14.1%) for CT. In the ST method, farm operational energy for mungbean was 8067 MJ/ha; the operation-wise energy was 38% higher in CT than in ST.

For all three crops, it was noticed that the total energy input was always less in the case of ST compared to CT resulting from less energy input for land preparation in ST. As the energy input decreased for land preparation in ST, the percentage of total energy for others increased significantly, and fertilizer application became the highest input for rice and wheat.

Relationship of the input energy variables with output energy

Table 3 shows the relationship of operational input energy parameters with the total output energy. The energy involved in the seedling raising of BRRI dhan49 had a low but significant impact ($p<0.01$) in regulating output in conventional tillage and strip tillage. The energy contribution for land preparation was higher in ST than in CT for wheat and mungbean, that was highly significant for wheat. Nevertheless, for rice, the energy involved in land preparation was negatively correlated, where it was higher for ST compared to CT. The energy for seeding exerted better impact on output for ST of wheat and mungbean than on rice. In fertilizer application, a significant correlation was found in the strip tillage practice of rice and wheat. The energy used for rice irrigation had a more significant influence on ST compared to CT. There was a negative correlation of plant protection with total output energy for all crops. However, strong correlations were found for all crops under ST for harvesting and winnowing, with a significant correlation for rice. A negative relation depicts that, for these operations, input energy increased but did not significantly impact the output; so, the output-input ratio decreased.

Table 3. Correlation of operational energy inputs with total output energy

Activity	BRRI dhan49		BARI Gom 25		Binamoog 8	
	CT	ST	CT	ST	CT	ST
Seedling Raising	0.573	1.000*	-	-	-	-
Land Preparation	-0.891	-0.955	0.997	1.000*	0.953	0.988
Transplanting	0.795	1.000*	-	-	-	-
seeding	-	-	0.397	0.975	-0.819	-0.785
Fertilizer Application	0.817	1.000*	-0.596	1.000*	0.990	0.995
Plant Protection	-0.935	-0.987	-0.596	0.297	-0.586	-0.098
Irrigation	-0.817	0.987	-	-	-	-
Harvesting and Winnowing	-0.911	1.000*	0.737	0.976	0.941	-0.995

*significant at 5% probability

Source-wise energy distribution

Source-wise energy distributions for all three crops under different tillage practices are presented in Table 4. Direct energy for rice cultivation (16.9% of total energy) under CT was higher compared to ST (10.3% of total energy). Fuel was the main contributor of direct energy sources, with 14.6% and 8.9% of total energy in CT and ST, respectively. The energy consumption in ST for particular energy sources, such as fertilizer application, seed, irrigation, and plant protection were 18.2%, 18%, 18.2%, and 18.3% higher compared to CT, respectively. In wheat cultivation, the direct energy consumption was a small portion of total energy consumption ranging from 18.4% in CT to 11.7% in ST. Indirect energy contributed most compared to direct energy in wheat production. The largest energy source of indirect energy was fertilizing in both CT (35.6% of total energy) and ST (45% of total energy). The energy consumption for fertilizing, seed, and plant protection was 21.3%, 21%, and 21.4% higher in ST compared to CT, respectively, for wheat cultivation. In mungbean cultivation, direct energy consumption accounted for only one-third of total energy consumption ranging from 30-35% in CT and 22-25% in ST. The largest energy source of indirect energy consumption was machinery in CT (5113 MJ/ha) that was 41.3% of the total energy consumption. For mungbean, human energy (41.5%), fuel energy (18.3%), and machinery energy (18.2%) were higher in CT than ST practice. On the contrary, the energy consumption in ST was 38.8%, 38.8%, and 38.9% higher compared to CT for seed, fertilizing, and plant protection, respectively.

Table 4. Energy consumption (MJ/ha) based on energy sources under conventional tillage (CT) and strip tillage (ST) options for rice, wheat, and mungbean cultivation

Source	CT (MJ/ha)	Percentage of total energy (%)	ST (MJ/ha)	Percentage of total energy (%)
		Rice (BRRI dhan49)		
Direct Energy				
Human	480	2.3	240	1.4
Fuel	3064	14.6	1532	8.9
Subtotal	3544	16.9	1772	10.3
Indirect energy				
Seed	792	3.8	792	4.6
Machinery	5113	24.3	3056	17.8
Fertilizing	5754	27.4	5754	33.5
Irrigation	3252	15.5	3252	18.9
Plant Protection	2548	12.1	2548	14.9
Subtotal	17459	83.1	14902	89.68
Total	**21003**	**100**	**17174**	**100**
		Wheat (BARI Gom 25)		
Direct Energy				
Human	800	3.8	400	2.4
Fuel	3064	14.6	1532	9.3
Subtotal	3864	18.4	1932	11.7
Indirect Energy				
Seed	367	1.8	367	2.2
Machinery	5113	24.4	2556	15.5
Fertilizing	7460	35.6	7460	45.2
Irrigation	0	0	0	0
Plant Protection	4181	19.9	4181	25.4
Subtotal	17121	81.6	14564	88.3
Total	**20985**	**100**	**16496**	**100**
		Mungbean (Binamoog-8)		
Direct Energy				
Human	1120	9	400	4.9
Fuel	3064	24.8	1532	19
Subtotal	4184	33.8	1932	23.9
Indirect Energy				
Seed	572	4.6	572	7.1
Machinery	5113	41.3	3056	37.9
Fertilizing	1743.5	14.1	1743.5	21.6
Irrigation	0	0	0	0
Plant Protection	763.5	6.2	763.5	9.5
Subtotal	8192	66.2	6135	76.1
Total	**12376**	**100**	**8067**	**100**

Table 5. Energy productivity and output-input relationship under different tillage options for rice, wheat, and mungbean cultivation

Crops	**Conventional Tillage**			**Strip Tillage**		
	Energy Output (MJ/ha)	**E_P (kg/MJ)**	**ER**	**Energy Output (MJ/ha)**	**E_P (kg/MJ)**	**ER**
Rice	154717.5	0.249	7.3	162085	0.320	9.4
Wheat	86660	0.133	4.1	95945	0.188	5.8
Mungbean	23178	0.035	1.9	29848	0.098	3.7

E_P= Energy productivity, ER= Energy output-input ratio

The energy output-input ratio varied for all three crops due to variation of yield between CT and ST practices (Table 5). The energy output-input ratio (ER) was 22.3%, 29.1%, and 64.3% higher in ST compared to CT for rice, wheat, and mungbean, respectively. The energy productivity in ST was 22.1%, 29.2%, and 48.6% higher compared to CT for the corresponding crops. The ST treatment augmented ER for the rice-wheat-mungbean cropping pattern. The comparison direct and indirect energies and energy output-input ratio are shown in Figure 3 and 4, respectively.

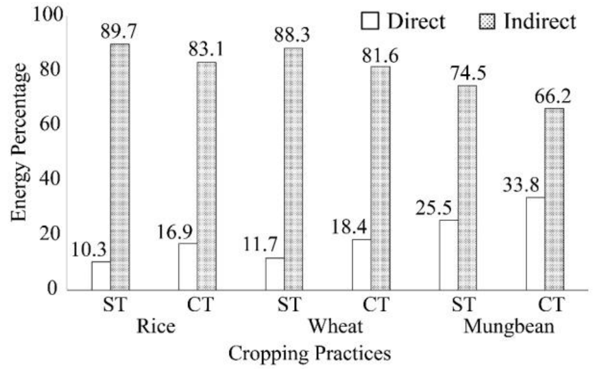

Figure 3. Comparison between direct and indirect energy of rice, wheat, and mungbean for both strip tillage (ST) and conventional tillage (CT)

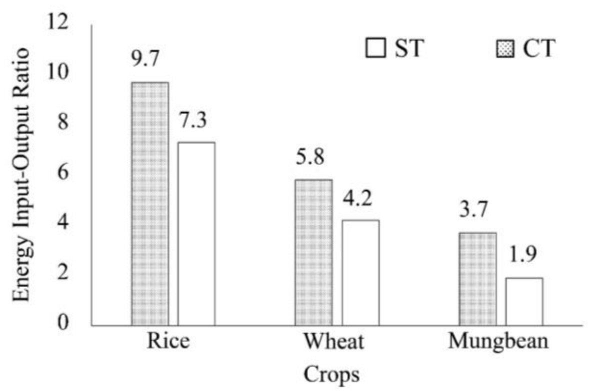

Figure 4. Energy output-input ratio of rice, wheat, and mungbean for strip tillage (ST) and conventional tillage (CT)

Conclusion

Conservation agriculture systems are being adopted by the farmers in Bangladesh day by day as an outcome of the extension of sustainable development goals. The research covers the scenario and comparison of different tillage methods, conventional and strip tillage, for the rice-wheat-mungbean cropping pattern. The strip-tillage, ST, system saved 18-20%, 21.3%, and 34.8% energy in rice, wheat, and mungbean cultivation, respectively, compared to conventional tillage, CT. The trends of output-input ratio in ST were higher than in CT. Analyses of the energy output-input parameters in cultivation and productivity revealed strip tillage as more energy-efficient in terms of energy produced in the rice-wheat-mungbean cropping system. Further studies on modelling the input-output factors for different cultivation techniques and crops considering the weather, soil inputs, and cropping pattern might reveal more insights into energy output-input relation.

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