



Energy use efficiency in paddy cultivation in Punjab

Sangeet Ranguwal¹, Jasdev Singh²

¹ Agricultural Economist, Department of Economics and Sociology, Punjab Agricultural University, Ludhiana, Punjab, India

² Principal Agricultural Economist, Department of Economics and Sociology, Punjab Agricultural University, Ludhiana, Punjab, India

Abstract

Efficient use of energy by the agriculture sector seems as one of the conditions for sustainable agriculture because it allows financial savings, fossil resources preservation and air pollution reduction. The steady decline in the energy-use efficiency in the present agriculture is a matter of great concern and calls for optimal and proper utilization of energy inputs. Energy intensive paddy cultivation is blamed for several ecological problems of state. Besides depleting the ground water, the consumption of energy in pumping underground water for paddy cultivation is increasing overtime. Therefore, present study was carried out to assess the energy use pattern and efficiency in rice production in Punjab during 2020-21. The results revealed that with net energy gain of 1.81 lakh MJ/Ha achieved with energy output of 2.42 lakh MJ/Ha, rice cultivation in the study area is energy efficient but over-whelming significance of irrigation water, electricity consumption and chemical fertilisers in energy input underpin the opportunities for energy saving. These three together consume more than 80 per cent of input energy. About 56 per cent of total operational input energy was consumed for irrigation only which has created extreme imbalance in energy consumption pattern and indicates energy wastage practices followed by the paddy growers. The direct and indirect source of energy consumption formed 65.34 and 34.66 per cent, respectively of the input energy where electrical energy for irrigation was the major source of direct energy consumption and fertilisers alone had about 89 per cent share in indirect energy. Further, the commercial source of energy comprising 96 per cent of total energy use indicated towards need for curtailing its proportionate use by introduction and enhancing the use of non-commercial energy in crop cultivation. Thus, energy management at the farm level needs serious attention both for efficient and economical use of energy as well as for the safe guard of agro-ecosystem. To improve paddy production without increasing the production cost include steps like reduction in chemical fertilizer use by replacing it with organic fertilisers or by encouraging farmers to adopt recommended farming practices and environment friendly technology *viz.* direct seeded technology (DSR) which may also help in energy saving without compromising the level of output.

Keywords: paddy, cultivation, energy, operations, direct, renewable

Introduction

Energy is the basic driving force in human development. The history of civilization is largely a story of man's progress in harnessing energy i.e. to convert energy to a more useful form. Agriculture, basically an energy conversion industry, requires energy as an essential input to production (Lal *et al.*, 2013)^[18], enhancing food security, adding value (Karimi *et al.*, 2008)^[13] and contributing to rural economic development (FAO 2000)^[9]. With time, the agriculture sector of developing countries has witnessed spectacular progress in farm mechanization that has markedly increased the energy inflows in agriculture (Saad *et al.*, 2016; Choudhary *et al.*, 2017)^[28, 8]. When a natural system capable of producing a certain amount of energy containing biomass is converted into an agro-ecological system, the natural capability limit is often exceeded by adding energy inputs. The greater the input of external energy, the more the natural capability of the system can be exceeded, and the less sustainable the system becomes. Because of this relationship, an analysis of agro-ecosystem's input/output energy balance can be a comprehensive indicator of its sustainability (Farshad and Zinck, 2001)^[10]. In this regard, efficient use of energy by the agriculture sector seems as one of the conditions for sustainable agriculture because it allows financial savings, fossil resources preservation and air pollution reduction (Pervanchon *et al.*, 2002)^[24].

Conservation of non-renewable energy sources and efficient resource management in agriculture is increasingly being realized for cleaner and sustainable production (Kumar *et al.*, 2019b)^[27]. Energy budgets for agricultural production can be used as building blocks for life cycle assessments that include agricultural products, and can also serve as a first step towards identifying crop production processes that benefit most from increased efficiency (Piringer, 2006)^[26]. Assessment of alternative forms of energy with reduced production costs and increased agricultural productivity requires a comprehensive assessment of the local situation, available energy sources, skills, and needs. Agriculture uses large quantities of locally available noncommercial forms of energy, such as manure and animal energy, and commercial energy directly and indirectly in the form of expensive seed, diesel, electricity, fertilizer, plant protection chemicals, irrigation water, machinery etc. which are liable to exhaust in near future (Alam *et al.*, 2005; Iqbal, 2007)^[1, 12]. The steady decline in the energy-use efficiency in the present agriculture is a matter of great concern and calls for optimal and proper utilization of energy inputs involved in various farm operations. Therefore, energy analysis becomes the basis for sound management and policy decisions for conservation and efficient management of scarce resources for improved agricultural production.

In India, rice is the staple food crop for more than 70 per cent people and accounts for 40-45 per cent of the total area covered by cereal crops. It is the main crop during rainy season in trans-Indo-Gangetic Plains, including Punjab. The growing demand of rice has to be met by producing more rice using less land, water, manpower and optimising all agricultural input energy usages. Punjab with 3.1 million hectares of land under rice during the *kharif* season which accounts for nearly seven per cent of total area under rice cultivation in India contributed greatly towards the food security of the country. Paddy production is a direct function of high yielding varieties, chemicals, fertilizers, mechanization and other energy inputs. However, energy intensive cultivation of paddy is blamed for several ecological problems of state. Besides depleting the ground water, the consumption of energy in pumping underground water for paddy cultivation is increasing overtime. Electricity being free for agriculture sector, the financial burden on state exchequer has been increased enormously. Therefore, present study was carried out to assess the energy use pattern and efficiency in rice production in Punjab.

Material and methods

The present study was carried out in the Moga district of central Punjab. At the first stage of sampling one block of selected district was selected randomly. From the selected block one village was selected randomly. From study village, ten paddy farmers representing various size categories were selected at the final stage of sampling. To estimate energy use in paddy, data on crop production and management practices were collected by interviewing the sample farmers using a specially designed and pre-tested questionnaire. Requisite information relevant to various inputs such seed, diesel fuel (consumed for various farm operations *viz.* seed bed preparation, inter-culture operations, harvesting, transport on farm etc.), fertilizers (N, P₂O₅, K₂O and ZnSO₄), chemicals (insecticides, fungicides, herbicides), crop yield (economical yield), total working hours of labors (men hours) for different farm operations and total working hours of agri-machinery and equipment etc. were recorded. Data on crop grain yield was used for the estimation of straw yield using grain to residue ratio method (Chauhan, 2012) [7].

Estimation of input energy expenditure

The data on inputs and output was converted to energy units using embodied energy equivalents for each input and output energy type, and expressed in Mega Jules (MJ) using specific energy coefficients (Table 1). Energy used in various field operations were calculated from time taken (h) by agri-machinery and human labor; in terms of volume (liters) for diesel fuel and liquid chemicals; in terms of weight (kg) for seeds, fertilizers and chemicals. The energy requirement of electricity consumed for lifting groundwater for irrigation purpose was calculated using HP of the submersible pump-set and duration of pump-set run as following:

$$\text{Electricity consumption (KWh)} = \text{HP of the submersible pump-set} \times \text{duration of pump-set run} \times 0.746$$

The input energy used in engaging agri-machinery was computed from the total weight, useful life, energy coefficient and time of operation. The conversion coefficients used to compute energy

values for different agri-machinery were 87.63 MJ/kg for combine harvester, 93.61 MJ/kg for tractor and 62.7 MJ/kg for other agri-machinery *i.e.* cultivator, disk harrow, plunger (Canakci *et al.*, 2005) [5]. Economic life of agri-machinery stated in the American Society of Agricultural and Biological Engineers (ASABE) standards were used in the estimation of agri-machinery energy expenditures. Data regarding average weights of different agri-machinery was collected and used to compute energy inputs from agri-machinery as explained in the following equation:

$$ME = \frac{W}{L \times A} \times C \times T$$

Where,

ME is agri-machinery energy (MJ/ ha),

C is conversion factor for the machinery (MJ/Kg)

W is weight of machinery (kg),

L is the useful life of the machinery (h),

T is the working time (h) and

A is the area under paddy (ha).

Further, each agricultural input was categorized as direct and indirect energy source. Direct energy sources (DE) are those which bring out the intended energy directly *viz.* diesel fuel, human labor, electricity and irrigation, while the indirect energy sources (IDE) comprised energy sources *i.e.* seed, agri-machinery, fertilizers and chemicals used in paddy cultivation. The energy sources were also classified into renewable energy (RE) and non-renewable sources (NRE). RE includes seed, human labor and irrigation, while NRE comprises diesel fuel, agri-machinery, electricity, chemical fertilizers and biocides (Ozkan *et al.*, 2007 and Hatirli *et al.*, 2006) [22, 11].

Table 1: Energy coefficients used in energy calculation for paddy cultivation

Energy source	Energy coefficient (MJ/unit)
Human labour	
Adult man	1.96 MJ/h
Adult woman	1.57 MJ/h
Fertilizer	
N	60.6 MJ/kg
P ₂ O ₅	11.1 MJ/kg
K ₂ O	6.7 MJ/kg
Farmyard manure (FYM)	0.3 MJ/kg
Micro nutrients	120 MJ/kg*
Chemicals	
Insecticides	199 MJ/kg **
Fungicides	92 MJ/kg#
Herbicide	238 MJ/kg#
Diesel	56.31 MJ/litre
Seed/Grain	14.57 MJ/kg
Straw	12.5 MJ/kg
Machinery	62.7/h
Water	0.63/m ³
Electricity	11.93/kWh

Source: Singh and Singh, 2002 [30]; *Mandal *et al.*, 2002 [20], **Nabavi *et al.*, 2014 [21] and #Pathak *et al.*, 1985 [23]

Energy indices

Energy use efficiency was worked out through construction of the energy indices. Agriculture is not only a consumer of energy but also producer of energy in the form of energy output. To compare how efficiently paddy crop converts input energy into output energy following ratios were carried out.

Net energy (MJ/Ha) = Output energy (MJ/ Ha) - Input energy (MJ/ Ha)

Specific energy (MJ/kg) = Input energy (MJ) /Crop yield (Kg)

Energy use efficiency (EUE) = Output energy (MJ / Ha)/Input energy (MJ / Ha)

Energy productivity (kg/MJ) = Economic output (Kg/Ha) /Input energy (MJ/Ha)

Water productivity ((Kg/m³) = Grain yield (Kg/ha)/ amount water applied (m³/ha)

Results and Discussion

Input energy use in paddy cultivation

The input-wise use of energy and the share of each input in total energy expenditure in the cultivation of paddy have been presented in Table 2 and Figure 1 respectively. The results of study revealed that on the sample farms total input energy of 61204.13 MJ/Ha was incurred in cultivation of paddy. Amongst different components, the electricity consumption for irrigation use (18974.81 MJ/Ha) accounted for the largest share constituting about 31 per cent of total input energy input. The pumping of irrigation water from deeper layers of underground water through submersible electric pumps led to the high electricity consumption in the area. Fertilisers input energy at 18841.77 MJ/Ha had an equally important share of 30.79 per cent in the total energy consumption in paddy cultivation. Among chemical fertilizers, fertilizer, Nitrogen (N) had the major energy expenditure (87.74%). Similarly, a study in Karnataka highlighted the indiscriminate use of nitrogen fertilizers and

irrigation water accounting for 36 per cent and 39 per cent of total energy input in the transplanted paddy (Basavalingaiah *et al.*, 2020)^[3]. Due to high water requirements of paddy crop, irrigation water with 15223.50 MJ/Ha constituted about one-fourth of the total input energy. Diesel, the fuel used in prime movers and oil engines/generators for running pumps formed about 7 per cent of the total input energy. Different chemicals used accounted for about 3 per cent of the total input energy and amongst these share of plant protecting insecticides (1.54%) was followed by micro nutrients in terms of zinc (0.70%), weedicides and fungicides with about 0.49 and 0.32 per cent of the total energy input respectively. Another 506 MJ/Ha of agri-machinery energy was also used for various cultural operations comprising mainly land preparation, harvesting and on farm post-harvest.

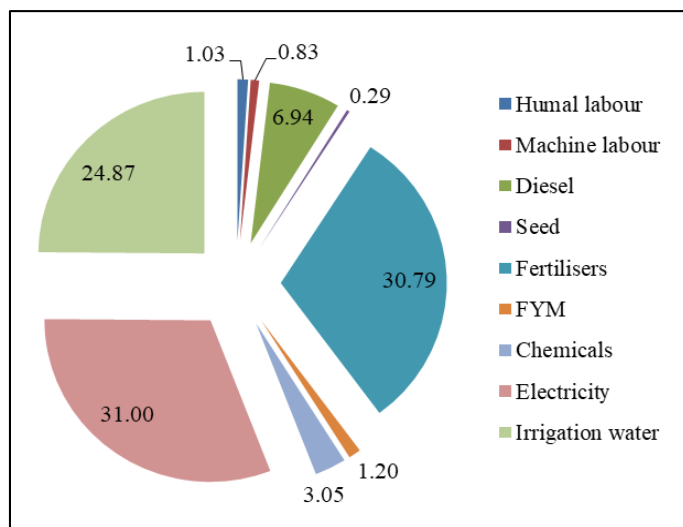


Fig 1: Different inputs in paddy production (% share in energy input)

Table 2: Energy input-output pattern in paddy cultivation, 2020-21

Sr. No.	Input (unit)	Qty used per unit area (Ha)	Total energy equivalent (MJ/Ha)
1	Human labour (Hr)	320.16	627.50
2	Machine labour (Hr)	8.07	505.88
3	Diesel (Litre)	75.49	4250.05
4	Seed (Kg)	12.08	177.50
5	Fertilisers (Kg)		
	N (Kg)	310.92	18841.77
	P (Kg)	0.023	0.25
6	FYM (Kg)	5.08	737.40
7	Micronutrients & plant protection chemicals		
	Plant protection chemicals (Kg)	4.75	944.69
	Micro nutrients (Kg)	3.55	425.78
	Weedicides	1.50	297.91
	Fungicides (litre)	0.91	197.09
8	Electricity (KWh)	1594.52	18974.81
9	Irrigation water (m ³)	24164.29	15223.50
10	Total energy input (MJ/Ha)		61204.13
11	Total energy output (MJ/Ha)		242012.95
	Grain (Kg)	7634.48	112226.82
	Straw (Kg)	10382.89	129786.12

Operations of paddy cultivation. Among other inputs, seed energy with only 177.50 MJ/Ha constituted the smallest share (0.29%) in total energy expenditure in paddy cultivation. The study revealed that quantity of paddy seed used by farmers was

significantly lower than the recommended one. Thus, on the sample farms input energy for irrigation and fertilizers were the major energy sinks in paddy cultivation. Alipour *et al.*, 2012^[2] also reported on the largest share of energy for irrigation in rice

production in Guilan province of Iran. Another study on the rice production in India revealed that irrigation and fertilizers accounts for the largest share of total energy input (Chaudhary *et al.*, 2017)^[6].

Crop productivity, output energy and energy use efficiency indices in paddy production

Total output energy realized on the study farms was computed to be 242013 MJ/Ha. The average paddy grain yield of about 7634 Kg/Ha and straw yield of 10383 Kg/Ha accounted for about 46 per cent and 54 per cent of the total energy output obtained respectively. The cultivation of long duration paddy varieties on the selected farms resulted in higher grain and straw yield as compared to other paddy varieties. The amount of net energy gain of 1.81 lakh MJ/Ha implies that paddy cultivation is energy efficient in the area (Table 3).

Table 3: Energy indices in paddy cultivation, 2020-21

Item (Unit)	Value
Net energy (Lakh MJ/Ha)	1.81
Specific energy (MJ/Kg)	8.02
Energy use efficiency	3.95
Energy Productivity (Kg/MJ)	0.12
Water Productivity (Kg/m ³)	0.50

Among different energy indices, the specific energy shows the amount of energy spent to produce a unit of marketable product. The calculated specific index of 8.02 MJ/Kg was along with a low energy productivity index of 0.12 kg/MJ indicating that there is room for improving energy productivity of puddle transplanted paddy crop in the study area. Similar results were reported in earlier studies where the lower energy productivity was largely owing to more use of fertilizers, machinery and diesel fuel (Tuti *et al.*, 2012; Soni and Soe, 2016)^[31]. The farmers resorted to the overuse of chemical fertilizers especially the nitrogenous fertilizers which are supplied on subsidized rates. Unawareness about the biological and ecological impacts of excessive use of chemical inputs is also one of the reasons for this. The results also revealed that water productivity could not follow the trend of energy productivity, as a low water productivity of 0.50 Kg/m³ was observed for transplanted paddy cultivation in the area.

With output energy of 242013 MJ/Ha and input energy of 61204.13 MJ/Ha, energy use efficiency (EUE) in paddy cultivation was estimated at of 3.95. Similar results with relatively low EUE for transplanted paddy were reported by

earlier studies. Basavalingaiah *et al.*, 2020^[3] estimated EUE at 4.4 and 7.3 for paddy cultivation in Karnataka under transplanting and Direct Seeded (DSR) methods respectively. The reason for higher EUE under DSR was mainly attributed to the large decrease in energy inputs and study also highlighted the scope for saving energy in transplanting method by 6 per cent. In South-Western Punjab, energy ratio of 5.0 was found for transplanted paddy cultivation (Singh *et al.*, 2019). In another study, the EUE varied from 4.36 to 6.96 in different size groups of Karnataka paddy growers (Kumar *et al.*, 2019a)^[27]. The transplanted paddy production had energy ratio of only 2.12 in Iran (Alipour *et al.*, 2010). In a comparative study for Australia, energy efficiency was found to be higher in wheat crop (9.21) and barley (8.21) compared to rice i.e. 6.70 (Khan *et al.*, 2010)^[14]. Total energy input is higher in transplanted paddy production while energy efficiency level is higher in DSR indicating the need to decrease dependency on energy which can be achieved either through efficient use of energy or utilizing organic input (Baharudin and Arshad, 2014). Yuan and Peng (2017)^[33] reported that in China, in comparison to commonly followed paddy cultivation practices, the adoption of simplified and reduced input practices resulted in increased EUE and energy productivity by about 19 and 25 per cent, respectively. Thus, the present study is in consonance with the earlier literature regarding the need to take suitable steps to increase the EUE in paddy cultivation either by minimizing input use or by using them judiciously.

Operation wise energy use in paddy cultivation

Energy requirement in agriculture sector depends on the size and quality of cultivated land, level of mechanization and climatic conditions and cultural practices followed by the farmers. The operation-wise use of energy involved in paddy cultivation and share of each operation in total energy used has been worked out and presented in Table 4 and Figure 2 respectively. The results revealed that due to of heavy irrigation water requirement (15223.5 MJ/Ha) and electricity consumption on pumping out the underground water for irrigation application (18974.81 MJ/Ha) to paddy accounted as much as 56 per cent of the total input energy use in this crop (Fig 2). In a similar study, energy expenditure (30,221 MJ/Ha) on irrigation water use plus electricity consumed for pumping of irrigation water comprised about 58 per cent of total energy input in paddy cultivation in Mansa district of Punjab (Singh *et al.*, 2019)^[29].

Table 4: Operation-wise energy use in paddy cultivation, 2020-21 (MJ/Ha)

Operation/ Source	Human energy	Machine energy	Diesel	Electricity	Water	Micro-nutrients & Chemicals	FYM	Fertilisers	Seed	Total
Land preparation	21.02	92.40	2367.69							2481.11
Transplanting	316.07									316.07
Irrigation	226.72	82.43		18974.81	15223.50					34507.46
Crop management	35.05					1865.46	737.40	18842.03	177.5	21479.94
Harvesting	14.75	277.24	889.50							1181.49
On farm Post-harvest and Transport	13.89	53.81	992.86							1060.56
Total	627.5	505.88	4250.05	18974.81	15223.50	1865.46	737.40	18842.03	177.5	61204.13

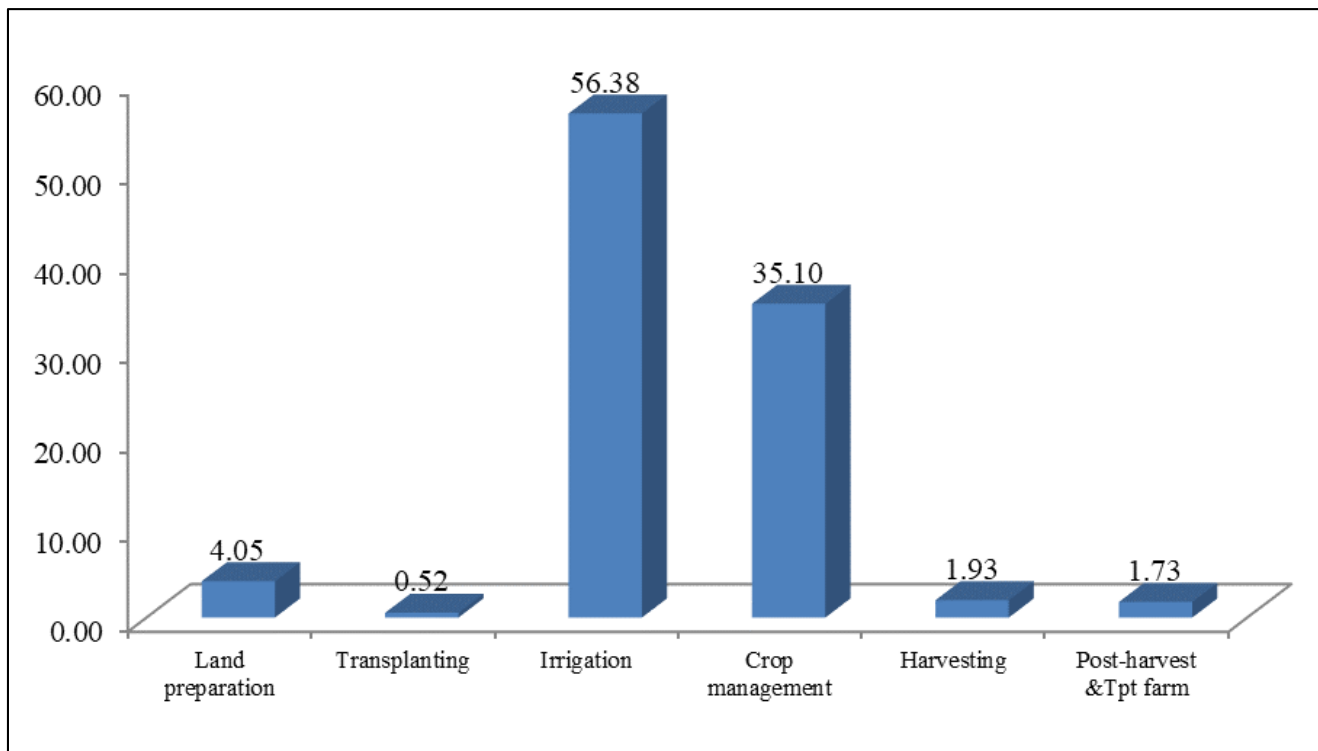


Fig 2: Operation-wise energy use in paddy cultivation (% share in total energy use)

Crop management activities with energy input to the tune of 21479.94 MJ/Ha accounted for about 35 per cent of total energy input in paddy cultivation. Share of fertilizers accounted for about 87 per cent (18842.03 MJ/Ha) of total energy used in crop management activities. Land preparation involving the use of human labour, diesel fuel, mechanical energy and constituted 4.05 per cent of the total input energy. Harvesting operation (labour, diesel and machine labour) accounted for 1.93 per cent of total energy use followed by and on farm transport and post-harvest operations (1.73%) and seedling transplanting (0.52%). In transplanting operation, only manual labour was used on the selected farms. Further, analysis of distribution of human energy use in paddy cultivation revealed that operation of seedling transplanting alone consumed the nearly half of the human input energy (50.37%) which was followed by irrigation operation (36.13%).

Direct and indirect energy use

Direct and indirect sources of energy use in paddy cultivation comprised about 65 per cent (39990.76 MJ/Ha) and 35 per cent (21213.36 MJ/Ha) total energy input respectively (Figure 3 and Figure 34). Amongst the direct energy sources, electricity constituted 47 per cent share in total direct energy use followed by human labour (38.07 %) and diesel fuel (10.63%) while the respective share of all other inputs remained below 2 per cent in this regard. On the other hand, among indirect energy sources involved in paddy cultivation, fertilisers alone accounted for about 89 per cent share in total indirect input energy. Micro-nutrients and chemicals and machine labour constituted 8.79 per cent and 2.38 per cent of total use of indirect form of energy.

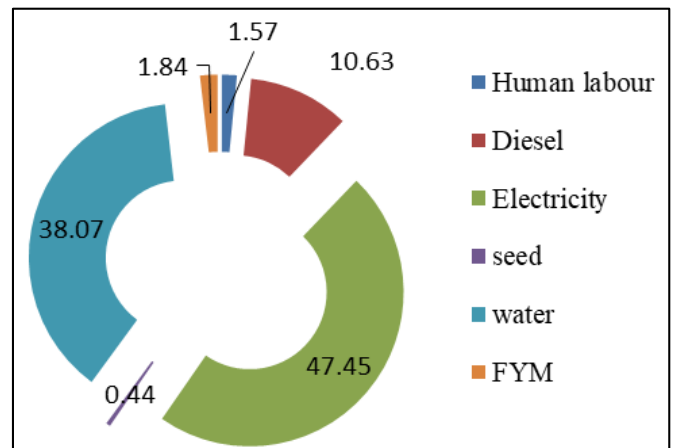


Fig 3: Sources of Direct Energy in Paddy cultivation (%share)

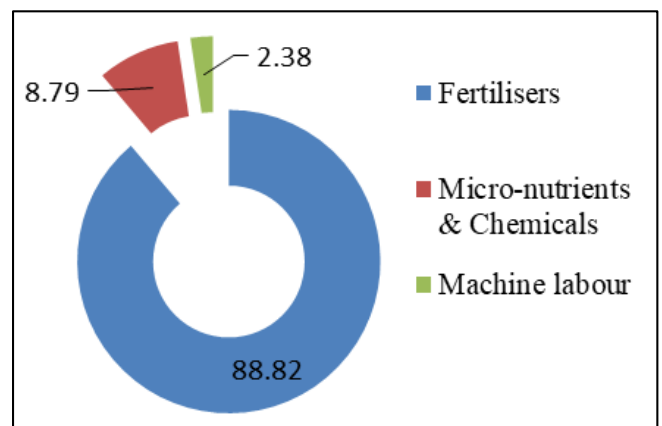


Fig 4: Sources of Indirect Energy in Paddy cultivation (%share)

Renewable and non-renewable energy use

In any production system, higher use of non-renewable energy lowers the energy ratio because of greater energy needs for the production from agro-chemicals and agri-machinery (Lal, 2004; Pimentel *et al.*, 2005) ^[19]. In present study the classification of input energy into renewable (RE) and non-renewable (NRE) sources indicated higher proportionate use of NRE (72.61%) as compared to RE (27.39%). Non-commercial energy constituting only about 4 per cent share in the total energy indicated that major part of total energy needs of paddy cultivation were being sourced from commercial sources. Kazemi *et al.*, 2015 ^[15] reported that about 85 per cent of the input energy used in rice cultivation in Iran is NRE while the contribution of RE was only 15 per cent in this regard. In a similar study, per hectare use of both commercial and non-commercial energy was more in paddy crop in comparison to wheat crop (Kumar *et al.*, 2020) ^[17]. Crop management practices with greater differences between input and output energy results in a positive energy balance with increased net energy gain. Thus, sufficient availability of the energy along with its effective and efficient utilization are prerequisites to achieve sustainable agricultural production.

Conclusions and Sugesstions

The results revealed that with net energy gain at 1.81 lakh MJ/Ha achieved with energy output of 2.42 lakh MJ/Ha, paddy cultivation in the study area was energy efficient but overwhelming significance of irrigation water, electricity consumption and chemical fertilisers in energy input in rice cultivation underpin the opportunities for energy saving. These inputs jointly accounts for more than 80 per cent of input energy consumption in paddy cultivation. About 56 per cent of total operational input energy was consumed for irrigation only. This has created extreme imbalance in energy consumption pattern and indicates energy wastage practices followed by the farmers in transplanted paddy.

The direct and indirect sources of energy respectively constituted about 65 per cent and 35 per cent of the total input energy. The electrical energy use in irrigation was the major source of direct energy consumption. Among indirect sources, ferilisers alone accounted for about 89 per cent proportion of total indirect energy use. Further, the commercial source of energy comprising 96 per cent of total energy use indicated towards need for curtailing its proportionate use by introduction and enhancing the use of non-commercial energy in crop cultivation. The results of present study suggests that energy management at the farm level needs serious attention both for efficient and economical use of energy as well as for the safe guard of agro-ecosystem. Lack of knowledge of scientific recommendations, improper use of modern means of energy and prevailing myth and mindset of the farmers may be the most likely obstacles in efficient energy utilization which need to be addressed. For sustainable paddy cultivation in State, strengthening of extension services will help in encouraging the judicious use of energy intensive inputs by replacing these with alternative organic sources as well by through adoption of recommended farming practices. Farm level adoption of environment friendly technology of paddy cultivation *viz.* direct seeded technology (DSR) may help in energy saving without compromising the level of output.

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