Estimation of energetics and energy-use efficiency of rice–green gram sequence in the coastal zone of Andhra Pradesh, India

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A field experiment was conducted at the Agricultural College, Bapatla, AP, India during *kharif* and *rabi* seasons from 2019 to 2021 using different establishment and nutrient treatments. The objectives of this study were to evaluate the energetics between the treatments in the rice–green gram. The results indicated that the input and output energy were the highest in the conventional and the lowest in the minimum tillage. Highest total energy productivity and energy use efficiency were recorded with the reduced tillage. In case of nutrient management, the highest input, output energy and energy productivity and energy use efficiency were recorded with inorganic fertilizer + cured poultry manure treatments. It can be concluded that the reduced tillage with the application of inorganic fertilizer + cured poultry manure is the best in the constraints-prone coastal zone with limited irrigation facilities due to low requirement of non-renewable energy.

Keywords: Coastal zone, crop establishment methods, energy use efficiency, energy productivity, rice and green gram.

IN Andhra Pradesh (AP), India, rice is the principal food crop cultivated throughout the state, providing food for its growing population, fodder for the cattle and employment to the rural population. Any decline in its acreage and production will have a perceivable impact on the state's economy and food security. The coastal regions of Andhra Pradesh, Tamil Nadu and Karnataka form an important rice fallow ecology in peninsular India. Pulses occupy a unique place in Indian agriculture by virtue of the fact that they constitute a major and the only high-protein component in the average Indian diet. Pulses also contribute to the sustainability of the global production system by enriching the soil with biological nitrogen fixation[1]. For effective utilization of land and human resources, the cultivation of rice fallow pulse is an effective approach. Rice–green gram is the most extensive and traditional cropping system in the coastal zone of AP, which provides secured income to the farmers and maintains sustainable agricultural production. The average area, production and productivity of rice in AP are 2.2 mha, 12.69 mt and 2.782 t ha^{-1} respectively[2]. The average area, production and productivity of green gram in the state are 0.139 m ha, 0.0930 mt and 0.661 t ha^{-1} respectively[3].

The possibility of expanding the area under paddy in the near future is limited. When natural resources such as labour, water, capital and energy are in short supply, it becomes less economical as these resources become extremely scarce. Cropping systems with higher productivity and lower input demand are considered more sustainable. Legumes have received significant attention in recent years as a result of their limited yield and high costs. If these crops are included in the cropping sequence, they will impact the economics of the cropping system. The cropping system, productivity, economics, energy and the environment have a strong relationship[4]. Both sustainable environment and sustainable agriculture are intertwined. Energy is an essential driver for the development of all sectors, including the agricultural sector, which is both a consumer and producer of energy. The agricultural and energy sectors have a close interaction, and efficient use of energy is one of the conditions for sustainable agriculture. All types of agricultural operations, which are on the rise to meet the needs of an ever-increasing population, use energy extensively. Higher energy efficiency will contribute to promoting sustainable agriculture by minimizing environmental problems and preventing natural resource destruction. Using renewable energy sources and increasing energy efficiency can significantly contribute to achieving sustainable energy development goals. Hence, agriculture and energy affect each other and have a complementary structure. The present study focuses on evaluating the best type of establishment method and nutrient management for the rice–green gram sequence with improved resource use efficiency and increased productivity and sustainability needed in the prevailing agricultural scenario.

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Materials and methods

An experiment was laid out in a strip-plot design with tillage practices in horizontal strips and nutrient management in vertical strips, and replicated three times for the crop during *kharif* seasons 2019–20 and 2020–21. The treatments were randomized according to the procedure given by Cochran and Cox. Four different crop establishment methods, viz. dry seeding on puddled soil (T_1), reduced tillage (T_2), minimum tillage (T_3) and conventional tillage (T_4), were taken as horizontal strip treatments. Also, five nutrient management treatments for rice, viz. 100% STBN through fertilizer (N_1), 75% STBN through fertilizer + 25% N through (farm yard manure (FYM)) (N_2), 50% STBN through fertilizer + 50% N through FYM (N_3), 75% STBN through fertilizer + 25% N through cured poultry manure (N_4) and 50% STBN through fertilizer + 50% N through cured poultry manure (N_5) were taken as vertical strips at the Agricultural College Farm, Acharya N.G. Ranga Agricultural University, Bapatla, Lam, Guntur, AP during *kharif* and *rabi* seasons of 2019–20 and 2020–21. The experimental site is situated at an altitude of 5.49 m amsl, 15°54′N lat., 80°25′E long. and about 7 km away from the Bay of Bengal in the coastal zone of AP. The experimental field was homogeneously fertile with even topography and uniform texture, and was attached to the main irrigation channel connecting the farm tube well for irrigation. A proper drainage facility was also provided to remove excess water during the experimental period. The average values of soil properties, as well as ranges of experimental fields during the two years of study, were: pH 7.9 and 7.6, EC 0.4 and 0.5 dS m^{-1}, organic carbon 0.50% and 0.49%, available nitrogen 248 and 256 kg ha^{-1}, P_2O_5 38 and 51.5 kg ha^{-1} and available K_2O 434 and 442 kg ha^{-1}. An annual rainfall of 979.2 and 877.8 mm, 90.5 and 23 mm was received during *kharif* and *rabi* seasons of 2019–20 and 2020–21 respectively.

In case of directed seeded rice plots, the field was dry-ploughed with a tractor-drawn cultivator followed by a rotovator. The area was divided into the required number of plots according to the layout plan. Sowing was done in rows opened by line markers in the reduced and minimum tillage plots. The seed was treated with carbendazim @1 g kg^{-1} seed and dibbled at a spacing of 20 cm × 10 cm. The transplanting experimental field was ploughed twice with a tractor-drawn puddler to obtain the required puddle after impounding 5 cm of standing water in the transplanted plots. After thorough puddling, levelling was done. Irrigation channels were formed so as to give sufficient water to each plot. Finally, the layout was done to meet the requirements of the experimental design. Seed rate was calculated based on test weight and germination percentage. Overnight water-soaked seeds were sown uniformly in the nursery bed on the same day of sowing of direct-seeded rice and dry seed on the puddle plots. The seeds were covered with straw and FYM immediately, and then light irrigation was done for the germination of seeds. Irrigation was done in the nursery according to the needs. Nursery seedlings were uprooted on the 25th day and transplanted in the main field at a spacing of 20 cm × 10 cm, in order to maintain the same population as in direct seeded rice plots. Application of fertilizers was done according to the treatments in the experimental plots. Nitrogen was applied through urea. In case of organic manure, viz. FYM and cured poultry manure were applied in the experimental plots before the final operation of seedbed, along with a full dose of P, K and Zn fertilizers through single super phosphate (SSP), muriate of potash (MOP) and $ZnSO_4$. After the harvest of the rice crop, the field area was cleared off weed trash and other unwanted stubbles of paddy. Healthy seeds of treated green gram were dibbled at a spacing of 30 cm × 10 cm.

Economics

After harvesting, data pertaining to biological and economic yield of the crop were converted into per hectare (Table 1). Economic produce of all the treatments were obtained manually. The gross return, net return and benefit : cost ratio were calculated for each treatment, using the purchase price of inputs and selling of outputs prevailing in the local market. To compare the performance of different crop establishment methods and nutrient management practices, the economic yield of all the treatments was converted into rice equivalent yield (REY) based on the prevailing market price using the following formulas:

$$\text{Gross return (Rs ha}^{-1}\text{)} = \text{Selling price of yield (Rs kg}^{-1}\text{)} + \text{yield (kg ha}^{-1}\text{)}.$$

$$\text{Net return (Rs ha}^{-1}\text{)} = \text{Gross return (Rs ha}^{-1}\text{)} - \text{Total cost of cultivation (Rs ha}^{-1}\text{)}.$$

$$\text{Benefit cost ratio (\%)} = \frac{\text{Net return (Rs ha}^{-1}\text{)}}{\text{Cost of cultivaiton (Rs ha}^{-1}\text{)}}.$$

$$\text{Rice equivalent yield} = \frac{\left(\begin{array}{c}\text{Yield of green gram (kg)} \times \\ \text{price of green gram (kg)}\end{array}\right)}{\text{Price of rice (kg)}}.$$

$$\text{System productivity (kg ha}^{-1}\text{ day}^{-1}\text{)} = \frac{\text{Total economical yield (kg ha}^{-1}\text{)}}{\text{Total duration of crop (days)}}.$$

$$\text{System profitability (Rs ha}^{-1}\text{ day}^{-1}\text{)} = \frac{\text{Net return (Rs ha}^{-1}\text{)}}{\text{Total duration of crop (days)}}.$$

Table 1. Economics of the rice–green gram cropping system during 2019–20 and 2020–21

Treatment	2019–20				2020–21			
	Rice grain yield (kg ha^{-1})	Green gram yield (kg ha^{-1})	Total cost of cultivation (Rs ha^{-1})	Total gross returns (Rs ha^{-1})	Rice grain yield (kg ha^{-1})	Green gram yield (Kg ha^{-1})	Total cost of cultivation (Rs ha^{-1})	Total gross returns (Rs ha^{-1})
Crop establishment methods								
T_1	5362.2	710.2	58,731.0	158,872.3	5376.1	719.6	60,031.0	163,827.5
T_2	4980.0	701.3	57,231.0	150,517.4	4991.9	712.2	58,531.0	155,411.7
T_3	4315.2	687.9	55,731.0	137,089.9	4399.6	698.8	57,031.0	142,947.0
T_4	5370.0	720.7	59,031.0	160,046.3	5416.0	727.3	60,331.0	165,485.4
SEm ±	115.78	12.12	–	2636.39	102.31	9.73	–	2147.93
CD (P = 0.05)	400.65	NS	–	9123.12	354.03	NS	–	7432.83
CV (%)	8.96	6.66	–	6.73	7.85	5.27	–	5.30
Nutrient management practices								
N_1	4585.3	602.4	56,339.0	135,283.3	4590.5	619.1	57,639.0	140,080.7
N_2	4728.3	708.0	59,019.0	146,000.9	4765.7	717.2	60,319.0	151,101.7
N_3	4800.5	714.4	61,714.0	148,527.9	4866.8	725.9	63,014.0	154,317.7
N_4	5399.5	741.9	55,869.0	161,872.6	5448.8	744.6	57,169.0	167,146.2
N_5	5520.6	758.6	55,464.0	166,472.7	5557.9	765.5	56,764.0	171,943.3
SEm ±	210.33	24.70	–	5234.71	197.70	23.15	–	4232.54
CD (P = 0.05)	685.92	80.56	–	17,071.36	644.72	75.49	–	13,803.07
CV (%)	14.55	12.14	–	11.96	13.57	11.22	–	9.34

Table 2. Energy equivalents for direct and indirect sources of energy

Particulars	Energy equivalents (MJ/unit)	Reference
Human labour (h)		
Male	1.96	14–16
Female	0.8	
Seed (kg)	14.70	
Rice–green gram	14.70	
Machinery (h)	62.70	14, 15, 17–19
Diesel fuel (litre)	56.31	20–22
Chemical fertilizers (kg)		
Nitrogen (N)	66.14	14, 15, 19, 23–26
Phosphate (P_2O_5)	12.44	
Potash (K_2O)	11.15	
Organic fertilizers (kg)		
Farmyard manure	0.3	14, 15, 17
Poultry manure	2.5	
Pesticides (kg)		
Insecticides	101.2	14, 15, 27
Herbicides	238	
Fungicides	216	
Water for irrigation (m^3)	1.02	14, 15, 28
Main product (kg)		
Grain yield	Same as seed	8, 14, 15
Straw yield	12.50	
Halum yield	10.42	

Data pertaining to various characters were subjected to statistical analysis as described by Panse and Sukhatme[5]. Statistical significance was tested by applying the F-test at 0.05 level of probability, and critical differences were calculated for the parameters that were found significant ($P < 0.05$) to compare the effects of different treatments. Statistical analysis for the data was done following the analysis of the variance technique for strip-plot design, as suggested by Gomez and Gomez[6].

Energetics

Energy input and energy output of different crop components in the cropping system were calculated on the basis of energy equivalents (Table 2). The total energy was calculated from the total material input energy with the required operational energy. The energy values were converted from physical to energy unit measures through published conversion coefficients and expressed as MJ ha^{-1} (ref. 7).

The energy input was calculated as follows

$$\text{EI} = [\{\Sigma(E_s * \varepsilon_s)\} + \{\Sigma(M_m * t_m)\}]/A,$$

where EI is the total energy input to a particular type of crop production (MJ ha^{-1}), E_s the total energy input and output components utilized for agricultural production of a specific crop, ε_s the energy equivalent coefficient for various input energy forms, M_m the machinery energy equivalent (MJ h^{-1}), t_m the actual working time of the machinery or equipment (h) and A is the total cropped area under a particular cropping system (ha).

The energy output was calculated as follows

$$\text{EI or EO} = \{\Sigma(P_{mc} * \varepsilon_{om})\}/A,$$

where EO is the net energy content of the output product (MJ ha^{-1}), P_{mc} the total production quantity of the main crop (kg), ε_{om} the net calorific value (NCV) of the main

Table 3. Total energy (MJ ha^{-1}) for different inputs in the rice–green gram sequence during 2019–20 and 2020–21

	Seed	Diesel	Machinery	Insecticide	Herbicide	Fungicide	Human labour	Manure and Fertilizer	Irrigation
2019–20									
Crop establishment method									
T_1	882.0	2,815.5	1,630.2	404.8	952.0	864.0	56.8	9,240.7	9,690.0
T_2	1,176.0	1,689.3	1,254.0	404.8	1,190.0	864.0	54.9	9,240.7	6,630.0
T_3	1,176.0	1,126.2	1,065.9	404.8	1,428.0	864.0	54.9	9,240.7	6,630.0
T_4	1,359.8	2,815.5	1,630.2	404.8	952.0	864.0	98.0	9,240.7	12,240.0
Nutrient management practices									
N_1	1,323.0	2,252.4	1,630.2	404.8	952.0	864.0	88.2	9,240.7	11,220.0
N_2	1,323.0	2,252.4	1,630.2	404.8	952.0	864.0	88.2	11,555.5	11,220.0
N_3	1,323.0	2,252.4	1,630.2	404.8	952.0	864.0	88.2	13,870.4	11,220.0
N_4	1,323.0	2,252.4	1,630.2	404.8	952.0	864.0	88.2	11,555.5	11,220.0
N_5	1,323.0	2,252.4	1,630.2	404.8	952.0	864.0	88.2	13,870.4	11,220.0
2020–21									
Crop establishment method									
T_1	882.0	2,815.5	1,630.2	404.8	952.0	864.0	66.6	9,240.7	9,690.0
T_2	1,176.0	2,252.4	1,254.0	404.8	1,190.0	864.0	66.6	9,240.7	6,630.0
T_3	1,176.0	1,689.3	1,065.9	404.8	1,428.0	864.0	64.7	9,240.7	6,630.0
T_4	1,367.1	2,815.5	1,630.2	404.8	952.0	864.0	107.8	9,240.7	12,240.0
Nutrient management practices									
N_1	1,323.0	2,252.4	1,630.2	404.8	952.0	864.0	107.8	9,240.7	11,220.0
N_2	1,323.0	2,252.4	1,630.2	404.8	952.0	864.0	107.8	11,555.5	11,220.0
N_3	1,323.0	2,252.4	1,630.2	404.8	952.0	864.0	107.8	13,870.4	11,220.0
N_4	1,323.0	2,252.4	1,630.2	404.8	952.0	864.0	107.8	11,555.5	11,220.0
N_5	1,323.0	2,252.4	1,630.2	404.8	952.0	864.0	107.8	13,870.4	11,220.0

crop and by-products (MJ kg^{-1}) and A is the total cropped area under a particular cropping system (ha).

The energy input–output relationship was calculated as follows[8]

$$\text{Energy productivity (MJ kg}^{-1}) = \frac{\text{Grain + by-product (kg ha}^{-1})}{\text{Energy input (MJ ha}^{-1})}.$$

$$\text{Energy efficiency (\%)} = \frac{\text{Energy output (MJ ha}^{-1})}{\text{Energy input (MJ ha}^{-1})}.$$

$$\text{Specific energy (MJ kg}^{-1}) = \frac{\text{Energy input (MJ ha}^{-1})}{\text{Grain yield (kg ha}^{-1})}.$$

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

$$\text{Net energy (MJ ha}^{-1}) = \text{Energy output (MJ ha}^{-1}) - \text{Energy input (MJ ha}^{-1}).$$

Energy consumption in the rice–green gram sequence

In this study, energy consumption in the rice–green gram sequence was determined in farming operations like tillage, puddling, sowing, pesticide application, fertilizer application, irrigation and harvesting. Operation energy like human labour and fuels were used. The use of fuel is for the machinery for operations like tillage, puddling, sowing, harvesting, transportation and irrigation. Human labour is the most important source of energy in field activities[9]. In agricultural activities, human labour is used at every step, from manual work on the farm, driving agricultural machinery, maintenance, pesticide and fertilizer application, irrigation and harvesting. Tables 3 and 4 show the input energy consumption in total energy (MJ ha^{-1}) and the percentage of the total energy of every component in the rice–green gram sequence. Manure fertilizers and irrigation have the highest share of energy consumption in every treatment.

Results and discussion

Productivity analysis

Table 5 presents the performance of the rice–green gram sequence in terms of system productivity. Figure 1 shows that conventional tillage (36.31 and 36.50 kg ha^{-1} day^{-1} during 2019–20 and 2020–21 respectively) was significantly

Table 4. Percentage of total energy for different inputs in the rice–green gram sequence during 2019–20 and 2020–21

	Seed	Diesel	Machinery	Insecticide	Herbicide	Fungicide	Human labour	Manure and fertilizer	Irrigation
2019–20									
Crop establishment methods									
T_1	3.32	10.61	6.14	1.53	3.59	3.26	0.21	34.82	36.52
T_2	5.23	7.51	5.57	1.80	5.29	3.84	0.24	41.06	29.46
T_3	5.35	5.12	4.85	1.84	6.49	3.93	0.25	42.02	30.15
T_4	4.59	9.51	5.51	1.37	3.22	2.92	0.33	31.21	41.34
Nutrient management practices									
N_1	4.73	8.05	5.83	1.45	3.40	3.09	0.32	33.03	40.11
N_2	4.37	7.44	5.38	1.34	3.14	2.85	0.29	38.15	37.04
N_3	4.06	6.91	5.00	1.24	2.92	2.65	0.27	42.54	34.41
N_4	4.37	7.44	5.38	1.34	3.14	2.85	0.29	38.15	37.04
N_5	4.06	6.91	5.00	1.24	2.92	2.65	0.27	42.54	34.41
2020–21									
Crop establishment methods									
T_1	3.32	10.61	6.14	1.52	3.59	3.25	0.25	34.81	36.50
T_2	5.10	9.76	5.43	1.75	5.16	3.74	0.29	40.04	28.73
T_3	5.21	7.49	4.72	1.79	6.33	3.83	0.29	40.95	29.38
T_4	4.62	9.50	5.50	1.37	3.21	2.92	0.36	31.20	41.32
Nutrient management practices									
N_1	4.73	8.05	5.82	1.45	3.40	3.09	0.39	33.01	40.08
N_2	4.36	7.43	5.38	1.34	3.14	2.85	0.36	38.12	37.02
N_3	4.06	6.90	5.00	1.24	2.92	2.65	0.33	42.52	34.39
N_4	4.36	7.43	5.38	1.34	3.14	2.85	0.36	38.12	37.02
N_5	4.06	6.90	5.00	1.24	2.92	2.65	0.33	42.52	34.39

higher for system productivity, and it was on par with dry seeding on puddled soil (36.09 and 36.20 kg ha^{-1} day^{-1} during 2019–20 and 2020–21 respectively). Lowest values were recorded in reduced tillage (34.24 and 34.36 kg ha^{-1} day^{-1} during 2019–20 and 2020–21 respectively, and minimum tillage (31.06 and 31.50 kg ha^{-1} day^{-1} during 2019–20 and 2020–21 respectively). The higher system productivity recorded under T4 treatment (conventional tillage) over other treatments could be attributed to better environmental and eco-physiological conditions, as well as less crop–weed competition for moisture and light, which resulted in better availability of nutrients for proper development of plant dry matter and yield attributing characters, i.e. productive tillers and filled grains per panicle, which led to higher rice grain yield[10]. Grain yield under dry seeding on puddled soil was also on par with conventional tillage. This might be due to the fact that the drilling of dry seeds was done on puddled soil, and later the soil was converted into submerged conditions as the growth and development of rice plants increased, similar to that of transplanting in conventional tillage.

Among different nutrient management practices, the combined application of inorganic and poultry manure treatments (37.63 and 37.79, 36.81 and 36.95 kg ha^{-1} day^{-1} during 2019–20 and 2020–21 respectively) was higher in for system productivity than the combined application of inorganic fertilizers with FYM treatments and inorganic treatment alone. Supply of the required nutrients through organic and inorganic sources facilitated balanced nutrition for the crop, which might have resulted in enhanced grain yield[11].

Profitability analysis

The results revealed that system profitability was the highest in conventional tillage (276.8 and 288.1 Rs ha^{-1} day^{-1} during 2019–20 and 2020–21 respectively) and on par with dry seeding on puddled soil (274.4 and 284.4 Rs ha^{-1} day^{-1} during 2019–20 and 2020–21 respectively) due to higher system productivity recorded in these two treatments that contributed to higher profitability. Lowest profitability values were observed in reduced tillage (255.5 and 265.4 Rs ha^{-1} day^{-1} during 2019–20 and 2020–21 respectively) and minimum tillage (222.9 and 235.4 Rs ha^{-1} day^{-1} during 2019–20 and 2020–21 respectively). In case of nutrient management practices, the combined application of inorganic fertilizers with poultry manure treatments (304.1 and 315.6, 290.4 and 301.3 Rs ha^{-1} day^{-1} during 2019–20 and 2020–21 respectively) was higher than the combined application of inorganic and FYM and inorganic alone (Tables 5 and Figure 1)[12]. This might be due to higher grain and straw yields obtained under transplanted rice and dry seeding on puddled soil, which in turn results in increase in system profitability.

Energy analysis

The total energy input consisted of human labour, seeds, machinery, fuel, fertilizers, manure, pesticides and irrigation.

Table 5. System productivity and system profitability of the rice–green gram cropping system during 2019–20 and 2020–21

	2019–20						2020–21					
Treatment	REY (kg ha^{-1})	Total REY	System productivity (kg ha^{-1} day^{-1})	Net returns	B : C ratio	System profitability (Rs ha^{-1} day^{-1})	REY (kg ha^{-1})	Total REY	System productivity (kg ha^{-1} day^{-1})	Net returns	B : C ratio	System profitability (Rs ha^{-1} day^{-1})
Crop establishment methods												
T_1	2,759	8,121	36.09	100,141	1.71	274.4	2,772	8,144	36.20	103,797	1.74	284.4
T_2	2,724	7,704	34.24	93,286	1.64	255.6	2,743	7,731	34.36	96,881	1.66	265.4
T_3	2,672	6,987	31.06	81,359	1.47	222.9	2,692	7,088	31.50	85,916	1.51	235.4
T_4	2,800	8,170	36.31	101,015	1.72	276.8	2,802	8,213	36.50	105,154	1.75	288.1
SEm ±	47.08	139.8	0.62	2,636	0.05	7.22	37.47	110.5	0.49	2,148	0.04	5.88
CD	NS	483.8	2.15	9,123	0.16	24.99	NS	382.4	1.70	7,433	0.12	20.36
CV (%)	6.66	6.99	6.99	10.87	10.96	10.87	5.27	5.49	5.49	8.49	8.37	8.49
Nutrient management practices												
N_1	2,340	6,925	30.78	78,944	1.40	216.3	2,385	6,972	30.99	82,442	1.43	225.9
N_2	2,750	7,478	33.24	86,982	1.47	238.3	2,763	7,524	33.44	90,783	1.50	248.7
N_3	2,775	7,575	33.67	86,814	1.41	237.8	2,796	7,659	34.04	91,304	1.45	250.1
N_4	2,882	8,281	36.81	106,004	1.89	290.4	2,868	8,313	36.95	109,977	1.92	301.3
N_5	2,947	8,467	37.63	111,009	2.00	304.1	2,949	8,502	37.79	115,179	2.03	315.6
SEm ±	95.95	281.6	1.25	5,235	0.09	14.34	89.17	223.4	0.99	4,233	0.07	11.60
CD	312.9	918.5	4.08	17,071	0.29	46.77	290.8	728.5	3.24	13,803	0.23	37.82
CV (%)	12.14	12.60	12.60	19.30	18.63	19.30	11.22	9.93	9.93	14.97	14.59	14.97

REY, Rice equivalent yield.

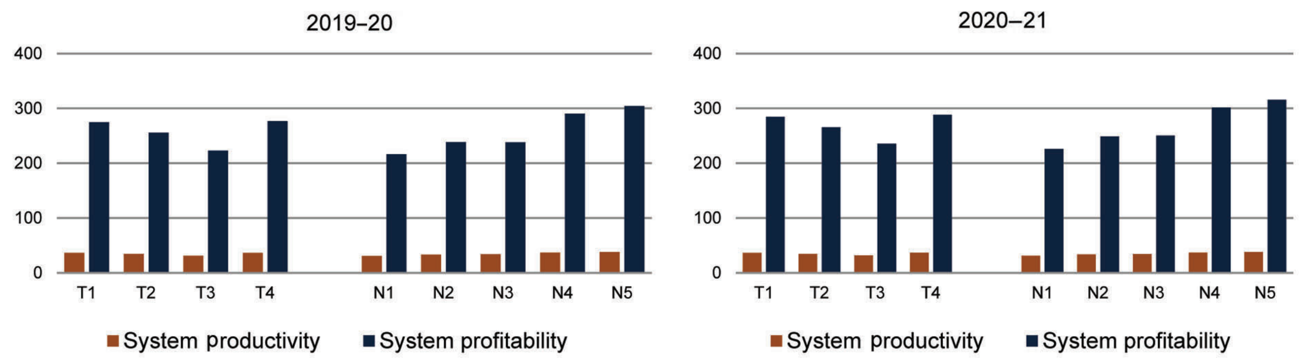

Figure 1. System productivity (kg ha^{-1} day^{-1}) and system profitability (Rs ha^{-1} day^{-1}) of the rice–green gram cropping system during 2019–20 and 2020–21.

Table 6. Energetics of the rice–green gram cropping system during 2019–20 and 2020–21

	Input energy (MJ ha^{-1})			Output energy (MJ ha^{-1})				
Treatment	Rice	Green gram	Total input energy (MJ ha^{-1})	Rice	Green gram	Rice	Green gram	Total output energy (MJ ha^{-1})
2019–20								
Crop establishment methods								
T_1	24,308.6	2227.4	26,536.0	78,821.4	10,440.5	89,512.5	15,338.2	194,112.7
T_2	20,276.2	2227.4	22,503.6	73,206.0	10,308.8	83,050.0	15,098.5	181,663.4
T_3	19,763.0	2227.4	21,990.4	63,430.5	10,112.8	79,775.0	14,504.6	167,823.2
T_4	27,377.5	2227.4	29,604.9	78,939.0	10,595.0	91,787.5	15,702.9	197,024.5
Nutrient management practices								
N_1	25,747.9	2227.4	27,975.3	67,399.5	8854.9	74,637.5	13,254.2	164,146.2
N_2	28,062.7	2227.4	30,290.1	69,501.6	10,407.7	79,712.5	15,442.4	175,064.3
N_3	30,377.5	2227.4	32,604.9	70,560.0	10,500.9	85,750.0	15,557.0	182,368.2
N_4	28,062.7	2227.4	30,290.1	79,380.0	10,905.6	90,100.0	15,755.0	196,140.7
N_5	30,377.5	2227.4	32,604.9	81,158.7	11,152.1	99,937.5	16,609.4	208,857.8
2020–21								
Crop establishment methods								
T_1	24,308.6	2237.2	26,545.8	79,027.2	10,578.1	90,600.2	15,557.0	195,762.4
T_2	20,841.3	2237.2	23,078.5	73,382.4	10,469.3	84,800.2	15,411.1	184,062.9
T_3	20,326.1	2237.2	22,563.3	64,680.0	10,272.3	81,500.0	14,556.7	171,009.1
T_4	27,384.9	2237.2	29,622.1	79,615.2	10,691.3	93,550.6	15,723.7	199,580.3
Nutrient management practices								
N_1	257,57.7	2237.2	27,994.9	67,487.7	9100.7	76,400.2	12,733.2	165,721.7
N_2	28,072.5	2237.2	30,309.7	70,060.2	10,542.8	81,550.3	15,598.7	177,751.8
N_3	30,387.3	2237.2	32,624.5	71,544.9	10,670.7	86,900.4	15,713.3	184,829.5
N_4	28,072.5	2237.2	30,309.7	80,100.3	10,945.6	91,462.5	16,776.2	199,284.6
N_5	30,387.3	2237.2	32,624.5	81,702.6	11,252.8	101,737.5	17,276.3	211,969.3

The energy equivalents were used to determine energy inputs and outputs. The energy inputs for rice production vary with the different establishment methods and nutrient management practices. The total energy input in conventional tillage and combined application of inorganic and poultry manure were higher than the other methods. The energy use was generally lower in these methods, but the yields were higher. This was mainly due to variable amounts of input energy required for crop growth. With regard to the energy output, there were significant differences between the crop establishment method and nutrient management for the rice–green gram sequence. During both years, total energy output was higher in conventional tillage and combined application of inorganic and poultry manure compared to the other methods (Table 6 and Figure 2). This indicates that more energy would be incurred for yield.

Regarding specific energy and energy intensiveness, the highest values were recorded in conventional tillage (8.19 and 8.14 MJ kg^{-1}, and 0.50 and 0.48 MJ Rs^{-1} during 2019–20 and 2020–21 respectively) and combined application of inorganic and poultry manure (8.44 and 8.39 MJ kg^{-1}, and 0.59 and 0.56 MJ Rs^{-1} during 2019–20 and 2020–21 respectively) compared to other methods (Table 7 and Figure 3). This is due to the inclusion of legumes

Table 7. Specific energy, energy productivity and energy intensiveness of the rice–green gram cropping system during 2019–20 and 2020–21

	2019–20									2020–21								
	Specific energy ($MJ\ kg^{-1}$)			Energy productivity ($MJ\ kg^{-1}$)			Energy intensiveness ($MJ\ Rs^{-1}$)			Specific energy ($MJ\ kg^{-1}$)			Energy productivity ($MJ\ kg^{-1}$)			Energy intensiveness ($MJ\ Rs^{-1}$)		
	Rice	Green gram	Total	Rice	Green gram	Total	Rice	Green gram	Total	Rice	Green gram	Total	Rice	Green gram	Total	Rice	Green gram	Total
Crop establishment methods																		
T_1	4.53	3.14	7.67	0.52	0.98	1.50	0.54	0.17	0.45	4.52	3.11	7.63	0.52	0.99	1.51	0.52	0.15	0.43
T_2	4.07	3.18	7.25	0.57	0.97	1.54	0.46	0.17	0.39	4.17	3.14	7.31	0.57	0.98	1.55	0.46	0.15	0.39
T_3	4.58	3.24	7.82	0.54	0.93	1.47	0.47	0.17	0.39	4.62	3.20	7.82	0.54	0.94	1.48	0.47	0.15	0.39
T_4	5.10	3.09	8.19	0.46	1.00	1.46	0.60	0.17	0.50	5.06	3.08	8.14	0.47	1.00	1.47	0.58	0.15	0.48
Nutrient management practices																		
N_1	5.62	3.70	9.32	0.41	0.84	1.25	0.60	0.17	0.50	5.61	3.61	9.22	0.42	0.82	1.24	0.58	0.15	0.48
N_2	5.94	3.15	9.09	0.40	0.98	1.38	0.62	0.17	0.51	5.89	3.12	9.01	0.40	0.99	1.39	0.60	0.15	0.49
N_3	6.33	3.12	9.45	0.38	0.99	1.37	0.63	0.17	0.53	6.24	3.08	9.32	0.39	1.00	1.39	0.61	0.15	0.51
N_4	5.20	3.00	8.2	0.45	1.01	1.46	0.66	0.17	0.54	5.15	3.00	8.15	0.45	1.05	1.50	0.64	0.15	0.52
N_5	5.50	2.94	8.44	0.44	1.06	1.50	0.72	0.17	0.59	5.47	2.92	8.39	0.45	1.08	1.53	0.70	0.15	0.56

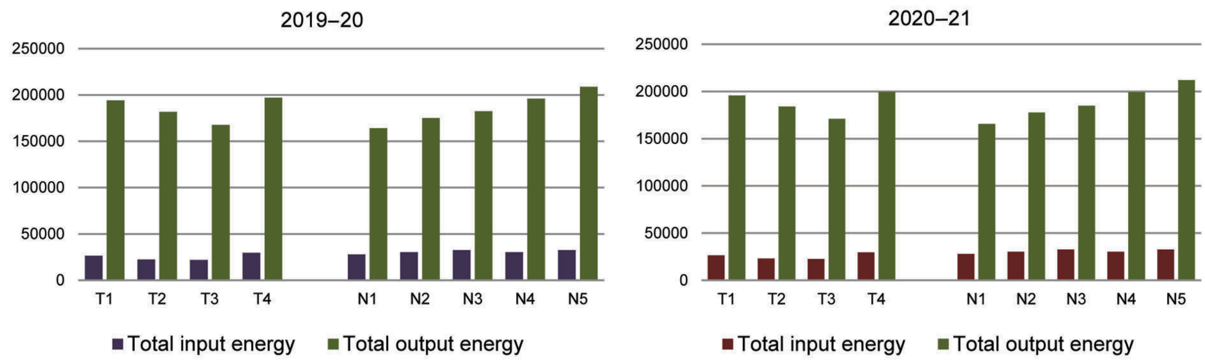

Figure 2. Total input energy (MJ ha^{-1}) and total output energy (MJ ha^{-1}) of the rice–green gram cropping system during 2019–20 and 2020–21.

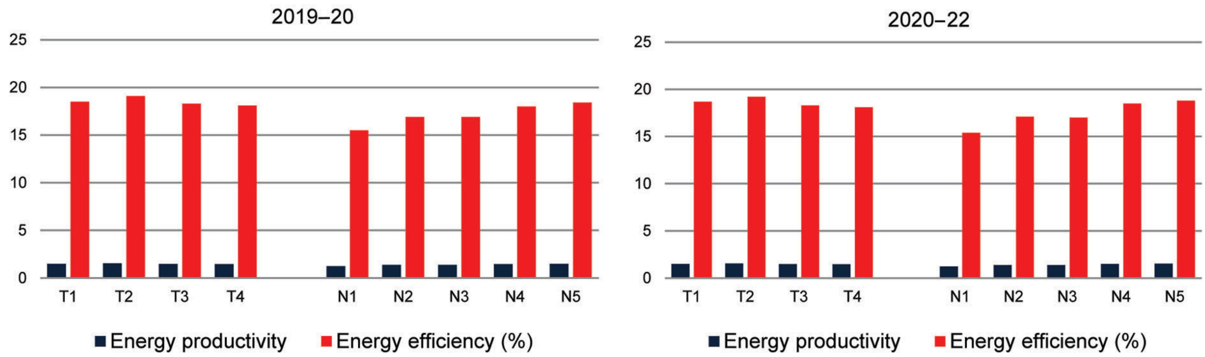

Figure 3. Energy productivity (MJ ha^{-1}) and energy efficiency (%) of the rice–green gram cropping system during 2019–20 and 2020–21.

Table 8. Net energy and energy efficiency of the rice–green gram cropping system during 2019–20 and 2020–21

	2019–20						2020–21					
	Net energy (MJ ha^{-1})			Energy efficiency (%)			Net energy (MJ ha^{-1})			Energy efficiency (%)		
	Rice	Green gram	Total	Rice	Green gram	Total	Rice	Green gram	Total	Rice	Green gram	Total
Crop establishment methods												
T_1	144,025	23,551	167,577	6.92	11.57	18.5	145,319	23,898	169,217	6.98	11.68	18.7
T_2	135,980	23,180	159,160	7.71	11.41	19.1	137,341	23,643	160,984	7.59	11.57	19.2
T_3	123,442	22,390	145,833	7.25	11.05	18.3	125,854	22,592	148,446	7.19	11.10	18.3
T_4	143,349	24,071	167,420	6.24	11.81	18.1	145,780	24,178	169,958	6.32	11.81	18.1
Nutrient management practices												
N_1	116,289	19,882	136,171	5.52	9.93	15.5	118,130	19,597	137,727	5.59	9.76	15.4
N_2	121,151	23,623	144,774	5.32	11.61	16.9	123,538	23,904	147,442	5.40	11.68	17.1
N_3	125,932	23,831	149,763	5.15	11.70	16.9	128,058	24,147	152,204	5.21	11.79	17.0
N_4	141,417	24,433	165,851	6.04	11.97	18.0	143,490	25,485	168,975	6.11	12.39	18.5
N_5	150,719	25,534	176,253	5.96	12.46	18.4	153,053	26,292	179,345	6.04	12.75	18.8

which require fewer inputs and their residual effect through mineralization and improvement of physico-chemical properties of soil and thereby improving nutrient and water holding capacity of soil[13].

Total energy productivity was found to be the highest in the reduced tillage system (1.54 and 1.55 MJ kg^{-1}) followed by dry seeding on puddled soil (1.50 and 1.51 MJ kg^{-1}), and combined application of inorganic and poultry manure (1.50 and 1.53 MJ kg^{-1} and 1.46 and 1.50 MJ kg^{-1} for T_5 and T_4 treatments respectively; Table 7 and Figure 3). This can be attributed to the fact that these treatments have much less energy expenditure than the other systems. Lowest total energy productivity (1.46 and 1.47 MJ kg^{-1}) was observed in the conventional tillage system due to the higher input energy. Hence higher energy efficiency of 19.1% and 19.2% during 2019–20 and 2020–21 respectively, was recorded in reduced tillage system, followed by dry seeding on puddled soil (18.5% and 18.7% during 2019–20 and 2020–21 respectively), and combined application of inorganic and poultry manure (18.4% and 18.8%, 18.0% and 18.5% in T_5

and T_4 treatments respectively; Table 8 and Figure 3). This shows that the quantity of energy used to produce unit output is higher with these treatments, and higher energy efficiency treatments have higher resource use efficiency with higher productivity[29].

Conclusion

The present study indicates that reduced tillage and dry seeding on puddled soil systems are the most energy-efficient and cost-effective rice establishment methods with combined application of inorganic and poultry manure compared to other treatments such as conventional and minimum tillage methods of rice establishment in the coastal zone of AP. The performance of these two rice establishment methods was superior, with higher energy productivity and efficient energy utilization. Application of poultry manure during summer sustained soil fertility of the system. The rapid decomposing nature of poultry manure might have enhanced soil nutrient availability during *kharif* and *rabi* crops.

The energy model has been used to analyse how to minimize energy inputs without reducing production and economic benefits. As a result, such an analysis is promising and should be used in future farming system studies to achieve sustainable production of the rice–green gram cropping system.

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