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Quantitative analysis of energy requirements and efficiency in rice production systems of Yadadri Buvanagiri District, Telangana

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Abstract

This study investigated the energy input-output relationship in rice production systems in Yadadri Bhuvanagiri district, Telangana, with the aim of identifying strategies to enhance production efficiency and sustainability. Data were collected from sixty rice-producing farms using a simple random sampling method. The total energy input was calculated at 18,841.37 MJ/ha, with nitrogen fertilizer contributing the largest share (37.72%), followed by diesel fuel (23.61%) and machinery use (11.09%). Farmyard manure, pesticides, and other inputs accounted for smaller proportions. The average rice grain yield was 6,916 kg/ha, corresponding to an output energy of 13,140.40 MJ/ha. Key performance indicators revealed an energy use efficiency of 0.70, specific energy of 2.72 MJ/kg, energy productivity of 0.37 kg/MJ, and a net energy balance of -5,700.97 MJ/ha, indicating an energy deficit. The findings suggested that excessive reliance on non-renewable energy sources, particularly synthetic nitrogen fertilizer and fossil fuels, was a major factor reducing system efficiency. Improving integrated nutrient management, optimizing machinery use, adopting renewable energy technologies, and implementing energy-conscious farming practices could have raised energy efficiency above 1.0 and improved both productivity and profitability. Transitioning to sustainable practices would not only have lowered production costs but also reduced environmental impacts such as greenhouse gas emissions and nutrient runoff. This research provided a framework for policymakers, researchers, and farmers to develop targeted interventions aimed at building resilient and energy-efficient rice production systems in the region.

Keywords: Energy efficiency rice production nitrogen fertilizer renewable energy mechanization energy intensiveness, energy productivity, net energy agrochemical energy ratio

Introduction

Rice (*Oryza sativa* L.) is one of the most important staple food crops globally, providing the primary source of calories for more than half of the world's population, particularly in Asia (Anonymous, 2023). India stands as the second-largest rice producer after China, contributing significantly to both global food security and national economic stability. During 2023-24, India produced approximately 136.7 million tonnes of rice from 47 million hectares (Anonymous, 2024). The crop plays a central role in rural livelihoods, food availability, and agricultural GDP, especially in states like Telangana, where rice cultivation is a dominant activity (Reddy *et al*., 2024) [23].

In modern agriculture, energy use has emerged as a critical determinant of crop productivity, economic viability, and environmental sustainability. Energy is consumed in every stage of rice production from land preparation, sowing/transplanting, and irrigation to fertilizer application, pest management, and harvesting (Sharma *et al.*, 2022) [26]. It comprises both direct energy inputs such as human labor, diesel, and electricity, and indirect energy inputs including fertilizers, pesticides, and machinery manufacturing (Kumar *et al*., 2021) [12]. Studies have shown that energy consumption patterns in crop production directly influence yield levels, production costs, and environmental footprints (Zhang *et al*., 2020) [32].

Globally, agriculture consumes about 30% of the world's total energy use, with significant variations between regions (Anonymous, 2022). In India, agriculture accounts for nearly 18.5% of total energy consumption (Vijayakumar *et al*., 2023) [29]. For rice, nitrogen fertilizer and diesel fuel are often the largest contributors to total energy inputs (Singh *et al*., 2019) [27]. High reliance on synthetic fertilizers increases the energy intensity of production and is associated with environmental issues such as greenhouse gas (GHG) emissions, soil degradation, and water pollution (Pishgar-Komleh *et al*., 2013; Mandal *et al*., 2020) [20, 14].

Energy use efficiency (EUE), defined as the ratio of output energy to input energy, is a widely used performance indicator in agricultural energy analysis (Hatirli *et al*., 2008) [9]. An EUE value above 1.0 indicates that the system produces more energy than it consumes, which is desirable for both economic and environmental reasons (Mohammadi *et al*., 2021) [17]. However, many rice-based systems in South Asia report

EUE values below 1.0 due to excessive use of nitrogen fertilizers, inefficient machinery, and poor resource management (Venkat *et al.*, 2024) [28].

Technological advancements, particularly in precision agriculture and mechanization, offer opportunities to improve energy efficiency (Ali *et al.*, 2023) [3]. Adoption of site-specific nutrient management, laser land levelling, direct-seeded rice (DSR), renewable energy-powered irrigation systems, and appropriate-scale mechanization can significantly reduce energy consumption while maintaining or increasing yields (Rahman *et al.*, 2022) [22]. Similarly, integrated nutrient management (INM) combining organic manures, green manures, and balanced fertilizer application has been shown to reduce energy intensity and improve soil health (Bhattacharyya *et al*., 2023) [4].

Yadadri Bhuvanagiri district in Telangana is a major rice-growing region, with about 194,510 hectares of cultivable land. The area's production systems are characterized by varied irrigation practices, machinery use patterns, and fertilizer application rates. Despite being a key agricultural zone, comprehensive studies evaluating the district's energy input-output relationships are limited. A systematic energy analysis is essential to identify high-consumption components, assess efficiency gaps, and recommend interventions for sustainability (Chaudhary *et al.*, 2021; Kamboj *et al.*, 2023) [5, 10].

This study aims to analyze the energy requirements and efficiency of rice production systems in Yadadri Bhuvanagiri district, quantify the share of each input, and propose strategies for improving EUE and reducing environmental impacts. By integrating recent scientific evidence and local field data, this research contributes to a broader understanding of how energy optimization can support sustainable intensification of rice farming in Telangana and similar agro-ecological regions.

Materials and Methods

The study was conducted during the Kharif season of 2023 (June-September, 2023) in Yadadri Bhuvanagiri district, Telangana State, India. This district, which was carved out of the erstwhile Nalgonda district, lies between latitude 17°30′36″N and longitude 78°53′25″E. The region fell under the semi-arid tropical climate, characterized by hot summers, moderate monsoon rains, and mild winters. The soils in the study area were predominantly sandy loam to clay loam, with rice being a major crop cultivated under both canal and borewell irrigation systems.

Sampling Procedure

Data were collected from 60 rice-producing farms across multiple mandals of Yadadri Bhuvanagiri district using a simple random sampling technique. The number of farms was determined using the sample size formula:

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

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

Data Collection

Primary data were obtained through face-to-face interviews with farmers using a pre-tested questionnaire. The survey gathered detailed information on input use (human labor, machinery hours, fuel consumption, fertilizer and pesticide use, seed rate, and farmyard manure) and output yield (grain and straw).

Energy Equivalents and Calculations

The energy equivalents for various inputs and outputs were adopted from standard literature sources (Ajay *et al.*, 2025; Gaurang *et al.*, 2022; Ozkan *et al*., 2004) [1, 8, 18] and were presented in Table 1 of the original dataset. The following energy indices were computed: energy use efficiency, specific energy, energy productivity, and net energy. These indices were calculated using standard equations as suggested by Hatirli *et al.* (2008) [9] and Mohammad *et al.* (2010) [16].

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

$$\text{Specific energy} = \frac{(\text{input energy}[MJha^{-1}])}{(\text{Rice yield}[Kgha^{-1}])}$$

$$\text{Energy productivity} = \frac{(\text{Rice yield}[Kgha^{-1}])}{(\text{input energy}[MJha^{-1}])}.$$

$$\text{Net energy} = \text{output energy } (MJha^{-1}) - \text{input energy } (MJha^{-1})$$

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

Agrochemical energy ratio was calculated by applying Equations

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

The following equation was used in the calculation of fuel consumption per hectare for each field operation. (Moerschner and Gerowitt, 2000) [15]:

$$ED = h \times AFU \times PEU \times RU$$

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) [1, 31]
2. Machinery	h	62.50	(Ajay *et al.*, 2025 and Esengun *et al.*, 2007) [1, 7]
3. Diesel fuel	L	51.33	(Gaurang *et al.*, 2022 and Seyed *et al.*, 2013) [8, 25]
4. Chemical Fertilizer	Kg		
(a) Nitrogen		66.14	(Gaurang *et al.*, 2022 Erdal *et al.*, 2007) [8, 6]
(b) Phosphate (P_2O_5)		12.44	(Ajay *et al.*, 2025 and Rafiee *et al.*, 2010) [1, 21]
5. FYM		0.3	(Seyed *et al.*,2013) [25]
6. Chemical		120	(Erdal *et al.*,2007 and Ozkan *et al.*, 2007) [6, 19]
7.Seed	Kg	14.7	(Ventkat *et al.*, 2024 and Ozkan *et al.*, 2004) [18]
B. Output			
1. Rice	Kg	14.7	(Ventkat *et al.*, 2024 and Mandal *et al.*, 2002) [13]

Table 2: Energy equivalents of input and output in Rice production systems in Yadadri Buvanagiri district

Quantity	Quantity per unit area (ha)	Total energy equivalents ($MJha^{-1}$)	Percentage of total energy (%)
A. Inputs			
1. Human Labour (h)	198.8	389.65	2.07
2. Machinery (h)	33.34	2090.42	11.09
3. Diesel fuel(L)	79	4448.49	23.61
4. Chemical Fertilizer(kg)			
(a) Nitrogen	107.44	7106.08	37.72
(b) Phosphate (P2O5)	56.81	706.72	3.75
(d) FYM	7410	2223.00	11.80
5. Pesticides(kg)	15.35	1805.02	9.58
6. Seed(kg)	20	72.00	0.38
Total energy input(MJ)		18841.37	100
B. Output		0.00	
1. Rice	6916	13140.40	100
Total energy output(MJ)		13140.40	100

Results and Discussion

The study unveiled that the average production cost per hectare of rice crop amounted to Rs. 47,424. Table 2 presented 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 18,841.37 MJ/ha, which was in line with a study conducted in Punjab, India (energy input in the range 52,400 ± 13,000 MJ/ha; Singh *et al.*, 2019) [27]. Nitrogen fertilizer employed in rice production systems accounted for the highest share at 37.72% (see Fig. 1). Diesel fuel energy ranked second with a 23.61% contribution to the total energy input. Seed, on the other hand, represented the smallest share of the total energy input at 0.38%. Additionally, the study observed a rice grain yield of 6,916 kg/ha, equating to a total energy equivalent of 13,140.40 MJ/ha. Table 3 presented the energy indicators for rice production systems.

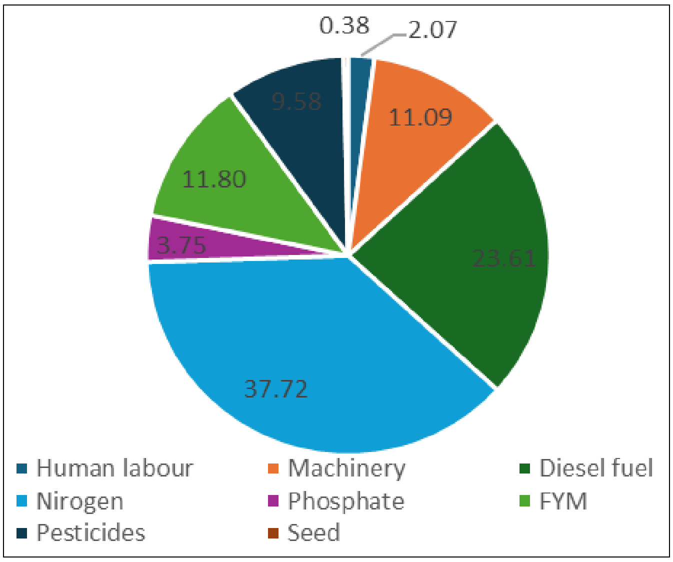

Fig 1: Percentage of energy inputs in Rice production system

Table 3: Indicators of energy use in Rice production systems

Indicators	Unit	Quantity
Inputs energy	$MJha^{-1}$	18841.37
Output energy	$MJha^{-1}$	13140.40
Grain yield	$Kgha^{-1}$	6916.00
Energy use efficiency		0.70
Specific energy	$MJkg^{-1}$	2.72
Energy productivity	$KgMJ^{-1}$	0.37
Agrochemical Energy Ratio	%	0.51
Net energy	$MJha^{-1}$	-5700.97
Energy intensiveness	$MJRs^{-1}$	0.40

Notably, from Table 3, the energy efficiency, represented by the output-input ratio, was 0.70. If energy use efficiency had been above 1, the production system would have generated surplus energy. The lower energy use efficiency observed in rice production systems was attributed to elevated energy inputs, particularly the high consumption of nitrogen fertilizer.

From the study, it was observed that in rice production systems, the energy productivity denoting the grain yield per unit of energy input was 0.37 kg MJ^{-1}, while the specific energy indicating the input energy required per unit of grain yield was 2.72 MJ kg^{-1}. A lower value of specific energy was considered desirable, as it indicated higher energy efficiency in production. In other words, for every MJ of input energy, 0.37 kg of rice grain was produced, or conversely, 2.72 MJ of energy was expended to produce one kilogram of grain.

Furthermore, the system's net energy, calculated as the difference between output and input, amounted to -5,700.97 MJ ha^{-1}. The net energy was low due to reduced yields in the study area. A high agrochemical ratio typically implies a large agrochemical footprint and negative environmental effects such as nitrogen leaching, air and water pollution, and greenhouse gas (GHG) emissions (Pishgar-Komleh *et al.*, 2013) [20]. In this study, the agrochemical energy ratio was 0.51% of the input energy, which was considered desirable. Additionally, the energy intensiveness indicating the amount of energy produced per rupee spent was computed at 0.40 MJ Rs^{-1}, signifying that for each rupee invested, 0.40 MJ of energy was generated. The energy consumption of different implements and machinery was shown in Table 4. From the table, it was concluded that the power sprayer consumed the least amount of fuel energy, while the combine harvester consumed the highest.

Table 4: Fuel energy of implements/machinery

Machine/Implement	Fuel energy MJ per ha
Puddler	5007.09
Power sprayer	667.61
Combine harvester	2083.47

Conclusion

Energy inputs and output was investigated for rice production system in Yadadri Buvanagiri district. This study reveals significant opportunities for enhancing energy efficiency in agricultural operations. The findings indicate that the current energy use efficiency is 0.70, with a negative net energy of -5700.97 MJ ha^{-1} and an energy productivity of 0.37 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 0.37 level but also contribute to sustainable agricultural intensification while reducing production costs for farmers in the region. In Yadadri Buvanagiri 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.

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