Indian Journal of Traditional Knowledge
Vol 20(3), July 2021, pp 846-851

Comparison of the energy consumption in traditional and advanced paddy residue management technologies for wheat sowing

Parveen*, Mukesh Jain, Vijya Rani, Hemant Kumar, Jaideep, Aman Mor & Sachin
COAE&T, CCS Haryana Agricultural University, Hisar, 125 004
E-mail: parveenfmpe@gmail.com

Received 02 April 2020; revised 07 June 2021

The study examines the energy consumption for paddy harvesting and wheat sowing using different techniques. The research was planned with ten treatments using three straw management practices, i.e., Retention, Incorporation, and Removal of straw. Major portion of energy is consumed in form of diesel energy, which was the highest energy consumption source, with a participation of 79.3 to 86.5%. It was resulted that T_4 had the opulent while T_7 had the miserable yield. Least energy was consumed in treatment T_2 (1582.9 MJ ha^{-1}) and the most was in treatment T_5 (3500.4 MJ ha^{-1}). The specific energy consumption was 25.47, 24.94, 27.74, 49.68, 58.15, 46.60, 55.82, 51.43, 53.01 and 37.78 MJ ha^{-1}, respectively for Treatment T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, and T_{10}. Specific energy is more in removal and incorporation of straw residue practices in comparison to residue retention practices. It can be concluded that treatments using direct drilling machine was the most efficient in case of specific energy consumption. Residue retention tillage practice with happy seeder should be used to make higher productivity with efficient energy input to manage paddy residue.

Keywords: Energy, Incorporation, Straw management, Tillage practice, Wheat sowing

IPC Code: Int Cl^{21}: A01B 33/08, A01B 49/06, A01B 79/02, A01C 7/12

Rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) are India's most grown cereal crops. India has different agro-ecological regions and a more significant part of the geographical area is used for agriculture where a lot of verities of crops are grown. It is anticipated that around 600-650 Mt of crop residue is generated in a year, with a yield of 122.39 Mt of fiber crops (Jute, Mesta, Cotton), 28.71 Mt of oilseeds crops, 361.85 Mt cereals (34% by rice and 22% by wheat) 107.49 million tons (Mt) of sugarcane in the year 2014-15[1]. From the country's total food production, 69% of the food produced is contributed by the two states Punjab and Haryana. Punjab and Haryana cultivate an area of about 2.81 million ha and 15.5 million ha, respectively in paddy. 5.5 kg of N, 2.3 kg Phosphorous pentoxide (P_2O_5), 25 kg Potassium oxide (K_2O), 1.2 kg Sulphur (S), 400 kg Carbon and 50-60% of micronutrients are available in 1 tonne of paddy straw[2]. After harvesting of rice, standing stubbles in the field become interruption for further timely operation like sowing of wheat. The easiest way for a farmer is to burn the straw, but straw burning is not a solution; instead, it is a problem for the nature and as well as for soil (Fig. 1). Straw burning is a major issue in both Punjab and Haryana state. Due to combustion, approximately the whole amount of Carbon, 75-79% of Nitrogen, more than 20% of Phosphorus, nearly fifty 50% of Sulphur and 19% of Potassium (K) available in paddy residue is lost but incorporation of paddy residue and stubble into moisturised soil (during ploughing) results in temporary immobilization of N and a significant increase in methane (CH_4) emission from the rice paddy, a practice that contributes to greenhouse gases. Burning the crop residue also results in the loss of microorganisms in the field which are beneficial in nutrient fixation and decomposition of the residue which in turn results in loss of fertility. When 1000 kg of paddy straw is burnt, 3 kg of particulate matter, 60 kg CO, 1460 kg CO_2, 2 kg SO_2 and 199 kg S are produced[3]. These gases contribute significantly in the degradation of air quality which results in the onset of cough, asthma, skin diseases, bronchitis and the particulate matter suspended in air causes heart and lung diseases.

Due to the above said harmful effects of straw burning, there is a need to manage the vast quantity of residue generated by incorporating the straw in the

*Corresponding author

farm through the use of various farm machineries available for the same. Crop residue is a by-product from the crop; therefore the amount of residue is generated in proper ratio depending upon type and production of crop and northern states reported in higher productivity, i.e., Punjab, Haryana, Uttar Pradesh and Rajasthan[4]. India also ranked at the third position in energy consumption after China and USA[5,6]. Agriculture is related to both a production and consumption of energy, as agriculture consumes energy; it also produces is in the form of bio-energy[7]. Energy has a very close relation with economics as well as environment also[8]. Profits of agriculture produce decreases due to increase in energy consumption. The demand for energy in agriculture can be divided into indirect and direct energies. In fine soils, more than 10 cultivations are resulted in more energy consumptions and wheat sowing also delayed. Therefore, the selection a proper cultivation method including evaluation of the energy conservation and environmental pollution control.

Therefore, the present research was done to evaluate different available technologies for crop residue management. The focus of the study was to provide the best efficient, economic and minimum energy consuming technology to the farmers for management of paddy straw and convince the farmers to avoid burning of straw. The trials were conducted at the farmer's field in order to make them understand the alternate methods to manage farm residue. When the farmers get convinced with alternative methods of straw incorporation and their effects such as saving of environment, protection of soil nutrients and soil organisms, increase in soil fertility, burning of straw will be reduced to a great extent.

Fig. 1 — A farmer field: Burning of paddy Straw

Materials and Methods

Experimental field climate characteristics

The experiment was conducted at farmer field at village Dabra in Hisar district of Haryana State in India. Hisar lies between the North latitudes 28^{0}56’00” to 29^{0}38’30” and East latitudes 75^{0}21’12” to 76^{0}18'12". It has a tropical monsoonal climate and is characterized as an arid type of weather. The summers are generally quite hot, and winters are relatively cold. The average rainfall of the area is 330 mm which mostly occur from mid-June to September with occasional wintry showers during December and January months.

Treatments

Rice harvesting was done in the 2nd fortnight of October, 2017 and then the field was prepared for sowing of Wheat crop. In the present study, a combination of ten treatments consisting of three type crop (paddy) residue management practices (Incorporation, retention and Straw removal). Each treatment was replicated three times. Different type of treatments is shown in Table 1. Paddy harvesting was done by Combine harvester with Straw management system (SMS) and Traditional combine. Wheat

Table 1 — Different type of treatments

Straw management practices	Treatment	Machinery used in the treatment
Straw Retention	T_1 =	Combine harvester with Straw management system (SMS) + Zero till drill
	T_2 =	Combine harvester with SMS + Spatial till drill
	T_3 =	Combine harvester with SMS + Happy seeder
Straw Incorporation	T_4 =	Combine harvester with SMS + Reversible mould board plough + Rotavator + Seed drill
	T_5 =	Combine harvester with SMS + Rotavator (2 pass) + Seed drill
	T_6 =	Combine harvester with SMS + Disc harrow (3 pass) + Planker + Seed drill
	T_7 =	Combine harvester with SMS + Rotavator + Manual broadcasting + Rotavator
Straw Removal	T_8 =	Traditional combine + Stubble shaver + Straw baler + Disc harrow (2 pass) + Planker + Seed drill
	T_9 =	Traditional combine + Stubble shaver + Hay Rake + Straw baler + Disc harrow (2 pass) + Planker + Seed drill
	T_{10} =	Traditional combine + Traditional straw removing method + Disc harrow (2 pass) + Planker + Seed drill

sowing was done using Zero till drill, Spatial till drill, Happy seeder, Seed cum fertilizer drill, and Manual broadcasting.

Energy parameters

The input energy from different sources and specific energy with respect to wheat yield was calculated. The energy equivalents of the inputs and outputs are shown in Table 2.

Input energy

On the basis of Use of energy, input energy can be mainly divided in two groups[19]: indirect energy and direct energy. In every treatment, the energy either used in the form of direct energy or in the form of indirect energy was calculated by taking all the inputs like man-hour, diesel, tractor and machinery.

Energy from direct sources

The direct energy[18] was obtained from man and diesel. The following relation was used to calculate the energy of man:

Energy of man (MJ ha^{-1}) = 1.96 × Working hours/ha

The following relation was used to calculate the energy of diesel:

Energy of diesel (MJ ha^{-1}) = 56.31 ×Working hours/ha

The following relation was used to calculate direct energy:

Direct energy (MJ ha^{-1}) = Energy of man + Energy of diesel

Energy from indirect sources

The indirect energy was obtained from tractor and machinery as given by previous findings.[19]. Machines and tractors are used in the agricultural field. Production of machine requires different type of metals along with some other materials also produced. In process of all operations energy consumption takes place. So, the energy in tractor and machinery is calculated by using the following equation:

Energy of tractor (MJ ha^{-1}) =

$$\frac{64.8 \times Working\ hour\ \left(\frac{h}{ha}\right) \times Weight\ of\ tractor}{Life\ of\ the\ tractor\ in\ hour}$$

Table 2 — Energy equivalent values for inputs

Particulars	Unit	Energy (MJ/unit)	Reference
A. Inputs			
Man	h	1.96	9-12
Diesel	l	56.3	11-15
Machinery	kg	62.7	12-15
Tractor	kg	64.8	16
B. Output			
Wheat Grain	kg	15.7	17,18

Energy of machinery (MJ ha^{-1}) =

$$\frac{62.7 \times Working\ hour\ \left(\frac{h}{ha}\right) \times Weight\ of\ machinery}{life\ of\ machinery\ in\ hour}$$

Indirect energy = Energy of tractor + Energy of machinery

Total Energy

The total energy is computed below:

TE = DE+ IE

Where, TE = Total Energy, MJ ha^{-1}

DE = Direct energy, MJ ha^{-1}

IE = Indirect energy, MJ ha^{-1}

Statistical analysis

Average grain yield was recorded per plot (converted to q ha^{-1}) after sun drying. The total energy used in different treatments was worked out. The Treatments layout in Randomized Block Design Experiment and analysis of data perform at IASRI server. The data on yield was subjected to analysis of variance (ANOVA)[20] which was analysed at IARSI. Different treatment means were separated by DUNCAN's Multiple Range Test[21], where Means with at least one letter common are not statistically significant. Adjusted p-value of less than 0.0001 was accepted for declaring an association significant.

Results and Discussion

Grain yield

Different methods of wheat sowing had shown a great effect on the yield as shown in Table 3. The reason may be due to better incorporation of plant residue into the soil which increases water holding capacity and proper growth of crop roots. Better incorporation of plant residue also results in more availability of essential nutrients required for crop. The highest yield was received from paddy straw incorporation in Treatment T_4 followed by Happy seeder in treatment T_3 and lowest in treatment T_7 (54.80 q ha^{-1}). The reason for a meagre yield of the wheat crop in particular treatment may be due to uneven spreading of wheat seed by manual broadcasting, and improper depth of seed placement of wheat seed due to rotavator operation after the manual broadcasting might have affected germination. The wheat yield in treatment T_3 was found as 67.64 q ha^{-1}.

Similar results were reported by previous studies[25] for wheat yield with happy seeder. The mean yield of the crop was found to be 63.44 q ha^{-1}. The yield obtained in zero tillage was 5% and 9% more than rotavator tillage and conventional tillage, respectively; a similar result was also reported previously[26]. Higher

Table 3 — The yield of Wheat under different treatment

Straw management practices	S. No.	Treatment	Treatment yield (q ha^{-1})
Straw Retention	T_1	Combine harvester with SMS + Zero till drill	62.37^{f}
	T_2	Combine harvester with SMS + Spatial till drill	63.47^{de}
	T_3	Combine harvester with SMS + Happy seeder	67.63^{b}
Straw Incorporation	T_4	Combine harvester with SMS + Reversible MB Plough + Rotavator + Seed drill	70.30^{a}
	T_5	Combine harvester with SMS + Rotavator (2 passes) + Seed drill	60.20^{g}
	T_6	Combine harvester with SMS + Disc harrow (3 pass) + Planker + Seed drill	63.57^{d}
	T_7	Combine harvester with SMS + Rotavator + Manual broadcasting + Rotavator	54.80^{h}
Straw Removal	T_8	Traditional combine + Stubble shaver + Straw baler + Disc harrow (2 pass) + Planker + Seed drill	64.20^{d}
	T_9	Traditional combine + Stubble shaver + Hay rake + Straw baler + Disc harrow (2 pass) + Planker + Seed drill	65.40^{c}
	T_{10}	Traditional combine+ Traditional straw removing method + Disc harrow (2 pass) + Planker + Seed drill	62.43^{ef}
		General Mean	63.44
		p-Value	<0.0001
		CV (%)	0.97

Table 4 — Treatment -wise energy consumed (MJ ha^{-1})

Straw management practices	S.No.	Treatments	Direct source of energy		Indirect source of energy		Total Energy
			Man	Diesel	Machinery	Tractor	
Straw Retention	T_1	Combine harvester with SMS + Zero-till drill	19.0	1265.2	266.0	38.0	1588.3
	T_2	Combine harvester with SMS + Spatial till drill	19.6	1255.1	268.5	39.8	1582.9
	T_3	Combine harvester with SMS + Happy seeder	21.3	1512.	296.4	46.0	1875.9
Straw Incorporation	T_4	Combine harvester with SMS + Reversible MB plough + Rotavator + Seed drill	29.2	2990.8	348.8	123.5	3492.2
	T_5	Combine harvester with SMS + Rotavator (2 passes) + Seed drill	28.1	2986.8	369.5	115.9	3500.4
	T_6	Combine harvester with SMS + Disc harrow (3 pass) + Planker + Seed drill	24.5	2551.5	312.9	73.3	2962.2
	T_7	Combine harvester with SMS + Rotavator + Manual broadcasting + Rotavator	21.4	2590.9	354.4	92.4	3059.1
Straw Removal	T_8	Traditional combine + Stubble shaver + Straw baler + Disc harrow (2 pass) + Planker + Seed drill	27.6	2788.2	366.2	120.0	3301.9
	T_9	Traditional combine + Stubble shaver + Hay rake + Straw baler + Disc harrow (2 pass) + Planker + Seed drill	29.9	2930.7	369.8	136.2	3466.6
	T_{10}	Traditional combine + Traditional straw removing method + Disc harrow (2 pass) + Planker + Seed drill	21.0	2013.0	250.9	73.8	2358.6

yield was obtained may be due to increase in porosity of the field and reduction in bulk density which enhances more crop growth and favourable conditions for the crop[26]. This showed that incorporations of straw helps in increasing the productivity of wheat only with tillage operations, which were mainly essential for incorporate the crop residue in the soil for its sufficient and proper decomposition[27].

Pattern of energy consumption

In various farm operations, the highest total energy input consumed from harvesting of paddy to sowing of wheat crop was obtained 3500.4 MJ ha^{-1} in treatment T_5 and Lowest energy consumption was recorded as 1582.9 MJ ha^{-1} in treatment T_2 Treatment-wise detail of energy requirement is shown in Table 4. The variation in energy consumption between the treatments was due to direct sowing without prior tillage in crop residue. Some authors[22] also stated that the energy required to produce per quintal of yield was higher in other treatments as compared to the energy needed in no-tillage treatments. The difference between energy requirement in direct sowing and after seedbed preparation was found to be more than

Table 5 — Energy comparison of different treatment

Straw management practices	S. No.	Treatment	Wheat yield (q ha^{-1})	Total energy consumption (MJ ha^{-1})	Specific energy consumption (MJ q^{-1})
Straw Retention	T_1	Combine harvester with SMS + Zero till drill	62.37^{f}	1588.3	25.47
	T_2	Combine harvester with SMS + Spatial till drill	63.47^{de}	1582.9	24.94
	T_3	Combine harvester with SMS + Happy seeder	67.63^{b}	1875.9	27.74
Straw Incorporation	T_4	Combine harvester with SMS + Reversible MB plough + Rotavator + Seed drill	70.30^{a}	3492.2	49.68
	T_5	Combine harvester with SMS + Rotavator (2 passes) + Seed drill	60.20^{g}	3500.4	58.15
	T_6	Combine harvester with SMS + Disc harrow (3 pass) + Planker + Seed drill	63.57^{d}	2962.2	46.60
	T_7	Combine harvester with SMS + Rotavator + Manual broadcasting + Rotavator	54.80^{h}	3059.1	55.82
Straw Removal	T_8	Traditional combine + Stubble shaver + Straw baler + Disc harrow (2 pass) + Planker + Seed drill	64.20^{d}	3301.9	51.43
	T_9	Traditional combine + Stubble shaver + Straw baler + Hay rake + Disc harrow (2 pass) + Planker + Seed drill	65.40^{c}	3466.6	53.01
	T_{10}	Traditional combine + Traditional straw removing method + Disc harrow (2 pass) + Planker + Seed drill	62.43^{ef}	2358.6	37.78

1900 MJ ha^{-1}. Previous study[23] reported that energy requirement for direct drilling and normal ploughing was 1.0 GJ ha^{-1} for sandy loam soil and 2.2 GJ ha^{-1} for clay soil. They[28] reported that tillage consumed 30% of energy in the field. Zero tillage technique helps in reducing consumption of fuel, increases the energy ratio, and helps in controlling soil erosion, also time saving and easily seedbed preparation. Highest man, machinery and tractor energy were found in treatment T_9 which is a straw removing method, whereas the lowest energy in man, diesel, machinery, and tractor was found in zero tillage treatments. Highest energy input was from diesel fuel, rather than the energy used from man, machinery and tractor. The diesel energy was obtained the largest energy source in total inputs, with a share of 79.3 to 86.5%. It was followed by machinery energy (10-17%), tractor energy (2.4-3.9%) and man energy (0.7-1.2%). As almost field operations were done with agricultural machinery. So, the share of man-power energy contributed only 1%. However, the high energy input decreases the specific energy and energy ratio also.

Evaluation of energy consumption under treatments

Table 5 shows the comparison between energy consumption and wheat yield obtained in the particular treatment. The minimum unit energy consumption was found in treatment T_2 (24.94 MJ q^{-1}) and maximum unit energy consumption was found in treatment T_5 (58.15 MJ q^{-1}). Treatment T_2 resulted in 55% energy saving in comparison to treatment T_5. It is seen in Table 4 that direct drilling treatments required less energy as compared to straw removing treatments and treatments where seedbed preparation is needed. The maximum yield was obtained from the Treatment T_4. However, the energy consumption was also high. Minimum yield was obtained in treatment T_7 (54.80 q ha-1). Moreover, in treatment T_7, energy consumption was more. Treatments T_1 and T_2 resulted in minimum energy consumption, but the yield of these treatments was significantly low as compared to Treatment T_3. Treatment T_3 was a combination of a combine harvester with SMS + Happy seeder. The best treatment among the treatments was T_3 due to higher yield and low value of energy consumption.

Conclusion

Highest energy consumption of 3500.4 MJ ha^{-1} was found in treatment T_5 (Combine harvester with SMS + Rotavator (2 passes) + Seed drill). Lowest energy consumption of 1582.9 MJ ha^{-1} was found in treatment T_2 (Combine harvester with SMS + Spatial till drill). Minimum specific energy consumption of 24.94 MJ q^{-1} was found in T_2 (Combine harvester with SMS + Spatial till drill). Maximum specific energy consumption of 58.15 MJ q^{-1} was found in T_5 (Combine harvester with SMS + Rotavator (2 passes) + Seed drill). Straw retention technology for straw management resulted in lesser energy consumption and yield obtained are also higher whereas energy consumption in straw incorporation and straw removal technologies was resulted in much higher. From obtained results we conclude that, in term of energy efficient treatment having combination of Combine harvester with SMS and Happy seeder will best as compared to the other treatment.

Acknowledgements

I would like to express my appreciation to COAE&T, CCSHAU, Hisar, for conducting this research and providing required materials and funding. I would particularly like to thank Dr. M Jain for directing and providing proper execution of experiments.

Conflict of interest

The authors declare no conflict of interest.

Authors' contributions

Parveen designed and executed the experiments and wrote the first draft of the manuscript, MJ wrote the protocol and supervised to conduct the experiments, VR and HK general work arrangement, Jaideep and AM assisted in writing this article and Sachin supervised the literature searches. All authors read and approved the final manuscript.

References

1 https://niti.gov.in/sites/default/files/2019-03/EOI_on_the_Topic_of_A_Researsh_Study_on_Mass_Production_of_Manure_Fertilizer_form_Agriculture_Bio-Mass.pdf, 2019.

2 Anonymous, *An extension booklet of Directorate of Research*, (Punjab Agricultural University, Ludhiana, Punjab), 2013.

3 Phutela U G & Sahni N, Effect of *Fusarium sp.* on paddy straw digestibility and biogas production, *J Adv Lab Res in Bio*, 3 (1) (2012) 9-12.

4 Anonymous, Wheat Farmers Portal, (Department of Agriculture & Cooperation and Farmers Welfare, Ministry of Agriculture and Farmers Welfare, Government of India) http://www.farmer.gov.in/, 2015.

5 Anonymous, India's energy market in 2015, BP Statistical Review (2016b) https://www.bp.com/content/dam/bp/pdf/energy-economics/statistical-review-2016/bp-statistical-review-of-world-energy-2016-full-report.pdf, 2016.

6 Anonymous. World Energy Consumption by Country http://www.usdebtclock.org/, 2016b.

7 Bhatnagar G V, High pollution levels from straw burning show green tribune orders were neglected-the WIRE 2016, http://www.downtoearth.org.in/news/crop-burning-Punjab-Haryana-s-killer-fields-55960, 2016.

8 Pimentel D, Herdendorf M, Eisenfeld S, Olander L, Carroquino M, *et al.*, Achieving a secure energy future: environmental and economic issues, *Ecol Econ*, 9 (3) (1994) 201–219.

9 Ozkan B, Akcaoz H & Karadeniz F, Energy requirement and economic analysis of citrus production in Turkey, *Energy Convers Manage*, 45 (2004) 18-30.

10 Canakci M, Topakci M, Akinci I & Ozmerzi A, Energy use pattern of some field crops and vegetable production: Case study for Antalya Region, Turkey, *Energy Convers Manage*, 46 (4) (2005) 655-666.

11 Chaudhary V P, Gangwar B & Pandey D K, Auditing of energy use and output of different cropping systems in India, *Agric Eng Int CIGREJ*, 8 (2006) 1-13.

12 Yilmaz I, Akcaoz H & Ozkan B, An analysis of energy use and input costs for cotton production in Turkey, *Renew Energy*, 30 (2006) 145-155.

13 Singh P, Singh G & Sodhi G P S, Energy auditing and optimization approach for improving energy efficiency of rice cultivation in south-western Punjab, India, *Energy*, 174 (3) (2019) 269-279.

14 Singh H, Mishra D & Nahar N M, Energy use pattern in production agriculture of a typical village in Arid Zone India Part I, *Energy Convers Manage*, 43 (16) (2002) 2275-2286.

15 Verma T S & Bhagat R M, Impact of rice straw management practices on yield, nitrogen uptake and soil properties in a wheat-rice rotation in northern India, *Ferti Res*, 33 (2) (1992) 97-106.

16 Erdal G K, Esengun H E & Gunduz O, Energy use and economical analysis of sugar beet production in Tokat province of Turkey, *Energy*, 32 (2007) 35-41.

17 Singh J M, On-farm energy use pattern in different cropping systems in Haryana, India, (Master of Science, Germany: International Institute of Management, University of Flensburg), 2002.

18 Singh P, Singh G & Sodhi G P S, Applying DEA optimization approach for energy auditing in wheat cultivation under rice-wheat and cotton-wheat cropping systems in north-western India, *Energy*, 181 (2019) 18-28.

19 Gajendra S, *Straw Management: Alternative to straw burning in combine harvested wheat crop field*, (M.Tech Thesis, JNKVV, Jabalpur, MP), 2016.

20 Gomez K A & Gomez A A, Statistical procedures for agricultural research, 2nd edition, (John Wiley and Sons Inc, New York, USA), 1984, p. 704.

21 https://iasri.icar.gov.in/division/design-of-experiments/#design-of-experiments

22 Kumar V, Saharawat Y S, Gathala M K, Jat A S, Singh S K, *et al.*, Effect of different tillage and seeding methods on energy use efficiency and productivity of wheat in the Indo-Gangetic plains, *Field Crops Res*, 142 (2013) 1-8.

23 Arvidsson J, Energy use efficiency in different tillage systems for winter wheat on a clay and silt loam in Sweden, *Eur J Agron*, 33 (3) (2010) 250-256.

24 Safa M, Samarasinghe S & Mohssen M, Determination of fuel consumption and indirect factors affecting it in wheat production in Canterbury, New Zealand, Energy, 2010; 35(12): 5400-5405.

25 Bansal N K & Kumar A, *Role of machinery for crop residue management.* (Deptt. Of Farm Machinery and Power Engineering CSS Haryana Agricultural University, Hisar), 2014.

26 Verma S & Bhagat R, Energy in production agriculture and food processing, In: *Proceedings of the National conference*, 30-31 October 1992, (Punjab Agricultural University, Ludhiana), 1992.

27 Ghuman B S & Sur H S, Tillage and residue management effects on soil properties and yields of rainfed maize and wheat in a sub-humid sub-tropical climate, *Soil Till Res*, 58 (2001) 1–10.

28 Borin M, Merini C & Sartori L, Effects of tillage systems on energy and carbon balance in north-eastern Italy, *Soil Till Res*, 40 (3) (1997) 209–26.