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Energy requirement for the sowing of wheat after the *in-situ* management of paddy residues

Parveen, Ajaib Singh and Ritu Dogra

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See end of the Paper for authors' affiliation

Correspondence to :

Parveen
Department of Farm Machinery and Power Engineering, Punjab Agricultural University, Ludhiana (Punjab) India
Email: parveenfmpe@gmail.com

ABSTRACT : The present study assessed the energy requirement for the harvesting of paddy with combine harvesting with/without Super Straw Management System and wheat sowing with different farm machinery having straw retention and straw incorporated in the fields. The straw retention treatments *i.e.* T_1 and T_2 whereas straw incorporation treatments *i.e.* T_3 and T_4 were taken in the study. The total energy consumption was maximum for treatment T_4 (5529.92 MJ/ha), followed by treatment T_3 (5487.47 MJ/ha), followed by treatment T_2 (3485.15 MJ/ha) and treatment T_1 (2539.40 MJ/ha). The least human energy consumption (22.01 MJ/ha), diesel energy (551.95 MJ/ha) and tractor and machinery energy (551.95 MJ/ha) was observed for treatment T_1, while the maximum human energy, diesel energy, and tractor and machinery energy was observed in treatment T_4 (52.17 MJ/ha), T_3 (3442.63 and T_4 (644.89 MJ/ha). The electrical energy (1401.78 MJ/ha) and submersible pump energy (13.68 MJ/ha) was observed in treatment T_3 and T_4, respectively. The residue retention practice of wheat sowing with Happy Seeder after paddy harvesting with combine harvester having Super Straw Management System is the efficient energy input to manage the paddy residue.

KEY WORDS : Energy, Straw management, Wheat sowing, Straw retention, Incorporation

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Rice-wheat (RW) cropping pattern is the most popular cropping pattern in the Indo- Gangetic plains of South Asia covering almost 13.5 million ha area each year (Timsina and Connor, 2001). Punjab has made discernible progress in agriculture and played a key role in green revolution salvaging the nation from being a chronic importer of food grains to its self-sufficiency. Punjab is contributing 30-40 per cent rice and 40-50 per cent wheat in the central pool and thus ensuring food security of the country from 1.5 per cent geographical area (Gill, 2012). Rice and wheat crops were covering an area of 30.46 and 34.95 lakh ha in Punjab with total production of 188.63 and 176.36 lakh tones during 2016-17, respectively (Anonymous, 2018 a and b). Combine harvesters are mostly used for the harvesting of these crops in the state. Cultivation of high yielding varieties of the rice and wheat has resulted in the production of crop residues in large quantities. There is no problem of managing wheat straw as it can be collected with the help of straw combine and act as leading food for animals. Combine harvesters leave the standing stubbles and loose straw after harvesting the paddy crop. Due to short turnaround time between the harvesting of paddy and sowing of wheat and the absence of a suitable method for straw management, farmers find burning of the straw as the easiest way (Fig. A). 81% of the paddy straw is burnt in the field by the farmers in Punjab every year (Kumar *et al.*, 2014). Burning is the usual and most natural method of crop residue management option because residues interfere with tillage and seeding operations for the next crop. The field burning of paddy straw is a significant contributor to reduced air quality and human respiratory ailments in intensive rice-production areas. Substantial loss of plant nutrients (especially N and S) and organic carbon occurs during the burning of crop residues as one tonne of rice straw contains approximately 5-6 kg N, 0.8-0.9 kg P and 15-20 kg K (Singh, 2012).

Fig. A : *In-situ* burning of paddy residue

The major problem in sowing under no-tillage is the frequent choking of the furrow opener of no-till drill due to the long loose straw of paddy lying in the windrows after harvesting by combines. The paddy straw present in the field often builds up in front of the tines of the drill and eventually blocks the tine and frame, causing unwanted interruptions, uneven seeding rate, and depth and a patchy stand of plants (Graham *et al.*, 1986). Garg and Singh (2004) developed and evaluated a tractor operated rice straw chopper-cum- spreader. The size of chopped straw was found 7-10 cm at 900 rpm of flail speed and 1500 rpm of chopped speed. The fuel consumption varied between 5.0-5.5 l/h while the field capacity ranged between 0.4-0.6 ha/h at 2.5 km/h. Sidhu *et al*. (2005) developed a combo happy-seeder operated with tractor above 45 hp and has field capacity of 0.3-0.4 ha/hr. Happy seeder cuts the standing stubbles and loose straw and throws it backward and sows the field in a single operation. Germination of seed was affected if the straw load was more than 7t/ha. For reducing the straw load over the row, straw managing rotor was modified to cut standing stubbles for 7.5 cm width just in front of furrow openers and leaves standing stubble in other 12.5 cm strip between two furrow openers as such. Sidhu *et al*. (2007) developed a new version of the happy Seeder named as Turbo Happy Seeder in collaboration with Dasmesh Mechanical Works, Amargarh, Punjab (India). The cutting and shredding are achieved with hinged J-type flails mounted on a high speed (1000-1300 rpm) rotor inside the straw management drum. Verma *et al*. (2009) developed and evaluated the performance of straw managing system (SMS) as an attachment for the existing combine harvesters. The optimal combination, at which there was maximum uniformity of straw thrown, *i.e.*, CV 15.25 % was observed at a combination of three rows of stationary blades, rotor speed index of 40 and deflector angle of 20°. Energy has a very close relation with different agricultural operations. Keeping in view the above facts, the present study focuses on assessment and management practices for effective management of paddy residue and to provide the best efficient, economical and minimum energy consuming technology to the farmers.

■ METHODOLOGY

A brief description of farm machinery used in the study is discussed below:

Super straw management system (Super SMS):

Super SMS is the machinery as an attachment to the existing conventional combine harvester having power 80-120 hp for managing and spreading the loose straw evenly in the harvested area. The machine will not only facilitate the smooth operation of second-generation drills in combine harvested fields but also will help in conserving moisture in the soil after harvesting. It increases the field capacity of happy seeder by 20 per cent. Fig. B shows the Super SMS attached with combine while harvesting paddy fields.

Happy seeder:

The happy seeder cut, lifts and manages the standing stubble and loose straw, retaining it as surface mulch and sows wheat in a single operational pass on the field. Fig. C shows the direct of wheat with Happy Seeder in paddy residue conditions.

Fig. B : Super SMS attached with Combine harvester in the field

Fig. C : Sowing of wheat with Happy Seeder in paddy residue retention

Mulcher:

Mulcher is machine attached with three hitch point of the tractor. It gets power from the PTO shaft of the tractor. The primary function of the mulcher is chopping and uniform spreading of anchored paddy stubbles and loose straw. There is a press roller behind the machine, which presses the chopped paddy residue over the ground. Fig. D shows the mulcher in operation in the fields.

Fig. D : Chopping of paddy residue with mulcher

Fig. E : Wet mixing of paddy residue into the soil with rotavator.

Rotavator:

It consists of a frame, a rotary shaft mounted with blades and power transmission system from the gearbox to the shaft. The power is transmitted from the tractor PTO (Power take off) shaft to a bevel gearbox mounted on the top of the unit, through the telescopic shaft and a universal joint. It is an implement that cuts and pulverizes the soil by impact forces. It is suitable for incorporation of paddy residue into the soil. Fig. E shows the wet mixing of paddy residue into the soil.

Experimental site and treatments:

The study was conducted at farmer's field of village Todarpur, Pandori Ganga Singh and Panjoura in Hoshiarpur district of Punjab State in India. Punjab state extends from the latitudes 29.30° North to 32.32° North

Table A : Treatment adopted in the experiment

Straw management practices	Treatments	Farm operations	Farm Machinery/ Technology used
Straw retention	T_1	Harvesting of paddy crop	Combine harvester having super SMS attachment
		Land preparation	None
		Sowing of wheat	Happy Seeder
		Irrigation	None
	T_2	Harvesting of paddy crop	Conventional combine harvester having no super SMS attachment
		Chopping of paddy residue	Mulcher
		Land preparation	None
		Sowing	Happy Seeder
		Irrigation	None
	T_3	Harvesting of paddy crop	Conventional combine harvester having no super SMS attachment
Straw incorporation		Pre Irrigation	Submersible pump
		Land preparation	Wet mixing with rotavator (one operation) + Disc harrow (two operations)+ Cultivator (one operation) + Planker (one operation)
		Sowing	Seed cum fertilizer drill
	T_4	Harvesting of paddy crop	Conventional combine harvester having no super SMS attachment
		Land preparation	Stubble shaver (one operation)+ Disc Harrow (two operations) + Cultivator (two operations)+ Planker (one operation)
		Sowing	Seed cum fertilizer drill
		Irrigation	Submersible pump

and longitudes 73.55° East to 76.50° East. Paddy was harvested in the second fortnight of October with the combine harvester, and wheat was sown with effective management of paddy residue, *i.e.* paddy residue retention and incorporation of paddy residue. The different types of treatment for the management of paddy residue are shown in Table A. The paddy was harvested with combine harvester having Super Straw Management System (Super SMS) attachment and conventional harvester.

Energy Parameters:

The energy expenditure during the harvesting of paddy with the combine harvesters, residue management machinery and wheat sowing machinery for the different practices were estimated by calculating the expanse of energy sources (human labour, machines, fuel, electricity, water) involved in the production process per hectare and then multiplied by their corresponding energy equivalent.

The human energy consumption (MJ/h) per operation, *i.e.*, combine harvesting, tillage, sowing, and irrigation was determined by the number of human labor used, the capacity of one human labour to do the operation and the energy equivalents. Fuel consumption for tractor-powered farm operations was from the actual fuel consumed (l/h) and effective field capacity (ha/h) of the machine. Net fuel energy consumption was determined by multiplying the fuel energy equivalent (MJ/l), consumption (l/ha) and effective field capacity (ha/h).

To calculate the electric energy required to pump water was deducted from the amount of electricity consumed (kWh) and rate of the area covered for irrigation (ha/h) and the energy equivalents of electricity. The energy contribution of machinery per field operation was determined through values of the weight of each

Table B : The values of energy equivalents from various sources used in the study are (Singh and Mittal, 1992)

Sr. No.	Source of energy	Unit	Energy equivalent, MJ
1.	Human labour	Man-h	1.96
2.	Electricity	kWh	11.93
3.	Diesel	L	56.31
4.	Tractor	kg	68.4
5.	Farm machinery	kg	62.7
6.	Electric motor	kg	64.8

machine/implement, its estimated life, effective field capacity of the machine and the energy equivalents of farm machinery.

Energy calculation:

The following formulas are used to calculate the energy of different sources:

Energy of man (MJ/ha) = 1.96x Working hours/ha

Energy of diesel (MJ/ha) = 56.31 x Working hours/ha

Energy of tractor (MJ/ha) = 64.8 x Working hours (h/ha) x weight of tractor (kg) / Life of tractor

Energy of machinery (MJ/ha) = 62.8 x Working hours (h/ha) x weight of machinery (kg)/ Life of machinery

Electric motor energy = 64.8 x Working hours x weight of electric motor (kg) / Life of electric motor

Electrical energy (MJ/ha) = 11.93 x electrical energy consumption (kWh) x Working hours (h/ha)

RESULTS AND DISCUSSION

The operation wise (harvesting of previous paddy crop with a conventional combine harvester and combine harvester having Super SMS attachment, seedbed preparation, sowing of wheat, irrigation purpose) energy consumption for various treatments of effective management of paddy residue was determined (Table 1). The combine harvester having Super SMS attachment was used for harvesting of previous paddy crop was used in treatment T_1 while the conventional combine harvester having no Super SMS attachment was used in other treatments, *i.e.*, T_2, T_3 and T_4. The treatment T_1 consumes 1235.64 MJ/ha more energy as compared to T_2, T_3 and T_4 (1038.21 MJ/ha) in previous paddy crop harvesting as the combine having Super SMS attachment consumes more power for chopping of paddy residue coming from the straw walker and this chopped paddy residue was evenly spreaded over the fields. There is no need for preparing the field for the sowing of the wheat crop in treatments T_1 as the sowing of wheat was done with Happy Seeder in uniformly spreaded chopped paddy residues, and hence no energy was spent on preparation of the fields. The energy consumption for preparing the seedbed in T_2 was 1143.18 MJ/ha as in this treatment

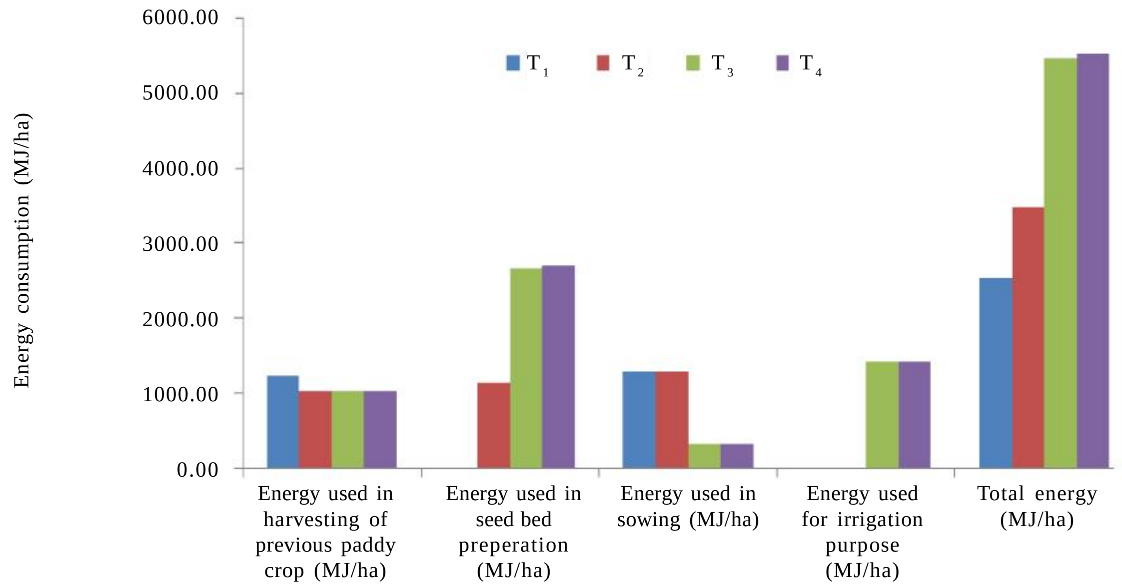

Fig. 1 : Operation-wise energy consumption for different treatments of paddy residue management

Table 1 : Operation-wise energy consumption for different treatments of paddy residue management

Treatments	Energy used in the harvesting of previous paddy crop with a combine harvester (MJ/ha)	Energy used in seedbed preparation (MJ/ha)	Energy used in sowing (MJ/ha)	Energy used for irrigation purpose (MJ/ha)	Total energy (MJ/ha)
T_1	1235.64	0.00	1303.76	0.00	2539.40
T_2	1038.21	1143.18	1303.76	0.00	3485.15
T_3	1038.20	2672.48	341.73	1435.06	5487.47
T_4	1038.20	2714.94	341.73	1435.06	5529.92

Table 2 : Source-wise energy consumption for different treatments of paddy residue management

Treatments	Human energy	Diesel energy	Electrical energy	Submersible pump energy	Tractor energy and machinery energy	Total
T_1	22.01	1965.44	0.00	0.00	551.95	2539.40
T_2	27.68	2846.12	0.00	0.00	611.35	3485.15
T_3	48.10	3442.63	1401.78	13.68	581.29	5487.47
T_4	52.17	3417.41	1401.78	13.68	644.89	5529.93

the previous paddy crop was harvested by the conventional combine harvester and there is even chopping and spreading of paddy residue coming from the straw walkers of the combine. For effective chopping and fine spreading of paddy residue, one operation of mulcher was done for effective sowing of wheat with Happy Seeder. The energy consumed in the preparation of fields in treatment T_3 was 2672.48 MJ/ha while it was 2714.94 MJ/ha for treatment T_4. The energy consumption for field preparation was less in T_3 as compared to treatment T_4 as one operation of rotavator, two operations of disc harrow, one operation of planker was used in T_3 as compared to one operation of stubble shaver, two operations of disc harrow, three operations of cultivator and one operation of planker was used in treatment T_4. The energy consumption for the sowing of wheat was the same (1303.76 MJ/ha) in treatment T_1 and T_2 as in both the treatments, the sowing of wheat was done with Happy Seeder. As the sowing of wheat was done with conventional seed cum fertilizer drill in treatment T_3 and T_4, where the energy consumption for the seed sowing was same (341.73 MJ/ha) and was consumed 962.03 MJ/ha of lower energy as compared to treatment T_1 and T_2. There was no energy consumption for irrigating the fields in treatment T_1, and T_2 as the sowing of wheat was done in residual moisture conditions, and the mulch of paddy residue over the fields also helps in moisture conservation. A net amount of 1435.06 MJ/ha of energy was being spent for irrigating the fields. In treatment T_3, irrigation was required for wet mixing of paddy residue left after the combine harvesting of previous paddy crop with the help of rotavator for effective incorporation of paddy residues into the soil while in treatment T_4, one irrigation was being applied for the availability of optimum moisture content at the time of sowing.

Electrical energy and submersible pump energy:

The electrical energy and submersible pump energy consumption was 1401.78 MJ/ha and 341.73 MJ/ha respectively in treatment T_3 and treatment T_4 as irrigation was provided in treatment T_3 and treatment T_4 for wet mixing/ incorporation of paddy residue into the soil with different farm machinery while there was no need of irrigation in treatment T_1 and T_2 as the sowing was done with Happy Seeder in residual moisture conditions.

Human energy:

As depicted from Table 2, the maximum human energy was consumed in treatment T_4 (52.17 MJ/ha), followed by T_3 (48.10 MJ/ha), T_2 (27.68 MJ/ha) and T_1 (22.01 MJ/ha). The maximum percentage of human energy consumption was observed in 37.49 % in treatment T_4 due to more involvement of human labour was involved, *i.e.* harvesting of paddy with combine harvester; irrigation for optimum moisture conditions for land preparation; land preparation through agricultural machinery like stubble shaver, disc harrow, cultivator, planker; sowing of wheat with conventional drill while minimum percentage human energy consumption was observed in 22.02 % in treatment T_1 as there was no requirement of human labour in operations like seedbed preparation for sowing of wheat and no need of irrigation as sowing of wheat was done with happy Seeder in residual moisture conditions in paddy residue conditions.

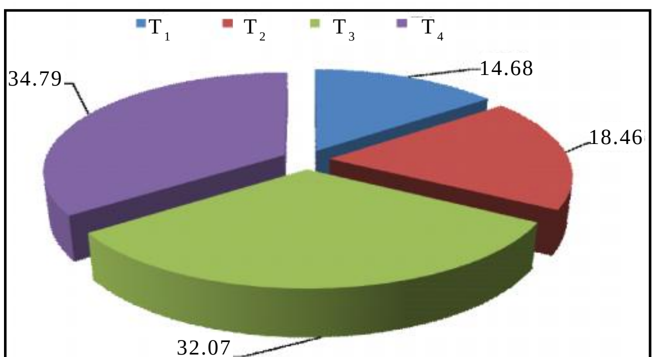

Fig. 2 : Per cent consumption of human energy for different treatments of paddy residue management

Diesel energy:

The maximum diesel energy was consumed in treatment T_3 (3442.63 MJ/ha), followed by T_4 (3417.41 MJ/ha), T_2 (2846.12 MJ/ha) and T_1 (1965.44 MJ/ha). The maximum percentage diesel energy consumption was observed in 29.50 % in treatment T_3 due to more diesel consumption of wet mixing of paddy residue with rotavator followed by disc harrow (2 times), cultivator (1 operation), planker (1 operation) and sowing of wheat with conventional seed cum fertilizer drill while minimum percentage diesel energy consumption was observed in 16.84 per cent in treatment T_1 as there was saving of diesel consumption as there was no requirement of seedbed preparation for sowing of wheat with Happy Seeder.

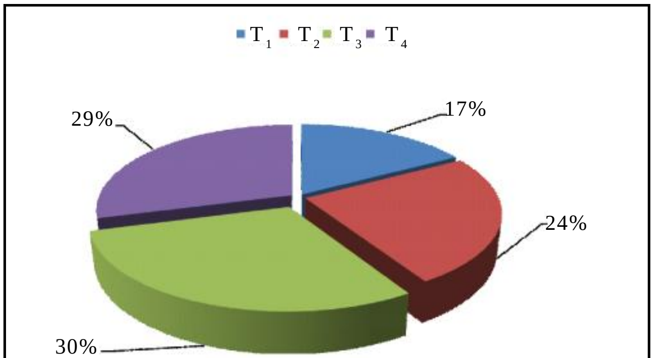

Fig. 2 : Per cent consumption of human energy for different treatments of paddy residue management

Tractor and machinery energy:

The maximum machinery energy was consumed in treatment T_4 (644.89 MJ/ha), followed by T_2 (611.35 MJ/ha), T_3 (581.29 MJ/ha) and T_1 (551.95 MJ/ha). The maximum machinery energy consumption was observed in treatment T_4 due to the involvement of more machinery, *i.e.* harvesting of paddy with combine harvester having no super SMS arrangement, stubble shaver (1 operation) for chopping of paddy residue, disc harrow (2 operations), cultivator (2 operations), planker (1 operation) for seedbed preparation and sowing of wheat with conventional seed cum fertilizer drill. The minimum machinery energy consumption was observed in treatment T_1 due to the involvement of less machinery, *i.e.* harvesting of paddy with combine harvester having super SMS arrangement and sowing of wheat with Happy Seeder as there was no need of seedbed preparation.

The maximum source wise energy consumption was observed in treatment T_4 (5529.93 MJ/ha) followed by T_3 (5487.47 MJ/ha), T_2 (3485.15 MJ/ha) and T_1 (2539.41 MJ/ha). The maximum source of wise energy consumption was observed in treatment T_4 due to more energy consumption through human labour, diesel energy, electrical energy, submersible pump energy, and machinery energy.

Energy consumption through direct and indirect energy sources:

The direct sources energy sources are human labour and diesel while the indirect energy sources are tractor and machinery involved in the study. Fig. 1 shows the energy consumption through direct sources and indirect sources of energy. The energy consumption through indirect energy sources was maximum for treatment T_3 (4892.5 MJ/ha) followed by T_4 (4871.37 MJ/ha), T_2 (2873.8 MJ/ha) and T_1 (1987.46 MJ/ha). The minimum energy consumption through indirect energy sources was observed in treatment T_1 (551.95 MJ/ha) while the maximum energy consumption was observed in treatment T_4 (658.56 MJ/ha).

Energy consumption through renewable/non-commercial and non-renewable/commercial energy sources:

The renewable sources/non-commercial energy sources are human labour while the non-renewable energy/commercial sources are diesel, tractor, and machinery involved in the study. Table 3 shows the energy consumption through renewable sources and non-

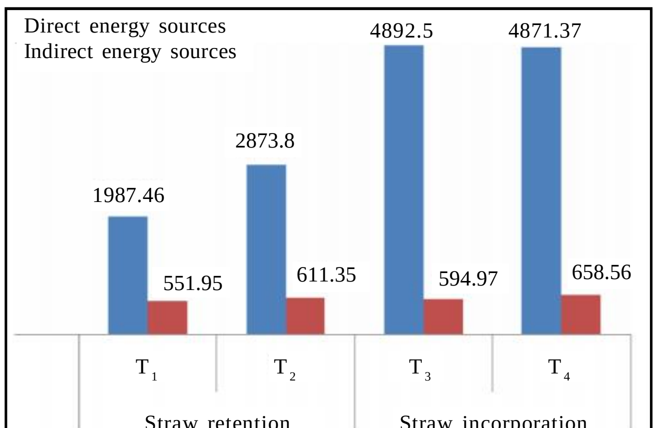

Fig. 3 : Energy consumption through direct and indirect energy sources

Table 3 : Energy consumption through renewable and non-renewable energy sources

Straw management practices	Treatments	Renewable/Non-commercial energy sources	Non-renewable/Commercial energy sources
Straw retention	T_1	22.02	2517.39
	T_2	27.68	3457.47
Straw incorporation	T_3	48.09	5439.38
	T_4	52.18	5477.75

renewable sources of energy.

The energy consumption through renewable energy sources was maximum for treatment T_4 (52.18 MJ/ha) followed by T_3 (48.09 MJ/ha), T_2 (27.68 MJ/ha) and T_1 (22.02 MJ/ha). The minimum energy consumption was observed in treatment T_1 (2517 MJ/ha) while the maximum energy consumption was observed in treatment T_4 (5477.75 MJ/ha).

The residue retention practice (Treatment T_1) of wheat sowing with Happy Seeder after paddy harvesting with combine harvester having Super Straw Management System is the efficient energy input to manage the paddy residue consuming 2539.40 MJ/ha while the practice of wheat sowing with conventional seed cum fertilizer drill after residue incorporation using stubble shaver, disc harrow (two operations), cultivator (two operations) and planker after the harvesting of paddy with conventional combine harvester (Treatment T_4).

Conclusion:

The residue retention practices were found more energy efficient to manage the paddy residue in comparison to residue incorporation practices. Maximum energy was consumed by the treatment T_4 (5529.92 MJ/ha) whereas minimum energy consumed in treatment T_1 (2539.40 MJ/ha). Source-wise significant energy consumption comes from Diesel energy followed by Electrical energy, and these sources contribute to energy consumptions was more than 80 per cent of the total energy consumed in particular treatment. Direct energy sources consumed energy in an only small range (550-660 MJ/ha), and the rest of the large amount (1987.46-4871.37 MJ/ha) was consumed in the form of Indirect energy sources. Similarly, Renewable/Non-conventional energy sources consumed energy in a tiny proportion in comparison to Non-renewable/Conventional energy sources. Further, for better results, the effect of the above treatments on soil fertility needs to be studied, and the needs of water and fertilizer requirement can be considered in the above practices of straw residue management.

Authors' affiliations:

Ajaib Singh, Krishi Vigyan Kendra, Bahowal, **Hoshiarpur (Punjab) India** (Email: as.ajaib82@gmail.com)

Ritu Dogra, Department of Farm Machinery and Power Engineering, Punjab Agricultural University, **Ludhiana (Punjab) India** (Email: ritudogra@pau.edu)

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