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Full Length Research Paper

ENERGY ASSESSMENT OF DIFFERENT RICE-BASED CROPPING SYSTEMS UNDER IRRIGATED CONDITION OF EASTERN UTTAR PRADESH, INDIA

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ABSTRACT

In an on-farm field experiment conducted over the consecutive years of 2021–23 at Kumarganj, Ayodhya, Uttar Pradesh, ten different rice -based crop sequences were evaluated for their performance inform of energy input- output dynamics, energy use efficiency productivity and sustainability. The sequences included: rice-wheat-fallow, rice-wheat-greengram, rice-frenchbean-greengram, rice-gram-cowpea, rice-mustard-greengram, rice-linseed- blackgram, rice-berseem-sudanchari, rice-cowpea-oat-maize + cowpea, rice-cauliflower-okra, and rice-potato- cowpea (vegetable). Among these, rice-potato-cowpea (vegetable) sequence had the highest energy input at

53.58 x 10^3 MJ/ha. However, the maximum energy output was achieved with fodder-based rice cropping systems, recording 341.02 x 10^3 MJ/ha during first year and 331.84 x 10^3 MJ/ha in the second year. The highest energy use efficiency was observed in rice-oat-maize+cowpea and rice-berseem-sudanchari systems for both years. The se- quence of rice-oat-maize+cowpea not only demonstrated the highest energy output efficiency at 1033 but also pro- vided the greatest energy net return of 299 x 10^3 MJ/ha and the highest energy intensity at 3.89 MJ/Rs. This was closely followed by rice-berseem-sudanchari sequence, which achieved an energy output efficiency of 941, an en- ergy net return of 288 x 10^3 MJ/ha, and an energy intensity of 3.42 MJ/Rs. When considering the combination of energy input, energy output, energy use efficiency, and energy output efficiency, the rice-oat-maize+cowpea se- quence emerged as the most effective among the ten crop sequences tested. This sequence offers a comprehen- sive advantage by maximizing energy efficiency and economic returns, making it the best choice for the specific conditions of the experiment.

Key words: Energy input, Eenergy intensity, Energy output, Energy net return, Rice-based cropping system, Use efficiency

Rice, as a staple food for more than half of the world's population, plays a crucial role in global food security and socio-economic development (Sudarshan *et al.*, 2022). The cultivation of rice encompasses various cropping systems, each with distinct characteristics in terms of energy input, output, and use efficiency. Understanding these aspects is essential for sustainable agricultural practices and ensuring food security amidst growing population pressures and en- vironmental challenges. Rice-based cropping systems ex- hibit a wide diversity, spanning from traditional rainfed

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practices to highly intensive irrigated methods (Kaur *et al.*, 2023). These systems draw upon a multitude of resources for energy input, encompassing labour, machinery, fertiliz- ers, pesticides, water, and fuel. These inputs serve to bol- ster crop productivity while concurrently striving to miti- gate the environmental impacts (Kumar *et al.*, 2024). For instance, the integration of precision agriculture tech- niques, like laser land levelling and drip irrigation, has demonstrated notable success in curbing water and energy consumption within rice cultivation (Mondal *et al.*, 2021). The energy output of rice-based cropping systems is primarily measured in terms of grain yield per unit area. However, it is crucial to consider not only the quantity but also the nutritional quality of the harvested rice. Sustain- able intensification practices, including integrated nutrient management (INM) and improved crop varieties, can en- hance both yield and nutritional value, thereby maximizing the energy output per unit input (Peng *et al.*, 2019). More- over, recent advancements in crop breeding technologies, such as marker-assisted selection and genomic selection, offer opportunities to develop high-yielding rice varieties with improved resilience to biotic and abiotic stresses, fur- ther enhancing energy output in rice cultivation (Kousalya *et al.,* 2024). Energy use efficiency in rice-based cropping systems is a key determinant of sustainability and profitability. Vari- ous indicators, such as energy productivity, energy inten- sity, and energy balance, are used to assess the efficiency of energy utilization in rice production. Research efforts have focused on identifying the strategies to improve en- ergy use efficiency through the adoption of conservation agriculture management practices, including minimum till- age, residue retention, and cover cropping (Yadav *et al.,* 2020). Additionally, the integration of renewable energy sources, such as solar-powered irrigation pumps and biogas digesters, has the potential to reduce dependence on fossil fuels and enhance energy sustainability in rice farming sys- tems (Khan *et al.,* 2021). Assessing the efficiency of energy use within rice-based cropping systems requires comprehensive evaluation frameworks that consider multiple factors, including envi- ronmental, social, and economic indicators. The life cycle assessment (LCA) and energy balance analysis are among the tools commonly employed to quantify the energy in- puts, outputs, and overall efficiency of agricultural systems. These approaches provide valuable insights into the envi- ronmental footprint of rice cultivation and help identify opportunities for improvement.

MATERIALS AND METHODS

A field experiment was conducted during all the three seasons of 2021 to 2023 at the Agronomy Research Farm, Acharya Narendra Deva University of Agriculture and Technology, Uttar Pradesh. The location, in the subtropical zone of the Indo-Gangetic plains, featured alluvial soil and was positioned between 24.4° and 26.5° North latitude and

82.12° and 83.98° East longitude, at an elevation of about 113 meters above sea level. The region's climate is sub- tropical, with minimal seasonal temperature fluctuations. The soil at the site was slightly alkaline (pH 8.20), with low available nitrogen (180 kg/ha), and medium levels of both phosphorus (16.7 kg/ha) and potassium (252 kg/ha). The experiment was laid out in randomized block design with 3 replications. The treatment consisting 10 crop sequences viz., rice-wheat-fallow (T_1), rice-wheat- greengram (T_2), rice-french bean-greengram (T_3), rice- gram-cowpea (T_4), rice-mustard-greengram (T_5), rice-lin- seed-blackgram (T_6), rice-berseem-sudanchari (T_7), rice-cowpea-oat-maize + cowpea (T_8), rice-cauliflower-okra

(T_9), and rice-potato-cowpea (vegetable) (T_{10}). Transplant- ing of rice seedling was done in 1st week of July, whereas, *rabi* crops were sown in 2nd fortnight of November and summer crops were sown in

1st fortnight of April. Fertilizer application was done as per recommended package of practices. Full recommended dose of nutrients i.e. 150 kg N and 60 kg of $P_2 O_5$ and 40 kg K_2O was applied to the ex- perimental rice crop. The whole amount of P_2O_5 and K_2O along with half of the nitrogen was applied as basal and rest of the half amount of nitrogen was top dressed in two equal splits through urea. In *rabi* season, nutrient require- ment of all the crops was met through urea (46% N), DAP (18% N and 46% P_2O_5), muriate of potash (60% K_2O) and sulphur. The various practices involved in crop production and economic yield of component crops in the sequences were converted in to equivalent value of chemical energy (MJ ha^{-1}). For these conversions, standard values as given by Sriram *et al.* (1999) were used (Table 1). Input energy was worked out in terms of different external sources uti- lized, i.e. (i) seed, (ii) fertilizer, (iii) herbicide, (iv) human labour and (v) plant protection chemicals. Input energy was calculated by multiplying energy equivalent per unit of in- put and output (Table 2) with amount of inputs used in various operations performed for growing rice under differ- ent establishment methods as described by Yuan and Peng (2017). The total energy return of the system was obtained by conversion of economic yield of the sequence into en- ergy equivalent whereas, the net energy return was worked out by deducting total input involved in the sequence in energy term from the total energy return. The energy use efficiency, energy productivity, net energy gain, energy in-

Table 1. Resource input and their energy equivalent in MJ/Unit

Resource Input	Unit	Equivalent (MJ/unit)
Labour	Hr	1.96
Diesel fuel	Litter	47.87
Electricity	kWh	3.60
Nitrogen (N)	Kg	60.60
Phosphorus (P_2O_5)	Kg	11.11
Potassium	Kg	6.70
Zinc Sulphate ($ZnSO_4$)	Kg	20.90
Mannure/FYM	Kg	0.30
Vermi-compost	Kg	0.50

Farm Machinary	Kg	62.50
Herbicides	Kg	254.45
Insecticides	Kg	186.63
Water	M^3	1.02
Minerals	Kg	2.00
Seed		
Rice, wheat, maize, lentil, moong, sorghum, cowpea, oat, okra, tomato, cauliflower, cabbage	Kg	14.70
Berseem	Kg	10.00

Table 2. Resource output and their energy equivalent

Resource output	Unit	Equivalent (MJ/unit)
Rice, wheat, maize, lentil, moong, sorghum, cowpea, oat, okra, tomato, cauliflower, cabbage	Kg	Same as input
Okra	Kg	1.9
Onion	Kg	1.6
Sorghum, berseem, oat and maize (dry mass)	Kg	18.00
Manure	Kg	0.30
Straw (Rice-wheat)	Kg	12.5
Fuel wood	Kg	18.00

Okra, tomato, cabbage, cauliflower, onion, banana (leaves and stem)	Kg	10.00
Lentil, moong	Kg	11.25
Mustard, toria	Kg	25.00
Potato	Kg (dry mass)	5.6
Cowpea (F)	Kg (dry mass)	18.0
Vegetable pea	Kg (dry mass)	13.4
Lady's finger	Kg (dry mass)	1.9
Cowpea (DP)	Kg (dry mass)	13.7
Residue of gram	Kg (dry mass)	11.23

tensiveness and the specific energy were calculated as (Demircan 2006):

Energy use efficiency (EUE) = Total energy output / total energy input

Net energy gain (NEG) = Total energy output - total energy input

Energy profitability (EP) = net energy gain / total energy input

Energy Output Efficiency = Total energy consumed in production (MJ) / Energy in harvested rice (MJ)

Energy Intensity = Total Crop Yield (kg) / Total Energy Input (MJ)

All variables were analysed, the significance of treat- ment differences was judged by the F test as out lined by (Gomez and Gomez, 1984). To evaluate the significance of difference between two treatment means, critical difference (CD) at 5 percent level was worked out.

RESULTS AND DISCUSSION

Energy input, energy output and energy use efficiency Pooled mean of two-year data revealed the mean analy- sis of energy input and output relationships across various rice-based cropping systems. The energy input for these cropping sequences ranged from 32.72 × 10^3 MJ/ha to 53.58 × 10^3 MJ/ha. The highest energy input (53.58 × 10^3 MJ/ha) was recorded for the rice-potato-cowpea (veg- etable) sequence, followed by rice–cauliflower–okra (46.92 × 10^3 MJ/ha). Conversely, the lowest energy inputs were observed in the rice-linseed-blackgram (32.72 × 10^3 MJ/ha) and rice–wheat–fallow systems. These variations are due to the different energy requirements for growing vegetables, cereals, and fodder crops.

Energy output, including both product and by-product, ranged from 201.74 × 10^3 MJ/ha to 282.79 × 10^3 MJ/ha. Fodder-based systems like rice–berseem–sudanchari (341.02 × 10^3 MJ/ha) and rice–oat–maize+cowpea [F] (331.84 ×10^3 MJ/ha) showed the highest output energy, whereas rice-mustard-greengram had the lowest. The in- creased energy output in these fodder-based systems is linked to higher energy equivalents from their produce, resulting in higher energy use efficiency (8.24% and 7.73%, respectively).

These findings highlight the significant influence of crop choice and sequencing on energy dynamics in agricul-

Table 3. Energy input, Output, Energy Use efficiency of different rice based cropping system

Treatment	Energy Input (10^3 × MJ/ha)			Energy Output (10^3 × MJ/ha)			Energy use efficiency		
	2021–22	2022–23	Pool	2021–22	2022–23	Pool	2021–22	2022–23	Pool
T_1	35.14	36.16	35.65	253.42	289.46	271.44	8.23	7.00	7.62
T_2	38.53	39.65	39.09	265.59	276.67	271.13	7.20	6.69	6.95
T_3	38.16	39.27	38.72	281.54	296.07	288.81	7.77	7.16	7.47
T_4	35.42	36.45	35.94	224.84	254.77	239.81	7.24	6.16	6.70

T_5	40.03	41.19	40.61	201.48	202.00	201.74	5.03	4.89	4.96
T_6	32.25	33.19	32.72	186.75	232.41	209.58	7.21	5.62	6.42
T_7	42.29	43.52	42.91	340.52	323.16	331.84	7.63	7.82	7.73
T_8	40.69	41.87	41.28	343.37	338.66	341.02	8.30	8.20	8.25
T_9	46.24	47.59	46.92	235.29	204.20	219.75	4.40	4.94	4.67
T_{10}	52.81	54.34	53.58	321.34	244.23	282.79	4.63	5.91	5.27
SEm±	1.50	1.54	1.52	9.85	9.52	9.69	0.24	0.23	0.24
CD (P=0.05)	4.43	4.56	4.50	29.16	28.19	28.68	0.70	0.68	0.69

Table 4. Energy Out efficiency, Net Energy and Energy Intensity of different rice based cropping system

Treatment	Energy output efficiency (MJ/ha/day)			Net energy (10^3 × MJ/ha)			Energy Intensity (MJ/Rs)		
	2021–22	2022–23	Pool	2021–22	2022–23	Pool	2021–22	2022–23	Pool
T_1	1,048.73	949.14	998.94	254.33	217.26	235.80	3.55	2.98	3.27
T_2	777.19	760.96	769.08	238.14	225.94	232.04	2.77	2.62	2.70
T_3	848.30	825.66	836.98	257.90	242.26	250.08	3.16	3.08	3.12
T_4	734.72	638.75	686.74	219.35	188.39	203.87	2.44	2.09	2.27

T_5	594.13	619.93	607.03	161.97	160.29	161.13	2.18	2.06	2.12
T_6	668.35	542.84	605.60	200.16	153.56	176.86	2.54	1.94	2.24
T_7	915.48	967.37	941.43	280.87	297.00	288.94	3.37	3.46	3.42
T_8	990.23	1,076.34	1033.29	297.97	301.49	299.73	3.90	3.87	3.89
T_9	577.65	660.01	618.83	157.96	187.70	172.83	1.82	2.01	1.92
T_{10}	712.06	1,007.31	859.69	191.42	267.00	229.21	1.94	2.44	2.19
SEm±	28.08	29.93	29.01	8.07	8.33	8.20	0.10	0.10	0.10
CD (P=0.05)	83.18	88.65	85.92	23.92	24.67	24.30	0.29	0.28	0.29

tural systems. Efficient cropping sequences enhance energy productivity and reduce environmental impacts. For ex- ample, integrating leguminous crops like cowpea or green gram into rotations can improve nitrogen fixation, lowering the need for synthetic fertilizers and thus reducing energy inputs. Additionally, high-yielding crops such as maize or oats can increase overall energy output/unit area.

Adopting sustainable farming practices like conserva- tion tillage, organic farming, and precision agriculture can further improve energy efficiency and productivity. These methods optimize energy use while promoting soil health and biodiversity, which are essential for sustainable agri- culture. A thorough understanding of energy dynamics within cropping systems is crucial for developing strategies that balance energy efficiency with productivity and envi- ronmental sustainability. Similar findings were reported by Walia *et al.* (2010 and 2022), Sahana *et al.* (2022), and Saha *et al.* (2022). *Energy output efficiency net energy and energy intensity* The efficiency of energy output in rice-based cropping sequences varies significantly based on the specific se- quences employed. The highest energy output efficiency was observed in the T_8 sequence (rice-oat-maize+cowpea [F]), followed by rice-wheat-fallow and rice-berseem- sudanchari. In contrast, the rice–linseed–blackgram sequence recorded the lowest efficiency (605.60 MJ/ha/ day).

Net energy productivity was notably higher in fodder- based systems, such as rice–oat–maize+cowpea and rice– berseem–sudanchari, with values of 299.73 and 288.94 × 10^3 MJ/ha, respectively. This is attributed to the increased inputs required for fodder cultivation. Conversely, the rice– linseed–blackgram sequence exhibited the lowest produc- tivity. The energy intensity of different cropping systems showed consistent trends over two years, suggesting stable energy efficiency over time.

Energy budgeting in rice-based cropping sequences is essential for optimizing resource allocation and maximiz- ing productivity. Understanding the energy dynamics of these systems allows farmers and policymakers to enhance sustainability and efficiency in agricultural practices. Fod- der-based systems, specifically T_8 and T_7, showed higher gross energy output compared to the rice-wheat system, indicating that incorporating more productive crops into intensive cropping regimes can generate increased energy yields. The higher bio-conversion efficiency in intensified systems contributes to their higher energy returns, as noted by Bohra *et al.* (2007). Babu *et al.* (2020) also reported significantly higher energy outputs from intensified crop- ping compared to conventional systems. Meena *et al.* (2015) and Walia *et al.* (2022) observed significant varia- tions in energy output among cropping systems due to dif- ferences in system productivity. The energy returns from various systems are influenced by the quality and quantity of harvestable products, as highlighted by Hatirli *et al*. (2006) and Gelfand *et al.* (2010). The increased energy expenditure in rice-based cropping systems can be attrib- uted to the intensive use of energy-rich inputs such as seeds and fertilizers. This underscores the importance of consid- ering both energy efficiency and productivity when evalu- ating different cropping strategies.

Incorporating diverse and productive crops into crop- ping systems can enhance overall energy output and bio- conversion efficiency, contributing to sustainable agricul- tural practices. Future research should explore optimal cropping combinations that maximize energy efficiency while maintaining productivity and environmental sustainability.

The evaluation of energy efficiency in rice-based sys- tems within the irrigated ecology of Eastern Uttar Pradesh, India, reveals significant variability in energy inputs and outputs across different cropping sequences. Fodder-based cropping systems, particularly rice–oat–maize+cowpea (T_8) and rice–berseem–sudanchari (T_7), demonstrated the highest energy efficiency and productivity, highlighting their potential for sustainable agricultural practices. These systems benefitted from increased energy returns due to higher bio-conversion efficiency and integration of diverse, high-yielding crops. Conversely, sequences like rice–lin- seed–blackgram showed the lowest energy efficiency, un- derscoring the need for careful selection of cropping com- binations. The findings emphasize the importance of opti- mizing energy use through the adoption of efficient crop- ping sequences and sustainable practices such as conserva- tion tillage and organic farming. By aligning energy effi- ciency with productivity goals, these strategies can enhance resource use efficiency, reduce environmental impact, and support sustainable agricultural development in the region.

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