Evaluation of rice (*Oryza sativa* L.)-based cropping systems for productivity and profitability in the vertisols of Telangana, India

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Field experiment with different rice based cropping systems, viz. rice–rice, rice–mustard, rice–chickpea, rice–green gram, rice–sorghum, rice–maize, rice–black gram, rice–cowpea (fodder), rice–sorghum (fodder) were evaluated with rice–rice at RS & RRS, Rudrur, Nizamabad, PJTSAU, Telangana. Green manure–rice–maize and green manure–rice–fodder sorghum produced 15,848 kg REY/ha and 15,292 kg REY/ha respectively, which was significantly more than other cropping systems. Production efficiency of green manure–rice–maize was significantly more (58.26 kg/ha/day) closely followed by green manure–rice–sorghum (54.32 kg/ha/day) and green manure–rice–black gram (54.04 kg/ha/day), while it was lower for green manure–rice–fodder cowpea (39.16 kg/ha/day) and green manure–rice–fodder sorghum (42.09 kg/ha/day). Green manure–rice–maize, green manure–rice–black gram and green manure–rice–fodder sorghum were at par with each other for system net returns with 202,341 Rs/ha, 199,916 Rs/ha, 189,623 Rs/ha respectively, and was least with green manure–rice–fodder cowpea (124,981 Rs/ha) and green manure–rice–rice (148,937 Rs/ha). Energy productivity was higher with green manure–rice–black gram (1.13 kg/MJ) and green manure–rice–green gram (0.91 kg/MJ) cropping system. Green manure–rice–maize, green manure–rice–blackgram are most suitable cropping systems over existing green manure–rice–rice cropping system for vertisols of Telangana state.

Keywords: Cropping systems, energy input and output, productivity and profitability, rice.

FOOD security in South Asia is mainly contributed from three major cereal crops, viz. rice, wheat and maize. Rice is cultivated as the first food crop and hence rice-based cropping systems make significant contribution towards food production with rice–rice as the major cropping system in irrigated agriculture, whereas rice–pulse–fallow is the predomimant system in rainfed agriculture. In rice-growing tracts different crop combinations are followed depending on the agro-ecological situations, prevailing market price, and domestic demands and resources available at the farms. In South India rice–rice is the predominant cropping system in both tropical weather characterized by dry and wet seasons and subtropical weather with cool winter. Most of the rice–wheat area is confined to the Indo-Gangetic Plains, whereas rice–maize system is followed in tropical, subtropical and warm temperate climates. Sustainability in productivity is the major objective in any crop planning. Cropping systems with greater productivity and low input demand are considered as efficient towards sustainability. In the recent past, oilseeds and legumes have gained more attention due to low production and high costs. These crops if incorporated in the cropping sequence will influence the economics of the cropping system. There is a close relationship between cropping system, productivity, economics, energy and environment[1]. Green manuring during summer mitigates the ill-effects of leaving barren lands and is the best practice for sustainable rice production.

Tuti *et al.*[2] reported that crop yield is inversely related to energy use efficiency, energy productivity and energy intensiveness. Atmospheric pollution can be reduced by adopting energy–efficient cropping systems which require less external inputs, thus providing an economically viable production choice for the future[3].

With the decline in availability of natural resources like land, water and energy, resource use efficiency plays a vital role in the suitability of any cropping system to a particular area[4]. Hence selection of component crops should be planned for a synergistic effect in efficient utilization of resources with enhanced productivity[5]. There is a need to evaluate suitable rice-based cropping systems in order to establish stability in the system. Inclusion of pulses and vegetables in any cropping system results in beneficial output[6].

Evaluating the possibilities of replacing post-rainy-season rice with suitable upland crops, including summer season crops with improved resource use efficiency and increased productivity and sustainability is needed in the prevailing agricultural scenario.

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Table 1. Agronomic management adopted for crops grown during the experiment

Cropping system	Variety		Seed rate (kg/ha)		Spacing (cm × cm)		Fertilizer (kg/ha; N : P_2O_5 : K_2O)		No. of irrigations	
	Kharif	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*
Rice–rice	KNM 118	KNM 118	50	50	20 × 15	20 × 15	100 : 60 : 40	120 : 60 : 40	10	24
Rice–mustard	KNM 118	Pusa 26	50	5	20 × 15	45 × 15	100 : 60 : 40	60 : 40 : 40	10	03
Rice–chickpea	KNM 118	JG 11	50	75	20 × 15	30 × 10	100 : 60 : 40	20 : 50 : 20	10	02
Rice–green gram	KNM 118	MGG 295	50	20	20 × 15	30 × 10	100 : 60 : 40	20 : 50 : 20	10	02
Rice–sorghum	KNM 118	M35-1	50	5	20 × 15	45 × 15	100 : 60 : 40	120 : 40 : 40	10	04
Rice–maize	KNM 118	DHM 117	50	20	20 × 15	60 × 20	100 : 60 : 40	200 : 60 : 50	10	06
Rice–black gram	KNM 118	PU31	50	20	20 × 15	30 × 10	100 : 60 : 40	20 : 50 : 20	10	02
Rice–cowpea (fodder)	KNM 118	Vijaya	50	16	20 × 15	30 × 10	100 : 60 : 40	20 : 40 : 0	10	02
Rice–sorghum (fodder)	KNM 118	SSG 293	50	12	20 × 15	30 × 10	100 : 60 : 40	120 : 40 : 30	10	06

Materials and methods

Field experiments with eight different rice-based cropping systems, viz. rice–rice, rice–mustard, rice–chickpea, rice–green gram, rice–sorghum, rice–maize, rice–black gram, rice–cowpea (fodder) and rice–sorghum (fodder) were performed with rice–rice during *kharif* (June to September) and *rabi* (October to January) at the Regional Sugarcane and Rice Research Station at Professor Jayashankar Telangana State Agricultural University, Telangana, India. This station is situated in the perennial zone of the Nizam Sagar ayacut, Nizamabad district of Telangana at 18°–30°N lat. and 77–51°E long. and an elevation of 404 m amsl.

The average annual rainfall recorded during the period of study (May 2018 to May 2019) was 473.5 mm, 30.66% lower than the decennial average rainfall (682.96 mm). The soil of experimental sites was clay loam with medium organic carbon content (0.67%), medium available N (387 kg/ha), medium available P_2O_5 (48 kg/ha) and medium available K_2O (298 kg/ha).

All the crops in the cropping sequence were grown in a gross area of 1080 sq. m, with recommended package and practices. Table 1 provides details of crop duration and inputs used.

Field preparation during *kharif* was done by running a rotavator once and green manure seeds were evenly broadcasted @ 50 kg ha^{-1}. Crops were grown up to 50% flowering stage (40 DAS) and incorporated in the soil by running cultivator followed by rotavator. Following submergence irrigation, single super phosphate was applied, and allowed to decompose for 48 h. The water was drained out from the field and freshwater was provided, and puddling was done with the rotavator. The 25-day-old rice seedlings were transplanted in the first week of July. After the harvest of rice in the second fortnight of September, *rabi* crops were sown in the second fortnight of October. Recommended doses of fertilizers to each crop in various cropping systems were applied. Irrigation was done according to the crop needs. At maturity all crops were harvested manually from a net plot area of 750 sq. m out of 1230 sq. m gross plot area. After harvesting, data pertaining to biproduce and economic yield of each crop were converted into per hectare. Economic produce of all the crops was obtained manually.

To compare the performance of different cropping sequences, economic yield of all the crops was converted into rice equivalent yield (REY) based on the prevailing market price using following formula

$$\text{REY (of a crop)} = Y_x (P_x)/P_r,$$

where Y_x is the yield of crop x (tonne/ha of economic harvest), P_x the price of crop x and P_r is the price of rice.

To study resource use efficiency of the system, land-use efficiency (LUE) was calculated from total duration of the crop in cropping system divided by 365 and production efficiency (PE; kg/ha/day) was calculated by dividing total economic yield (REY) by total duration of crops in the cropping system. The relative production efficiency (RPE) of the system was calculated and expressed as percentage.

$$\text{RPE} = (B - A)/A \times 100,$$

where A is the productivity (REY) of rice–rice system and B is the productivity (REY) of the diversified cropping system.

Energetics

Energy input and energy output for the individual crops in the cropping system were calculated and the energy value was determined. Energy input from humans, animals, machineries, fuel sources, seeds, fertilizers, farmyard manure and pesticides was recorded during different stages of application. Energy input and output were converted from physical to energy unit measures through published conversion coefficients[7,8]. The biomass of the crop was separated into economic yield (grain/fodder) and by-product (straw). Energy output from the economic product (grain/fodder) and by-product (straw) was calculated by multiplying the amount of production and its corresponding energy equivalent. The total energy was calculated from the total material input energy with the required operational energy.

Energy input was calculated as follows

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

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

$$\text{EO} = \left\{\sum (P_{\text{mc}} * \varepsilon_{\text{om}})\right\} / A,$$

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

The energy input–output relationship was determined by calculating energy use efficiency, energy productivity and specific energy as follows

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

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

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

Economics

Total expenditure incurred was calculated by taking into account the prevailing market price of the inputs. Minimum support price was used for grain and local market price was used for green fodder and by-products (straw) of crops for calculating gross returns. Profitability of the system was calculated by dividing the net return (Rs ha^{-1}) in a sequence by 365 days. The relative economic efficiency (REE) of the system was calculated and expressed as percentage.

$$\text{REE} = (B - A)/A \times 100,$$

where A is the net return (Rs ha^{-1}) of the existing system and B is the net return (Rs ha^{-1}) of the diversified cropping system.

The data were subjected to statistical analysis using the analysis of variance and the significance of different sources of variations was tested by error mean square of Fisher Snedecor's '*F*' test at probability level 0.05, as suggested by Cochran and Cox[9].

Results

Productivity analysis

During *kharif*, rice grain yield was non-significant between treatments (Table 2). Performance of crops in terms of REY-yield was significant between treatments during *rabi*. Maize crop was significantly superior with 7677 kg REY/ha followed by grain sorghum (6385 kg REY/ha) and black gram (6336 kg REY/ha), indicating the possibility of replacing *rabi* rice with maize. Lowest REY was observed in fodder cowpea (1987 kg REY/ha), mustard (4505 kg REY/ha) and rice (4630 kg REY/ha). Cropping sequence green manure–rice–maize and green manure–rice–fodder sorghum produced 15,848 and 15,292 kg REY/ha respectively, which was significantly greater than other cropping systems with production of more than 2537 and 1981 kg than the prevailing rice–rice cropping system. Variations in the yield of crops may be due to the biological and environmental complexities and interactions in the cropping systems[10]. Rice after rice cropping sequence is an exhaustive system[11]. PE of different cropping systems (Table 3) indicated that green manure–rice–maize was significantly more efficient (58.26 kg/ha/day) closely followed by green manure–rice–sorghum (54.32 kg/ha/day) and green manure–rice–black gram (54.04 kg/ha/day). Lowest PE was with fodder-based cropping systems green manure–rice–fodder cowpea (39.16 kg/ha/day) and green manure–rice–fodder sorghum (42.09 kg/ha/day). Analysis of all the cropping systems for RPE revealed that except for green manure–rice–fodder cowpea, all other cropping systems with positive values were better compared to the existing rice–rice system and that the green manure–rice–maize cropping system with RPE of 20.06% could replace the existing rice–rice system. Highest LUE was recorded with cropping system green manure–rice–fodder sorghum (95.89%) followed by green manure–rice–maize (84.93%), proving their efficiency for occupying the land for maximum duration.

Economic analysis

Among cropping systems, green manure–rice–maize, green manure–rice–black gram and green manure–rice–fodder sorghum were at par with each other for system net returns of Rs 202,341/ha, Rs 199,916/ha and Rs 189,623/ha respectively (Table 4). Higher system productivity recorded with these cropping systems has contributed to higher returns. Lowest net returns were recorded with green manure–rice–fodder cowpea (Rs 124,981/ha) and green manure–rice–rice (Rs 148,937/ha) due lower productivity recorded with these systems. In terms of returns per rupee

Table 2. Grain and straw yield of different rice-based cropping systems during 2018–19

Treatment	Grain yield (kg/ha)		REY (kg/ha)	Total grain REY (kg/ha)	Straw yield (kg/ha)		Straw REY (kg/ha)		Total straw REY (kg/ha)
	Kharif	*Rabi*	*Rabi*		*Kharif*	*Rabi*	*Kharif*	*Rabi*	
T1-GM–rice–rice	8681	8692	4630	13,311	9722	9561	1111	1093	2204
T2-GM–rice–mustard	8758	1971	4505	13,263	9809	4336	1121	496	1617
T3-GM–rice–chickpea	8381	2149	5219	13,600	9387	2472	1073	282	1355
T4-GM–rice–green gram	8585	1186	4726	13,311	9615	1304	1099	149	1248
T5-GM–rice–sorghum	8552	4598	6385	14,937	9749	6438	1114	736	1850
T6-GM–rice–maize	8784	7903	7677	15,848	9315	10431	1065	1192	2257
T7-GM–rice–black gram	8956	1980	6336	15,292	10,210	2218	1167	253	1420
T8-GM–rice–cowpea (fodder)	8371	17,383	1987	10,770	10013	0	1144	0	1144
T9-GM–rice–sorghum (fodder)	8674	43,750	6059	14,733	9888	0	1130	0	1130
SEm ±	133.61	788.62	198.57	259.61	157.06	142.46	18	49	24.86
CD (*P* = 0.05)	NS	2384.64	600.45	785.01	474.92	430.80	54	16	75.17

GM, Green manure; REY, Rice equivalent yield.

Table 3. Production efficiency (PE) and land-use efficiency (LUE) of different rice-based cropping systems during 2018–19

Treatment	Duration of crops (days)	PE (kg/ha/day)	Relative PE (%)	LUE (%)
T1-GM–rice–rice	285	46.70	–	78.08
T2-GM–rice–mustard	272	50.16	2.50	74.52
T3-GM–rice–chickpea	310	43.87	2.18	84.93
T4-GM–rice–green gram	270	49.79	1.00	73.97
T5-GM–rice–sorghum	275	54.32	12.22	75.34
T6-GM–rice–maize	310	58.26	20.06	84.93
T7-GM–rice–black gram	283	54.04	14.89	77.53
T8-GM–rice–cowpea (fodder)	275	39.16	–19.08	75.34
T9-GM–rice–sorghum (fodder)	350	42.09	10.68	95.89
SEm ±		0.886		–
CD (*P* = 0.05)		2.678		–

Table 4. Economics of different rice-based cropping systems during 2018–19

Treatment	System cost of cultivation (Rs)	Total net returns (Rs/ha)	B : C ratio	System profitability (Rs/ha/day)	Relative economic efficiency (%)
T1-GM–rice–rice	84,000	148,937	1.77	408.00	–
T2-GM–rice–mustard	72,500	159,604	2.20	437.67	7.16
T3-GM–rice–chickpea	68,200	169,807	2.49	465.35	14.01
T4-GM–rice–green gram	66,500	166,444	2.50	456.00	11.75
T5-GM–rice–sorghum	74,200	187,194	2.52	512.86	25.69
T6-GM–rice–maize	75,000	202,341	2.78	554.54	35.86
T7-GM–rice–black gram	67,700	199,916	2.95	547.68	34.23
T8-GM–rice–cowpea (fodder)	63,500	124,981	1.97	342.45	–16.08
T9-GM–rice–sorghum (fodder)	68,200	189,623	2.70	519.28	27.32
SEm ±	–	4,541.84	0.064	12.376	
CD (*P* = 0.05)	–	13,733.67	0.195	37.423	

invested, green manure–rice–black gram (2.95) and green manure–rice–maize (2.78), were more economical and on par with each other, closely followed by green manure–rice–fodder sorghum (2.70) due to more market price coupled with higher productivity and lower cost of cultivation for black gram and higher productivity for maize and fodder sorghum. Cropping systems green manure–rice–fodder cowpea (1.97) and green manure–rice–rice (1.77) were observed to be less economical. Economic analysis of cropping systems clearly indicated that green manure–rice–maize, green manure–rice–black gram and green manure–rice–fodder sorghum were significantly superior over other cropping systems with system profitability of Rs 554.54/ha/day, Rs 547.68/ha/day and Rs 519.68/ha/day and higher relative economic efficiency of 35.86%, 34.23% and 27.32% respectively.

Energy analysis

Energy input and output relationships for growing crops in the studied cropping systems have been analysed and

Table 5. Energetics (energy input and energy output) of different rice-based cropping systems during 2018–19

Cropping system	Input energy (MJ ha^{-1})			Output energy (MJ ha^{-1}) Grain/fodder			Output energy (MJ ha^{-1}) By-product			Total output energy (MJ ha^{-1})
	Kharif	*Rabi*	Total	*Kharif*	*Rabi*	Total	*Kharif*	*Rabi*	Total	
T1-GM–rice–rice	35,002.75	31,105.67	66,108.42	127,605.8	127,772.4	255,378.2	121,529.3	119,515	241,044.3	496,423
T2-GM–rice–mustard	35,002.75	20,129.86	55,132.61	128,747.5	49,270.83	178,018.3	122,616.7	54,197.92	176,814.6	354,833
T3-GM–rice–chickpea	35,002.75	11,803.19	46,805.94	123,200.7	31,592.75	154,793.5	117,334	30,894.27	148,228.3	303,022
T4-GM–rice–green gram	35,002.75	7,645.52	42,648.27	126,194.6	17,431.75	143,626.4	120,185.3	16,305.21	136,490.5	280,117
T5-GM–rice–sorghum	35,002.75	25,188.92	60,191.67	125,709.5	67,595.5	193,305	121,861.3	80,470.83	202,332.1	395,637
T6-GM–rice–maize	35,002.75	24,843.68	59,846.43	129,119.9	116,166.8	245,286.7	116,441.5	13,0391.3	246,832.8	492,119
T7-GM–rice–black gram	35,002.75	7,848.84	42,851.59	131,658.1	29,106	160,764.1	127,627.8	27,720	155,347.8	316,112
T8-GM–rice–cowpea (fodder)	35,002.75	6,982.51	41,985.26	120,118.6	312,900	433,018.6	125,167.3	0	125,167.3	558,186
T9-GM–rice–sorghum (fodder)	35,002.75	20,123.76	55,126.51	127,502.9	787,500	915,002.9	123,599.8	0	123,599.8	1,038,603

Table 6. Energy use efficiency, energy productivity and specific energy of different rice-based cropping systems during 2018–19

Cropping system	Energy efficiency (%)	Energy productivity (kg/MJ)			Specific energy (MJ/kg)		
		Kharif	*Rabi*	Total	*Kharif*	*Rabi*	Total
T1-GM–rice–rice	7.51	0.28	0.18	0.46	4.03	3.58	7.61
T2-GM–rice–mustard	6.44	0.28	0.25	0.53	4.00	10.21	14.21
T3-GM–rice–chickpea	6.47	0.27	0.47	0.74	4.18	5.49	9.67
T4-GM–rice–green gram	6.57	0.28	0.64	0.91	4.08	6.45	10.52
T5-GM–rice–sorghum	6.57	0.28	0.28	0.56	4.09	5.48	9.57
T6-GM–rice–maize	8.22	0.28	0.36	0.64	3.98	3.14	7.13
T7-GM–rice–black gram	7.38	0.29	0.84	1.13	3.91	3.96	7.87
T8-GM–rice–cowpea (fodder)	13.29	0.27	0.28	0.55	4.28	0.40	4.69
T9-GM–rice–sorghum (fodder)	18.84	0.28	0.30	0.58	4.04	0.46	4.50

are presented here (Tables 5 and 6). The highest input energy (31,105.67 MJ ha^{-1}) was required for growing rice crop in sequence and the lowest energy was required for growing fodder cowpea (6982.51 MJ ha^{-1}), and green gram (7645.52 MJ ha^{-1}) and black gram (7848.84 MJ ha^{-1}) in sequence. This was mainly due to variable amount of inputs required for growing the crops. Hence the highest input energy was required for cereal-based cropping systems green manure–rice–rice (66,108.42 MJ ha^{-1}), green manure–rice–sorghum (60,191.67 MJ ha^{-1}), green manure–rice–maize (59,846.43 MJ ha^{-1}), while the lowest was for pulse-based cropping systems green manure–rice–fodder cowpea (41,985.26 MJ ha^{-1}), green manure–rice–green gram (42,648.27 MJ ha^{-1}), green manure–rice–black gram (42,859.89 MJ ha^{-1}) and green manure–rice–chickpea (46,805.94 MJ ha^{-1}).

Maximum output energy was realized with fodder-based cropping systems green manure–rice–fodder sorghum (1,038,603 MJ ha^{-1}) and green manure–rice–fodder cowpea (558,186 MJ ha^{-1}) and hence higher energy efficiency of 18.84% and 13.29% respectively, because of higher energy equivalents of the produce. This indicates that more energy would be incurred for the yield (both grain and straw).

Energy productivity was higher with green manure–rice–black gram (1.13 kg/MJ) and green manure–rice–green gram (0.91 kg/MJ) cropping systems, which may be attributed to inclusion of legumes which require less inputs. During *rabi*, lower specific energy values were recorded with fodder cowpea (0.40 MJ/kg) and fodder sorghum (0.46 MJ/kg), followed by maize (3.14) rice (3.58) and black gram (3.96). Hence the total specific energy of the cropping system which includes these crops was low compared to other crops. This indicates that the amount of energy utilized to produce unit output was lower with these cropping systems. Walia *et al.*[12] reported, that groundnut–toria+ gobhi sarson and maize–potato–onion cropping were more energy efficient than rice–wheat cropping system.

Conclusion

From the present study it can be concluded that maize, black gram and fodder sorghum are the most suitable crops in *rabi* after harvest of *kharif* rice. The performance of these crops was superior with higher productivity, profitability and efficient energy utilization. Growing manure crops during summer sustained soil fertility of the system. The quick decomposing nature of green manure crop might have contributed towards enhancing soil nutrient availability during both *kharif* and *rabi* crops. Therefore green manure–rice–maize and green manure–rice–black gram are more suitable cropping systems than the existing green manure–rice–rice systems for vertisols of Telangana. Farmers practising dairy with crops can follow green manure–rice–sorgum (fodder) cropping sequence for assured green fodder production for the cattle during post-rainy season.

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