Indian Journal of Agricultural Sciences **92** (1): 26–30, January 2022/Article
https://doi.org/10.56093/ijas.v92i1.120824

Productivity and energetics of rice (*Oryza sativa*) based cropping systems in Indo-Gangetic plains

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Received: 13 January 2020; Accepted: 17 August 2021

ABSTRACT

A field experiment was conducted at the Agricultural Research Farm, Banaras Hindu University, Varanasi, Uttar Pradesh during 2016–17 and 2017–18 to study the productivity and energetics of rice (*Oryza sativa* L.)-based cropping systems under irrigated condition. The experiment was conducted in randomized block design with three replications. The treatment comprised ten rice-based cropping sequences. Results revealed that rice-potato-green gram recorded significantly high system rice equivalent yield over rest of the cropping sequences during both the years of study. Energy input was recorded highest in rice-potato-green gram followed by rice-potato-cowpea fodder, rice-mustard-sudan grass fodder, rice-wheat-cowpea fodder and lowest in rice-*berseem*-cowpea fodder sequence. Rice-mustard-sudan grass fodder sequence recorded significantly high energy output, net energy, energy output-input ratio and energy intensity as compared to rest of the cropping sequences during both the years of investigation, whereas energy productivity was high in rice-cabbage-cowpea fodder sequence compared to other sequences during both the years of experimentation. However, specific energy was higher in rice-wheat-green gram sequence than rest of the cropping sequences except rice-wheat sequence during second year of investigation where it remained at par with rice-wheat-green gram sequence.

Keywords: Energy Intensity, Energy Productivity, Rice, Specific Energy

Rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) is the predominant cropping system in India It is considered as backbone of food security in South-east Asia (Baghel *et al.* 2018). In the era of shrinking resource base of land, water and energy, resource-use efficiency is an important aspect for considering the suitability of a cropping system (Yadav 2002, Ray *et al.* 2020). In the high productivity zone of the Indo-Gangetic Plains (IGP), continued practice of the rice–wheat system for over four decades has posed a serious threat to agricultural sustainability (Bhatt *et al.* 2016, Singh *et al.* 2019). Under existing agro-climatic situation of Varanasi region particularly in low land condition, complete replacement of rice by any other crop is practically not feasible. However, there is possibility of diversifying rice-wheat system by growing oilseeds, grain legumes as well as some short duration vegetable and fodder crops particularly under integrated farming system. Energy is the basic need of human life and main stay of economy. However, the energy use in crop production had not been given adequate importance in earlier years, but more emphasis must be laid on renewable and non-commercial sources of energy, that are actively involved in crop production processes using intensive energies directly or indirectly. Crop production is often considered as an energy conversion industry. Through photosynthesis plants convert solar and chemical energy derived from the soil into storable chemical energy as carbohydrates, fats, proteins as well as all cellulose. Excessive use of energy results in high unit cost of production, loss of income and market competitiveness (Kachroo *et al.* 2012). Therefore, crop diversification needs to be designed in such a way that apart from higher productivity and profitability it must be an efficient converter of energy. Hence, in the present investigation ten different rice-based cropping sequences were evaluated to find the options for higher productivity and energy efficient rice based cropping sequence under irrigated condition of eastern Uttar Pradesh.

MATERIALS AND METHODS

A field study was carried out at the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi during 2016–17 and 2017–18, as a part of ongoing experiment under Varanasi centre of AICRP on Integrated Farming System initiated during 2016–17. The soil of the experimental field was alluvial deep, slightly alkaline (*p*H 7.95), moderately fertile

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with low organic carbon (0.41%) and available nitrogen (194.7 kg/ha) as well as medium available phosphorus (21.7 kg/ha) and potassium (215.8 kg/ha). The experiment was laid out in randomized block design with three replications on fixed plots. Treatment involved ten rice-based cropping systems, viz. S_1: rice-wheat, S_2: rice-wheat-green gram, S_3: rice-potato-green gram, S_4: rice-wheat-cowpea (fodder), S_5: rice-potato-cowpea (fodder), S_6: rice-*berseem*-maize (fodder), S_7: rice-*berseem*-cowpea (fodder), S_8: rice-mustard-sudan grass(fodder), S_9: rice-mustard-cowpea(fodder), S_{10}: rice-cabbage-cowpea (fodder). Individual plots were thoroughly prepared in isolation to avoid mixing of soil in different treatments. All the crops in different seasons were grown with recommended package of practices under irrigated condition of eastern Uttar Pradesh. Full recommended doses of nutrients were applied to each crop. However, half of the nitrogen requirement of the rice in each sequence was applied through farm yard manure (FYM) a week before transplanting, and basal dose of phosphorus as well as potassium application through fertilizer was adjusted on equivalent basis as per their application as FYM. Well decomposed FYM available in the IFS model at Agricultural Research Farm was used. However, in subsequent winter and summer crops the whole quantity of P_2O_5 and K_2O along with half of the nitrogen was applied as basal application through urea, DAP and MOP. The remaining half quantity of nitrogen was top dressed in the form of urea in one or two equal splits at recommended stages of crops. The irrigation was applied to the crops optimally as and when required and need based plant protection measures were adopted. Similarly, all other recommended package and practices were followed. The yield obtained from winter and summer crops were converted into rice equivalent yield by multiplying yield with prevailing market price of produce and divided by price of rice in different years and sum of rice equivalent yield of rainy, winter and summer season to obtain system rice equivalent yield. Prevailing market price of different produce were used to work out the economics of different systems. Energy values of various input and outputs used in the experiment are presented in Table 1 (Devasenapathy *et al.* 2009). The energy input for a particular cropping system was calculated as the sum of energy requirement for human, labour, diesel, electricity, water, seed, herbicide, FYM, chemical fertilizers used in the system. The other energy studies were done with the help of established equations mentioned below:

Energy output ($10^3 \times$ MJ/ha) = Total biological yield (Seed + straw) × Equivalent energy (MJ/kg)

Net energy = Energy output (MJ/ha) - Energy input (MJ/ha)

$$\text{Energy output-input ratio} = \frac{\text{Energy output (MJ/ ha)}}{\text{Energy input (MJ/ ha)}}$$

$$\text{Energy intensity (MJ/₹)} = \frac{\text{Energy output (MJ/ ha)}}{\text{Cost of cultivation (₹/}ha\text{)}}$$

$$\text{Energy producivity (kg/MJ)} = \frac{\text{Crop yield (kg/ ha)}}{\text{Energy input (MJ / }ha\text{)}}$$

Table 1 Energy values of various inputs and outputs used in system based crop diversification

Particulars		Unit	Energy coefficient (MJ)
Input			
Labour	(Adult man)	Man/hr	1.96
	(Adult women)	Women/hr	1.57
Diesel		Litre	56.31
Electricity		KWH	11.93
Water		Per m^3	0.63
FYM		per kg	0.30
Chemical fertilizer	Nitrogen	per kg	60.00
	P_2O_5	per kg	11.10
	K_2O	per kg	6.70
	Sulphur	per kg	1.12
	Zinc	per kg	120
Pesticide	Herbicide	per Litre	238
	Fungicide	per kg	92
	Insecticide	per Litre	199
Seed	Rice, wheat, maize, Sudan grass	per kg	14.70
	Green gram, cowpea,	per kg	14.70
	Mustard	per kg	25
	Potato	per kg	6.8
	Cabbage	per kg	25
	Berseem	per kg	14.7
Output			
Economic produce	Rice, wheat	per kg	14.70
	Green gram	per kg	14.70
	Mustard	per kg	25
	Potato	per kg	5.6
	Cabbage	per kg	1.2
	Berseem fodder (dry)	per kg	12
	Cowpea fodder (dry)	per kg	10.7
	Maize and sudan grass fodder (dry)	per kg	8.2
Straw/Stover		per kg	12.50

Source: Devasenapathy *et al.* (2009).

$$\text{Specific energy} = \frac{\text{Energy input (MJ/ ha)}}{\text{Crop yield (kg/ ha)}}$$

RESULTS AND DISCUSSION

Productivity: Among the cropping sequences having 300% cropping intensity, rice-potato-green gram (S_3) produced significantly higher system rice equivalent yield (REY) than all the other sequences during both the years of experimentation (Table 2). This could be ascribed to higher production potential of potato as well as good grain yield and better market value of green gram that proved instrumental for attaining higher REY by this sequence. These results are in close conformity with the results of earlier workers (Bohra *et al*. 2007). Similarly, rice-potato-cowpea fodder sequence ranked second and being comparable to rice-cabbage-cowpea fodder produced significantly higher REY than other cropping sequences during both the years of study. This might be due to higher production potential of potato along with good yield of cowpea fodder due to sufficient time period available for cultivation after potato in this sequence. Similar results were also reported by Kachroo *et al.* (2012). Rice equivalent yield of sytems, viz. rice-mustard-sudan grass fodder, rice-*berseem*-maize fodder, rice-*berseem*-cowpea fodder, rice-mustard-cowpea fodder, rice-wheat-cowpea fodder and rice-wheat-green gram were also found significantly higher as compared to rice-wheat sequence during both the years of experimentation. However, among the sequences having 300% cropping intensity, lowest REY was obtained in rice-wheat-green gram sequence (S_2). That was mainly due to poor performance of green gram after wheat, and only one picking was possible due to limited period available for green gram after wheat harvest. These results are in close conformity with the findings of earlier workers (Baishya *et al.* 2016).

Energy input × 10^3 MJ/ha: Data pertaining to energy requirement of rice based cropping system are presented in Table 2. It is evident from the data that among the different sources; fertilizer consumed highest energy in all the cropping sequences and it varied from 58.23% in rice-mustard-sudan grass fodder to 39.45% in rice-potato-green gram. The highest energy in terms of human labour was required in rice-potato-green gram (3887 MJ/ha) owing to higher number of labourers required for potato sowing, earthing up and digging as well as green gram picking. This sequence also recorded maximum total energy input across the different rice based cropping sequences (Table 2). Rice-potato-cowpea fodder ranked second followed by rice-mustard-sudan grass fodder, rice-wheat-cowpea fodder, rice-wheat-green gram, rice-cabbage-cowpea fodder, rice-*berseem*-maize fodder, rice-mustard-cowpea fodder, rice-wheat and rice-*berseem*-cowpea fodder sequences. Similarly, Kachroo *et al.* (2012) working on different rice-based cropping sequences reported that rice-potato-maize+green gram utilized higher energy input followed by rice-potato-onion sequence.

Energy output and net energy (10^3 × MJ/ha): In general, energy output and net energy were noticed higher in second year in comparison to first year in most of the cropping sequences (Table 2). Rice-mustard-sudan fodder sequence registered significantly higher energy output and net energy than remaining sequences. This might be due to higher energy equivalent of mustard associated with higher yield of sudan grass that resulted in higher energy output and net energy in this sequence. The next better sequence was rice-wheat-cowpea fodder closely followed by rice-potato-cowpea fodder both being at par produced significantly higher energy output than other sequences. Similar trend was observed for net energy. It has been earlier established that cropping sequences with high productive component crops and higher intensity brought about greater system net energy (Bohra *et al.* 2007). Similar results were also reported by Sharma *et al.* (2008) and Saha *et al.* (2010). Nevertheless, lowest energy output and net energy recorded in rice-cabbage-cowpea fodder during both the years of experimentation might be due to lower energy equivalent of both cabbage and cowpea in spite of good performance of cabbage.

Energy output: input ratio and energy intensity (MJ/₹): The rice-mustard-sudan grass fodder sequence consistently maintained its significant superiority in energy output: input ratio as compared to rest of the cropping sequences (Table 2). This was mainly due to its higher energy return as compared to other sequences. Similarly, cropping sequences, viz. rice-mustard-cowpea fodder, rice-wheat, rice-wheat-cowpea fodder, rice-*berseem*-cowpea fodder, rice-wheat-green gram and rice-*berseem*-maize fodder also exhibited significantly higher energy output: input ratio than rice-cabbage-cowpea fodder and rice-potato-green gram during both the years of investigation. Despite better energy returns, the rice-potato-green gram sequence recorded lowest energy output: input ratio owing to its higher energy input demand compared to other cropping sequences. Similar results have also been reported by Saha *et al.* (2010) and Singh *et al.* (2016).

With regard to energy intensity, rice-mustard-sudan grass fodder cropping sequence recorded significantly high value over rest of the cropping sequences during both the years of experimentation (Table 2). This could be ascribed to its higher energy return in proportion to the of cultivation cost. The next sequences with respect to energy intensity in descending order were rice-wheat-cowpea fodder>rice-mustard-cowpea fodder>rice-cabbage-cowpea fodder>rice-wheat-green gram and all these sequences proved distinct superiority over rice-potato-green gram sequence. The higher energy intensity of these sequences might be due to their lower cost of production in comparison to rice-potato-green gram. These results are in conformity with the findings of Bastia *et al.* (2008), who reported significantly high energy intensity in rice-maize-cowpea sequence.

Energy productivity (kg/MJ) and specific energy: Rice-cabbage-cowpea fodder sequence registered significantly high energy productivity over rest of the cropping sequences during both the years of investigation (Table 2). This was primarily due to higher yield of cabbage along with contribution of cowpea fodder in total productivity of the sequence. Similarly, cropping sequences, viz. rice-potato-cowpea fodder, rice-potato-green gram, rice-mustard-sudan grass fodder and rice-wheat-cowpea fodder also recorded significantly higher energy productivity than rice-wheat-green gram sequence during both the years of experimentation. The lowest energy productivity of rice-wheat-green gram was mainly due to poor performance of green gram owing to short growing period after wheat and higher energy consumed by wheat. These results are in conformity with findings of Singh *et al.* (2016), who reported

Table 2 Effect of different rice-based cropping sequences on system's rice equivalent yield (REY), energy input, energy output and net energy, energy output: input ratio, energy intensity, energy productivity and specific energy

Treatment	System REY (t/ha)		Energy Input (MJ/ha×10^3)		Energy output (MJ/ha×10^3)		Net Energy (MJ/ha×10^3)		Energy output : input ratio		Energy intensity (MJ/₹)		Energy productivity (kg/MJ)		Specific energy	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
S_1: Rice-Wheat	8.64	8.49	34.21	34.21	264.41	261.47	230.20	227.25	7.73	7.64	2.12	2.09	0.576	0.570	1.74	1.76
S_2: Rice-Wheat-Green gram	11.50	11.92	41.71	41.71	280.16	287.44	238.44	245.72	6.72	6.89	2.14	2.19	0.500	0.513	2.01	1.96
S_3: Rice-Potato-Green gram	20.40	21.13	52.46	52.46	281.72	290.50	229.25	238.03	5.37	5.54	1.72	1.77	0.660	0.675	1.52	1.49
S_4: Rice-Wheat-Cowpea (F)	11.80	12.19	41.88	41.88	322.97	333.95	281.09	292.06	7.71	7.97	2.62	2.71	0.602	0.622	1.67	1.62
S_5: Rice-Potato-Cowpea (F)	18.45	18.72	51.92	51.92	322.46	330.38	270.54	278.46	6.21	6.36	1.97	2.02	0.749	0.763	1.34	1.32
S_6: Rice *Berseem*-Maize (F)	13.32	13.35	39.25	39.25	255.72	256.07	216.46	216.82	6.51	6.52	2.10	2.11	0.598	0.599	1.68	1.68
S_7: Rice *Berseem*-Cowpea (F)	12.13	12.84	33.58	33.58	233.75	251.51	200.17	217.93	6.96	7.49	1.85	1.99	0.568	0.608	1.77	1.65
S_8: Rice Mustard-Sudan grass (F)	13.59	13.49	45.17	45.17	416.77	415.29	371.60	370.12	9.23	9.19	3.44	3.43	0.634	0.632	1.58	1.59
S_9: Rice Mustard-Cowpea (F)	11.85	12.09	38.99	38.99	306.57	314.17	267.59	275.18	7.86	8.06	2.53	2.60	0.580	0.594	1.73	1.69
S_{10}: Rice Cabbage-Cowpea (F)	18.22	18.52	39.92	39.92	218.55	224.96	178.63	185.04	5.48	5.64	2.14	2.21	1.170	1.188	0.86	0.84
SEm±	0.32	0.31	-	-	11.48	11.86	11.48	11.86	0.28	0.29	0.09	0.10	0.030	0.032	0.07	0.08
CD (P=0.05)	0.94	0.92	NA	NA	34.10	35.24	34.10	35.24	0.83	0.86	0.28	0.29	0.089	0.096	0.22	0.23

NA, Not applicable.

the highest energy-use efficiency with the rice-lentil-maize (fodder) system at Nainital.

Contrary to energy productivity, rice-wheat-green gram sequence recorded significantly high specific energy compared to rest of the cropping sequences except rice-wheat sequence during second year of investigation where it remained at par with rice-wheat-green gram (Table 2). Further, it was observed that all the cropping sequences exhibited distinct superiority over rice-cabbage-cowpea fodder sequence with respect to specific energy. This could be attributed to the lower yield of component crops under these sequences as compared to rice-cabbage-cowpea fodder. Here, it is pertinent to mention that specific energy is dependent on yield of crops. Nevertheless, rice-cabbage-cowpea fodder registered lowest specific energy as compared to other cropping sequences owing to its higher productivity accompanied with lesser input requirement. Similar results were reported by Kachroo *et al.* (2012). Thus, from the above study it may be concluded that existing rice-wheat cropping can be diversified with rice-cabbage-cowpea fodder sequence that recorded significantly high system rice equivalent yield and proved most productive. The next productive and remunerative option is rice-potato-green gram sequence. Rice-mustard-sudan grass fodder was found best in terms of energy return, energy output: input ratio and energy intensity under irrigated condition of eastern Uttar Pradesh.

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