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Energy Balance and Fuel Consumption Analysis in Rice Cultivation in Medak District, Telangana, India

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Aims: To study fuel energy and energy input-output analysis in Rice production system.
Study Design: Cross-sectional descriptive study.
Place and Duration of Study: Medak district 2023.
Methodology: Data for the study were gathered through face-to-face surveys conducted on sixty Rice-producing farms in Medak district. The selection of farms for the survey was determined using a simple random sampling method. After collecting the data, fuel energy and input-output energy ratios were calculated.
Results: Rice production cost averaged Rs. 44,000/ha with total energy input of 17,349.64 MJ/ha. N fertilizer (38.61%) and diesel fuel (23.37%) were major energy contributors, while seed contribution was minimal (0.41%). Grain yield reached 7,410 kg/ha, generating net energy of 3,270.64 MJ/ha and energy productivity of 0.43 kg MJ^{-1}. The output-input ratio was low (0.81) due

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to high fertilizer inputs. Specific energy was 2.34 MJ kg^{-1} and energy intensiveness 0.39 MJ Rs^{-1}. Among machinery, cultivator had lowest fuel consumption while combine harvester had highest.
Conclusion: The analysis reveals that rice production in Medak District faces significant energy efficiency challenges that require immediate attention. The key finding that the system consumes more energy than it produces (output-input ratio of 0.81) indicates an unsustainable production model that threatens both economic viability and environmental sustainability.

Keywords: Fuel energy; rice; energy intensiveness; net energy.

1. INTRODUCTION

Rice (Oryza sativa) is one of the most important, widely grown cereal crops in the world, and it feeds half of the world's population, especially in Asia, where it is a main diet. India is the second-largest producer of rice after China with a production of 136.7 million tons from a 47 million hectare area in 2023-24 (https://upag.gov.in). Energy plays a pivotal role in agriculture, dating back to the era of subsistence farming. It's widely acknowledged that agricultural production correlates positively with energy input (Taheri Garavand *et al*., 2010). Reduced energy consumption in crop production translates to lower production costs, particularly in developing countries where traditional methods persist, elevating production expenses. Agriculture consumes approximately 18.5 per cent of India's total energy consumption (Vijayakumar *et al.,* 2023). Agriculture is both a significant consumer and producer of energy. Improving energy efficiency in agricultural production involves assessing the effectiveness of methods and techniques employed (Khan *et al*.,2009) Energy usage in agriculture has surged due to population growth, dwindling arable land, and aspirations for higher living standards (Kizilaslan, 2019). The sector, like others, relies heavily on resources such as electricity, fuels, natural gas, and coke. This dependence, coupled with capital-intensive technologies, is partly fueled by relatively low energy prices compared to the resources they substitute.

Efficient energy utilization boosts production, productivity, and contributes to the economic viability and competitiveness of agriculture, especially in rural areas (Ozkan *et al*., 2007 and Singh *et al*., 2002). Energy use efficiency in rice-based cropping systems is a key determinant of sustainability and profitability. Various indicators, such as energy productivity, energy intensity,and energy balance, are used to assess the efficiency of energy utilization in rice production. Medak district's economic status is relatively lower compared to other districts in Telangana, It was designated as one of India's most backward districts and receives funding from the Backward Regions Grant Fund Programme (BRGF). While it has a significant Gross Domestic Product (GDP), its per capita income is also lower than some other districts in Telangana state. In Medak district, Agriculture is the most predominant sector of the district economy, as 80 percent of the population is engaged in Agriculture and allied activities for their livelihood. The gross cropped area of the district is 352262 ha with 154731 no. of farm holdings.

2. MATERIALS AND METHODS

This research was undertaken within the Medak District of Telangana State, focusing on farms cultivating rice during the year 2023. Data for the study were gathered through face-to-face surveys conducted on sixty rice-producing farms in Medak district. The selection of farms for the survey was determined using a simple random sampling method. The formula for this method is outlined as follows

$$n = \frac{N * s * s * t * t}{(N-1) * d^2 + s^2 * t^2}$$

Where

n = the volume of sample,
s = the standard deviation,
t = the t value of the 95% confidence interval (1.96),

N = the number of farms belonging to the sampling frame and

d = desired margin of error or allowable error

Finally energy use efficiency, specific energy, energy productivity and net energy were determined by applying standard equations (Hatirli *et al*., 2008 and Mohammad *et al*., 2010).

$$\text{Energy use efficiency} = \frac{(\text{output energy}[MJha^{-1}])}{(\text{input energy }[\text{MJ}]ha^{-1}]} \quad (1)$$

$$\text{Specific energy} = \frac{(\text{input energy}[\text{MJ}ha^{-1}])}{(\text{Rice yield}[\text{Kg}ha^{-1}])} \quad (2)$$

$$\text{Energy productivity} = \frac{(\text{Rice yield}[\text{Kg}ha^{-1}])}{(\text{input energy}[\text{MJ}ha^{-1}])} \quad (3)$$

Net energy=output energy (MJha-1) – input energy(MJha^{-1}) (4)

$$Energy\ intensiveness = \frac{\text{Energy input } (\text{MJ}ha^{-1})}{\text{Cost of cultivation } (\text{Rs } ha^{-1})} \quad (5)$$

Agrochemical energy ratio was calculated by applying Equations

$$Agrochemical\ energy\ ratio = \frac{\text{input energy of agrochemicals}(\text{MJ}ha^{-1})}{total\ input\ energy\ (MJ\ ha^{-1})} \quad (6)$$

The following equation was used in the calculation of fuel consumption per hectare for each field operation. (Moerschner and Gerowitt, 2000):

ED = h × AFU × PEU ×RU

where:

ED = Specific direct energy use (fuel) for a field operation, MJ ha^{-1}.

h = Specific working hours per run, h ha^{-1}
AFU = Average fuel use per working hour, L h^{-1}

PEU = Specific energy value per litre of fuel, MJ L^{-1}

RU = Runs, number of applications in the considered field operation

Table 1. Energy equivalents of input and output in Rice production systems.

Equipment /inputs	Unit	Energy equivalents	Reference
A. Inputs			
1. Human Labor	H	1.96	(Ajay *et al*., 2025 and Yilmaz *et al*., 2005)
2. Machinery	h	62.50	(Ajay *et al*., 2025 and Esengun et al., 2007)
3. Diesel fuel	L	51.33	(Gaurang Meher Diljun *et al.,* 2022)
4. Chemical Fertilizer	Kg		
(a) Nitrogen		66.14	(Gaurang Meher Diljun et al., 2022 Erdal *et al*., 2007)
(b) Phosphate (P_2O_5)		12.44	(Ajay *et al*., 2025 and Rafiee *et al*., 2010)
5. FYM		0.3	(Seyed *et al*.,2013)
6. Chemical		120	(Erdal *et al*.,2007 and Ozkan et al., 2007)
7.Seed	Kg	14.7	(Regatti *et al*., 2024 and Ozkan et al., 2004)
B. Output			
1. Rice	Kg	14.7	(Regatti *et al*., 2024 and Mandal et al., 2002)

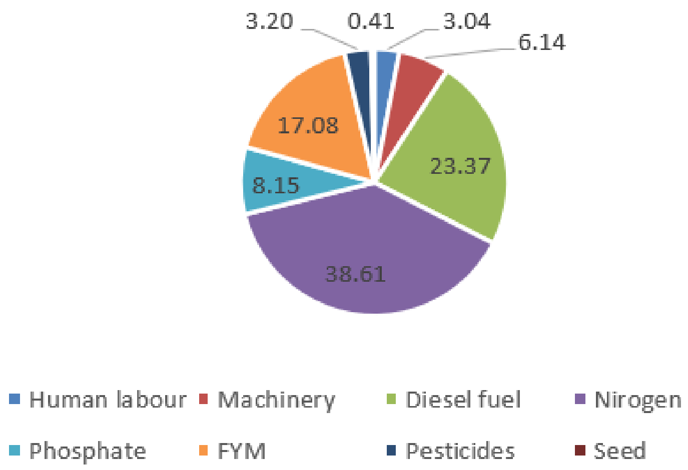

Fig. 1. Percentage of energy inputs in Rice production system in Medak district

Table 2. Energy equivalents of input and output in Rice production systems in Medak district

Quantity	Quantity per unit area (ha)	Total energy equivalents (MJha^{1-})	Percentage of total energy (%)
A. Inputs			
1. Human Labour (h)	269	527.24	3.04
2. Machinery (h)	17	1065.9	6.14
3. Diesel fuel(L)	72	4054.32	23.37
4. Chemical Fertilizer(kg)			
(a) Nitrogen	101	6697.99	38.61
(b) Phosphate (P_2O_5)	114	1413.18	8.15
(d) FYM	9880	2964	17.08
5. Pesticides(kg)	7.5	555	3.20
6. Seed(kg)	20	72	
Total energy input(MJ)		17349.64	100
B. Output		**0**	
1. Rice	7410	14079	100
Total energy output(MJ)		14079	100

3. RESULTS AND DISCUSSION

The study unveiled that the average production cost per hectare of Rice crop amounted to Rs. 44,000. Table 2 presents a breakdown of inputs utilized and outputs in Rice production systems, along with their energy equivalents and percentages of the total energy input. Results indicated that the total energy input in Rice production systems was 17349.64 MJ/ha, which is in line with a study conducted in Punjab, India (energy input in the range 52,400 ± 13,000 MJ ha^{-1} (Singh *et al*.,2019). The, Nitrogen fertilizer employed in Rice production systems accounted for the highest share at 38.61% (Demircan et al.,2006) (see Fig. 1). Diesel fuel energy ranked second with 23.37% contribution to the total energy input. Seed, on the other hand, represented the smallest share of the total energy input at 0.41%. Additionally, the study observed a Rice grain yield of 7410 kg/ha, equating to a total energy equivalent of 17349.642. MJ/ha. Table 3 presented the energy indicators for Rice production systems.

Notably, from Table 3 the energy efficiency, represented by the output-input ratio, was 0.81. If energy use efficiency is above 1, the production system generates energy The lower energy use efficiency observed in rice production systems can be attributed to the elevated energy inputs, particularly the consumption of Nitrogen fertilizer

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From the study it is observed that in rice production systems, the energy productivity, denoting the grain yield per unit of energy input, was 0.43 kg MJ^{-1}, while the specific energy, indicating the input energy required per unit of grain yield, was 2.34 MJ kg^{-1}. A lower value of specific energy is desirable as it indicates higher energy efficiency in production. Put differently, for every MJ of input energy, 0.43 kg of rice grain was produced, or conversely, 2.33 MJ of energy was expended to yield one kilogram of grain. Furthermore, the system's net energy, is calculated as the output minus input, which is amounted to 3270.64 MJ ha-1. The net energy is

Table 3. Indicators of energy use in Rice production systems

Indicators	Unit	Quantity
Inputs energy	MJha^{-1}	17349.64
Output energy	MJha^{-1}	14079.00
Grain yield	*Kgha^{-1}*	7410.00
Energy use efficiency		0.81
Specific energy	MJkg^{-1}	2.34
Energy productivity	KgMJ^{-1}	0.43
Agrochemical Energy Ratio	%	0.33
Net energy	MJha^{-1}	-3270.64
Energy intensiveness	MJRs^{-1}	0.39

low because of less yield in the study area. A high agrochemical ratio implies a large agrochemical footprint and negative environmental effects such as nitrogen leaching, *air* and water pollution and GHG emissions (Pishgar-Komleh *et al*.,2013). In this study, the agrochemical energy ratio was 0.33% of the input energy, which is desirable. Additionally, the energy intensiveness, indicating the amount of energy produced per rupee spent, was computed at 0.39 MJ Rs^{-1}, signifying that for each rupee invested, 0.39 MJ of energy could be generated. The energy consumption of different implements/machinery is shown in Table 4 From table it can be concluded that cultivator consumed less fuel energy than puddler. Combine harvester consumed highest fuel energy.

Table 4. Fuel energy of implements/ machinery

Machine/Implement	Fuel energy MJ per ha
Cultivator	985.43
Puddler	1666.78
Combine harvester	1875.12

4. CONCLUSION

Energy inputs and output was investigated for rice production system in Medak district. This study reveals significant opportunities for enhancing energy efficiency in agricultural operations. The findings indicate that the current energy use efficiency is 0.81, with a negative net energy of -3270.64 MJ ha^{-1} and an energy productivity of 0.43 kg MJ^{-1}. There is need to increase energy use efficiency above 1, net energy and energy productivity for making rice production system more efficient. Energy use efficiency above 1.0 with positive net energy and enhance energy productivity is feasible by adopting integrated nutrient management, use appropriate-scale machinery, crop diversification to reduce nitrogen fertilizer, and adopting energy-conscious farming practices. Such improvements would not only enhance the energy productivity beyond the current 0.43 level but also contribute to sustainable agricultural intensification while reducing production costs for farmers in the region. In Medak district, effort should be made at increasing the level of rice production through mechanization and move from the use of energy from non-renewable sources to renewable sources to attain a self-sufficient and sustainable rice production system.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc have been used during writing or editing of this manuscript. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology.

Details of the AI usage are given below:

1. Claude Sonnet 4

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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