

## Energy consumption and its indices under different tillage methods in mungbean (*Vigna radiata*)–wheat (*Triticum aestivum*) system in semi-arid conditions of Haryana

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### ABSTRACT

A field experiment was conducted during 2019–20 and 2020–21 at the Chaudhary Charan Singh Haryana Agricultural University, Regional Research Station, Bawal (Rewari), to study the energy consumption and indices under different tillage methods in mungbean (*Vigna radiata* L.) R. Wilczek–wheat (*Triticum aestivum* L.) cropping system. The treatments included 9 tillage combinations for crop establishment under mungbean–wheat cropping system (MWCS), viz. zero-tillage mungbean (ZTM) followed by (*fb*) zero-tillage wheat (ZTW), ZTM *fb* reduced tillage wheat (RTW), ZTM *fb* conventional tillage wheat (CTW), reduced tillage mungbean (RTM) *fb* ZTW, RTM *fb* RTW, RTM *fb* CTW, conventional tillage mungbean (CTM) *fb* ZTW, CTM *fb* RTW, CTM *fb* CTW, laid out in randomized block design with 3 replications. The yields of mungbean sown after ZTW were higher (775–785 kg/ha) than after RTW (756–783 kg/ha) or CTW (753–780 kg/ha). However, the highest grain yield (5,367 and 5,025 kg/ha during 2019–20 and 2020–21, respectively) of wheat was obtained under ZTM–ZTW. Energy inputs under ZTM–ZTW were lowest, which saves 18% of energy incurred in CTM–CTW. Output: input ratio of energy was highest (10.13) under ZTM–ZTW and lowest (7.67) under CTM–CTW. Zero-tillage resulted in the minimum specific energy (energy consumed/kilogram of grain production) in mungbean (4.37–5.16 MJ/kg) and wheat (2.94–3.10 MJ/kg). Zero-tillage based establishment of MWCS was realized to be sustainable for resource conservation as well as crop productivity.

**Key words:** Energy use, Mungbean, Wheat, Yield, Zero-tillage

Conservation agriculture (CA) is an approach to manage agro-ecosystems for sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment. Under CA, there is an urgent need to follow and encourage zero-tillage (ZT) practice along with maintaining soil cover and suitable crop rotations preferably by involving pulses/ legumes. Cropping sequence and crop rotations involving legumes and pulses help in minimizing the insect-pests attack through life-cycle disruption, control of off-site pollution, enhancing biological nitrogen fixation and biodiversity (Kassam and Friedrich, 2009). Conventional tillage (CT) practices,

especially for wheat (*Triticum aestivum* L.) cultivation, are very intensive in India accounting for the major cost of production, as tillage alone involves around one-fourth of the total cost of wheat production. The introduction of zero-tillage in Haryana saved 59.0 L/ha diesel, 8 hr/ha of tractor time and approximately 3,000 MJ/ha of tractor-operation energy as compared to conventional tillage (Sharma *et al.*, 2002). The ZT in wheat across different cropping systems and landscapes is now a very widely accepted proposition to improve productivity, profitability, soil health, input-use efficiency and overall system sustainability including effective management of crop residues, natural resources and environmental pollution (Coventry *et al.*, 2011; Malik *et al.*, 2014; Yadav *et al.*, 2012, 2020).

The use of machinery in the cultivation of fields consumes a large amount of direct energy as fuel and electricity. This energy consumption can be managed by replacing or changing the existing practices used in crop cultivation. The agricultural sector requires energy as an essential input

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for crop production. Of late, it has become more energy-intensive to supply sufficient food for the increasing population of the country. This continuous increase in the use of energy in agriculture has been resulting in the depletion of non-renewable energy resources and simultaneously, induced the application of chemical fertilizers and pesticides causing environmental pollution. However, the success and profitability of any agricultural production system are dependent on energy consumption. The amount of fertilizer application to succeeding crops in cropping system results in significantly higher system net energy returns, energy output: input ratio and energy intensiveness. But the inclusion of legume crops in a system reduces the input energy required for obtaining a higher yield by fixing atmospheric nitrogen, thereby resulting in higher output: input ratio and system net energy returns (Pacharne, 2017). Hence, energy-use analysis in agriculture is essential for an efficient, sustainable and financially viable production system, since such production entails lower costs and reduces dependency on fossil fuels.

In the cultivation of arable crops, tillage is one of the highest energy and labour-intensive operations. Primary tillage practices require 70–75% of the total energy consumed before seed-time. The energy savings by minimum and zero-tillage are often offset by higher energy requirements for herbicides and nitrogen fertilizers (Zentner *et al.*, 2004). However, Borin *et al.* (1988) reported that 30% of energy in the field is consumed by tillage. Therefore, the selection of an appropriate tillage method is very important for the assessment of system's energy conservation and environmental pollution control. Despite yield benefits and savings in cost of production, the ZT technology has not been adopted at scale so far in south-west (SW) Haryana. This could be due to lack of suitable ZT-machines and insufficient information on ZT in mungbean (*Vigna radiata* (L.) R. Wilczek)–wheat system. Hence, it was planned to generate data on the impacts of ZT technology on energy dynamics in mungbean–wheat cropping system (MWCS) in semi-arid conditions of SW Haryana, keeping in view the growing importance of pulses in India.

## MATERIALS AND METHODS

A field experiment was conducted during 2019–20 and 2020–21 on mungbean–wheat cropping system at the Regional Research Station of the Chaudhary Charan Singh Haryana Agricultural University, Bawal, Rewari, (28.1° N, 76.5° E, 266 m above mean sea-level) with sub-tropical climatic conditions. Soil of the experimental field was loamy sand, low in organic carbon, available N and P, while medium in available K. Peculiar characteristics of Bawal region are semi-arid climate with hot sunny days along with dry winds during the summer and severe cold

days during the winter. Mean maximum temperature reaches as high as 48°C and mean minimum temperature reaches as low as 2°C. Sometimes minimum temperature touches the freezing point. South-west monsoon season, i.e. from July to September contributes around 80% of the total annual rainfall. Western disturbances also cause significant amount of rainfall during the winter months. The total rainfall was 428 mm during the rainy (*khariif*) season of 2019, while it was 227 mm during the rainy season of 2020. The rainfall during the winter (*rabi*) season was 101 mm in 2019–20 and 68 mm in 2020–21. The experiment was laid out in a randomized block design with 9 tillage treatment combinations, viz. zero-tillage mungbean (ZTM) followed by (*fb*) zero-tillage wheat (ZTW); ZTM followed by (*fb*) reduced tillage wheat (RTW); ZTM *fb* conventional tillage wheat (CTW); reduced tillage mungbean (RTM) *fb* ZTW; RTM *fb* RTW; RTM *fb* CTW; conventional tillage mungbean (CTM) *fb* ZTW; CTM *fb* RTW and CTM *fb* CTW with 3 replications. The varieties used were 'MH 421' (mungbean) and 'WH 1105' (wheat). For conventional tillage treatments, each plot was prepared with 2 harrowing + 2 ploughings (with tiller), followed by planking as preparatory tillage, whereas for reduced tillage, 1 harrowing followed by planking was done. In ZT treatment, no tillage operations were carried out for both the crops and crops sown directly a week after applying pre-seeding herbicide glyphosate @ 1.0% + 0.1% surfactant to knock-down the pre-emerged weeds. Both the crops were raised as per recommended package of practices of the State Agriculture University.

Energy balance on soil tillage and crops was determined by the methods explained by Hülsbergen *et al.* (2001). Total energy inputs (ET<sub>i</sub>) were divided into 2 main groups: direct and indirect energy. Direct energy (Ed) consisted of fuel consumption and human labour, and indirect energy (Ei) comprised the energy used for machinery, fertilizers, herbicides and seeds. In agricultural production systems, human labour energy is usually not taken into consideration in energy-balance calculations, but in the present study, this factor has been considered for energy calculations.

Direct energy (Ed) was calculated as:

$$Ed = (HL \times E_{HL}) + (FC \times E_{FC})$$

where, HL, human labour; FC, fuel consumption; E<sub>HL</sub>, energy-equivalent of human labour; E<sub>FC</sub>, Energy equivalent of fuel.

Indirect energy (Ei) calculations were done as per the following formula.

$$Ei = [(ME \times E_{ME}) / (TE \times E_{FC})] + (FE \times E_{FE}) + (HE \times E_{HE}) + (SE \times E_{SE})$$

In the formula, each additional component means the energies for machinery (ME), tractor (TE), fertilizers (FE), herbicides (HE) and seeds (SE). The pertinent

energy-equivalent values of different components recommended for agricultural production as shown in Table 1 were used for calculations.

Total energy input was obtained by the sum of direct energy and indirect energy input. In calculating the energy inputs, energy required for storage and transportation was not taken into consideration (Hülsbergen *et al.*, 2001). This input energy was calculated in each soil tillage treatments for both the crops.

$$ET_i = E_d + E_i$$

While calculating the energy output ( $E_o$ ), both grain ( $E_g$ ) and straw ( $E_s$ ) energy values were used. Energy output for each crop (mungbean and wheat) was obtained by the following formula.

$$E_o = E_g + E_s$$

### Energy parameters

Energy output: input ratio (Energy-use efficiency) in crop production was calculated as:

$$\text{Energy input: output ratio (Energy - use efficiency)} = \frac{\text{Energy output (MJ/ha)}}{\text{Energy input (MJ/ha)}}$$

Specific energy used in crop production was calculated as under:

$$\text{Specific energy (MJ/kg)} = \frac{\text{Energy input (MJ/ha)}}{\text{Crop grain yield (kg/ha)}}$$

### Statistical analysis

Data collected during the study were statistically analysed by using the technique of analysis of variance

(ANOVA) described by (Cochran and Cox, 1959). To judge the significant difference between means of 2 treatments, the critical difference (CD) was worked out using following formula:

$$CD = (\sqrt{2EMS/r}) \times t \text{ value at } 5\%$$

where, CD, critical difference; EMS, error mean sum of square; R number of replication; T, value of t- distribution at 5% level of error degree of freedom.

The results were tested for treatment means by applying 'F' test of significance on the basis of null hypothesis. The 'OPSTAT' (Sheoran *et al.*, 1998) software of CCS Haryana Agricultural University, Hisar, was used for statistical analysis.

## RESULTS AND DISCUSSION

### Crop productivity

The seed yield of mungbean was not affected significantly by different methods of crop establishment in MWCS during both the years and resulted statistically similar grain yields (911–926 kg/ha during 2019 and 753–785 kg/ha during 2020) (Table 2). However, the grain yield during the first year was higher than that of the second year due to unfavourable weather parameters, particularly continuous rainfall during maturity period of crop, in later year.

The grain yield of wheat was not significantly affected by different methods of tillage in MWCS during 2019–20 (Table 2). However, the differences were significant in 2020–21. The maximum grain yield in the first year was obtained under ZTM–ZTW (5,367 kg/ha), followed by

**Table 1.** Energy equivalents of the inputs and outputs in mungbean–wheat cropping system

Particulars	Unit	Energy equivalent	Reference
<i>A. Input</i>			
Human labour	Hour	1.96	Tabatabaefar <i>et al.</i> (2009)
Diesel fuel	Litre	56.31	Singh (2002)
Farm machinery	kg	62.70	Singh (2002)
Tractor	kg	68.40	Singh (2002)
Threshers	kg	17.40	Singh (2002)
Nitrogen	kg	78.23	Ali <i>et al.</i> (2013)
Phosphate	kg	13.07	Tabatabaefar <i>et al.</i> (2009)
Potash	kg	6.70	Tabatabaefar <i>et al.</i> (2009)
ZnSO <sub>4</sub>	kg	20.90	Tabatabaefar <i>et al.</i> (2009)
Herbicide	Litre	120.00	Canakci <i>et al.</i> (2005)
Electricity	KW	11.93	Pathak and Binning (1985)
Seed (wheat)	kg	14.70	Ali <i>et al.</i> (2013)
Seed (mungbean)	kg	14.70	Ali <i>et al.</i> (2013)
<i>B. Output</i>			
Grain (wheat)	kg	14.70	Ozkan <i>et al.</i> (2004)
Straw (wheat)	kg	12.50	Ozkan <i>et al.</i> (2004)
Grain (mungbean)	kg	14.70	Ali <i>et al.</i> (2013)
Stover (mungbean)	kg	12.50	Ali <i>et al.</i> (2013)

Note: Distributed the weight of the machinery equally over the total life span of the machinery (hours) for the particular operation of crop

**Table 2.** Effect of different tillage combinations on grain yield (kg/ha) of mungbean and wheat crops and the system productivity of mungbean–wheat cropping system

Treatment	Mungbean		Wheat		System productivity (Wheat-equivalent yield)	
	2019	2020	2019–20	2020–21	2019–20	2020–21
ZTM–ZTW	926	785	5,367	5,025	8,619	7,880
ZTM–RTW	925	783	5,241	4,622	8,490	7,468
ZTM–CTW	925	780	5,191	4,593	8,440	7,429
RTM–ZTW	915	778	5,346	4,959	8,560	7,768
RTM–RTW	919	757	5,232	4,698	8,462	7,450
RTM–CTW	917	754	5,178	4,641	8,400	7,381
CTM–ZTW	911	775	5,329	4,822	8,528	7,640
CTM–RTW	913	756	5,196	4,722	8,403	7,471
CTM–CTW	915	753	5,157	4,625	8,372	7,362
SEm±	32	37	155	89	225	185
CD (P=0.05)	NS	NS	NS	270	NS	NS

ZTM, Zero-tillage mungbean; ZTW, zero-tillage wheat; RTM, reduced tillage mungbean; RTW, reduced tillage wheat; CTM, conventional tillage mungbean; CTW, conventional tillage wheat

RTM–ZTW (5,346 kg/ha) and CTM–ZTW (5,329 kg/ha) in 2019–20. Similarly, during 2020–21, the maximum grain yield was obtained under ZTM–ZTW (5,025 kg/ha), followed by RTM–ZTW (4,959 kg/ha) and CTM–ZTW (4,822 kg/ha). During 2020–21, the grain yield of wheat in sequence with ZTM was significantly higher under ZTW (5,025 kg/ha) than RTW (4,622 kg/ha) and CTW (4,593 kg/ha). Whereas in sequence with RTM, ZTW (4,959 kg/ha) was superior to CTW (4,641 kg/ha) but it was similar to RTW (4,698 kg/ha). The wheat sown under ZT, RT or CT after CTM gave similar grain yield. These results indicated that productivity of crops was higher when ZT was used as establishment method in either or both of the seasons. This indicated the suitability and superiority of ZT as an alternate method of establishment in wheat as well as mungbean under MWCS.

Impact of different establishment methods on system productivity (wheat-equivalent yield) of MWCS was non-

significant during both the years (Table 2). However, the system productivity was maximum when both the crops were sown with zero tillage (ZTM–ZTW) (7,880–8,619 kg/ha), which was followed by RTM–ZTW (7,768–8,560 kg/ha) and it was lowest under CTM–CTW (7,362–8,372 kg/ha). The zero tillage in wheat had comparatively more impact on system productivity than ZT in mungbean.

### Energy dynamics

**Energy input:** Tillage treatments showed significant effect on energy inputs in MWCS. In comparison to ZTM–ZTW, the total direct energy input accounted was 1.90 and 1.93 times higher in CTM–CTW in 2019–20 and 2020–21 respectively (Table 3). The energy difference between tillage treatments arose from the differences in the use of direct inputs (fuel and lubricants). The indirect energy consumption was almost similar in all methods of tillage treatment during both the years. However, it was slightly higher

**Table 3.** Effect of different tillage combinations on direct and indirect energy inputs of mungbean and wheat crops in mungbean–wheat cropping system

Treatment	Energy inputs (MJ/ha)											
	Direct					Indirect						
	Mungbean		Wheat		Total	Mungbean		Wheat		Total		
2019–20	2020–21	2019–20	2020–21	2019–20	2020–21	2019–20	2020–21	2019–20	2020–21	2019–20	2020–21	
ZTM–ZTW	1,467	1,467	3,233	3,042	4,700	4,509	2,582	2,582	12,553	12,553	15,135	15,135
ZTM–RTW	1,467	1,467	4,279	4,088	5,746	5,555	2,582	2,582	12,610	12,610	15,192	15,192
ZTM–CTW	1,467	1,467	5,340	5,149	6,807	6,616	2,582	2,582	12,748	12,748	15,330	15,330
RTM–ZTW	2,513	2,513	3,233	3,042	5,746	5,555	2,358	2,358	12,553	12,553	14,911	14,911
RTM–RTW	2,513	2,513	4,279	4,088	6,792	6,601	2,358	2,358	12,610	12,610	14,968	14,968
RTM–CTW	2,513	2,513	5,340	5,149	7,853	7,662	2,358	2,358	12,748	12,748	15,106	15,106
CTM–ZTW	3,574	3,574	3,233	3,042	6,807	6,616	2,465	2,465	12,553	12,553	15,018	15,018
CTM–RTW	3,574	3,574	4,279	4,088	7,853	7,662	2,465	2,465	12,610	12,610	15,075	15,075
CTM–CTW	3,574	3,574	5,340	5,149	8,914	8,723	2,465	2,465	12,748	12,748	15,213	15,213

ZTM, Zero-tillage mungbean; ZTW, zero-tillage wheat; RTM, reduced tillage mungbean; RTW, reduced tillage wheat; CTM, conventional tillage mungbean; CTW, conventional tillage wheat

under zero-tillage treatment owing to pre-emergence herbicide spray for controlling the weeds before sowing of crops (Table 3).

The total energy input in wheat (15,786–18,088 MJ/ha during 2019–20 and 15,795–17,897 MJ/ha during 2020–21) was much higher than mungbean (4,049–8,723 MJ/ha during both years), which could be due to higher energy contribution by seed, fertilizers and irrigation inputs in wheat crop (Table 4). Yadav *et al.* (2013) also reported lower energy input under rice–legume cropping systems as compared to rice–cereal cropping system. However, total system energy inputs were minimum under system-based ZT followed by combination of RTM–ZTW and it was maximum under CTM–CTW. The main reason for this could be the extensive use of tillage tools, machinery and fuels in conventional tillage (Zentner *et al.*, 1998; Parihar *et al.*, 2018).

The rainfall was higher during the first year as compared to the second year; however, it did not result in saving in number of irrigations due to its untimely occurrence. Therefore, expected yearly variations in energy input due to variation in rainfall were not there.

**Energy output:** Total system energy output was recorded 4.7 and 8.4% higher in ZTM–ZTW in 2019–20 and 2020–

21, respectively, as compared to CTM–CTW (Table 4), which was owing to higher yields under zero-tillage method of crop establishment.

**Energy output: input ratio:** The highest energy output: input ratio was reported in ZTM–ZTW (10.78 in 2019–20 and 10.13 in 2020–21), closely followed by RTM–ZTW, and the lowest was in CTW–CTW (8.46 in 2019–20 and 8.02 in 2020–21) (Table 4). Minimum energy was consumed to produce a unit of grains of mungbean and wheat crops under zero-tillage, which was owing to higher grain production and less energy input under zero-tillage as compared to conventional tillage practice. Yadav *et al.* (2020) also reported the benefits of zero tillage in terms of diesel saving and better productivity in rice–wheat system.

**Specific energy:** In mungbean, specific energy was the lowest in ZTM–based systems (4.37–5.19 MJ/kg) and the highest in CTM–based systems (6.60–8.02 MJ/kg) (Figs. 1, 2). Similarly in wheat, specific energy was the lowest in ZTW–based systems (2.94–3.23 MJ/kg) and the highest in CTW–based systems (3.48–3.90 MJ/kg). In wheat, ZTM–ZTW, ZTM–RTW and ZTM–CTW, the specific energy was 2.94, 3.22 and 3.48 MJ/kg, respectively, in 2019–20, and 3.10, 3.61 and 3.90 MJ/kg, respectively, in 2020–21. An identical trend was found for both the crops in RTM–

**Table 4.** Effect of different tillage combinations on system-based energy input, energy output and energy output: input ratio in mungbean–wheat cropping system

Treatment	Total energy input (Mungbean) (MJ/ha)		Total energy input (Wheat) (MJ/ha)		System energy input (MJ/ha)		System energy output (MJ/ha)		System energy output: input ratio	
	2019–20	2020–21	2019–20	2020–21	2019–20	2020–21	2019–20	2020–21	2019–20	2020–21
ZTM–ZTW	4,049	4,049	15,786	15,595	19,835	19,644	213,732	198,920	10.78	10.13
ZTM–RTW	4,049	5,555	16,889	16,698	20,938	20,747	207,465	187,841	9.91	9.05
ZTM–CTW	4,049	6,616	18,088	17,897	22,137	21,946	206,568	187,358	9.33	8.54
RTM–ZTW	4,871	5,555	15,786	15,595	20,657	20,466	211,224	196,459	10.23	9.60
RTM–RTW	4,871	6,601	16,889	16,698	21,760	21,569	207,045	186,126	9.51	8.63
RTM–CTW	4,871	7,662	18,088	17,897	22,959	22,768	205,984	184,857	8.97	8.12
CTM–ZTW	6,039	6,616	15,786	15,595	21,825	21,634	210,016	195,288	9.62	9.03
CTM–RTW	6,039	7,662	16,889	16,698	22,928	22,737	205,215	185,427	8.95	8.16
CTM–CTW	6,039	8,723	18,088	17,897	24,127	23,936	204,058	183,569	8.46	7.67

ZTM, Zero-tillage mungbean; ZTW, zero-tillage wheat; RTM, reduced tillage mungbean; RTW, reduced tillage wheat; CTM, conventional tillage mungbean; CTW, conventional tillage wheat

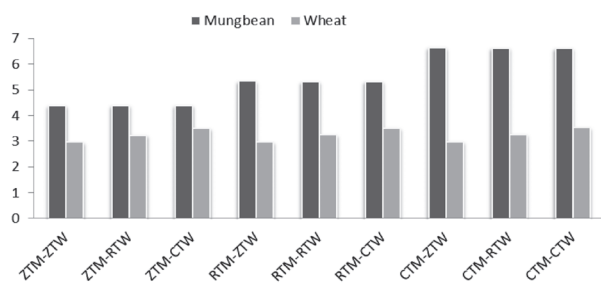


Fig. 1. Specific energy (MJ/kg) of mungbean and wheat crops under different tillage methods in mungbean wheat cropping system (2019–20)

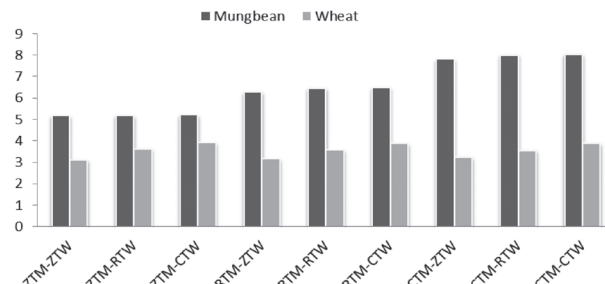


Fig. 2. Specific energy (MJ/kg) of mungbean and wheat crops under different tillage methods in mungbean wheat cropping system (2020–21)

ZTM, Zero-tillage mungbean; ZTW, zero-tillage wheat; RTM, reduced tillage mungbean; RTW, reduced tillage wheat; CTM, conventional tillage mungbean; CTW, conventional tillage wheat

and CTM-based systems, where output: input ratio increased with RTW and CTW as compared to ZTW. In mungbean–wheat cropping system, the lowest total output: input ratio was obtained under ZTM–ZTW (8.26 MJ/kg) and the highest under CTM–CTW (11.89 MJ/kg), which indicated better energy output: input ratio under ZT than CT method of establishment in MWCS.

Based on this study, it may be concluded that tillage treatments showed significant effect on energy inputs. Total system energy of inputs was the minimum under ZTM–ZTW and the maximum under CTM–CTW. Total energy output was 4.7–8.3% higher in ZTM–ZTW than CTM–CTW. The highest output: input ratio and the lowest specific energy (required to produce a unit of grains) were recorded in ZTM–ZTW. It indicated the sustainability of zero-tillage-based mungbean–wheat cropping system in terms of energy saving and crop productivity in semi-arid conditions of south–west Haryana.

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