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Production potential and energy-use efficiency of rice (*Oryza sativa*)-based cropping systems

P. JAYAPAUL, S. PURUSHOTHAMAN AND V. VEERABADRAN

Agricultural College and Research Institute, Tamil Nadu Agricultural University Madurai 625 104

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ABSTRACT

A field experiment was conducted during 1986–88 at Madurai with 5 different rice (*Oryza sativa* L.)-based cropping systems, 2 fertilizer levels and 2 irrigation regimes. The production potential in terms of rice-yield equivalent was more in groundnut (*Arachis hypogaea* L.) + blackgram (*Phaseolus mungo* L.) – rice – sesame (*Sesamum indicum* L.) sequence. Irrigating the rice crop to 5 cm depth on the day of disappearance of ponded water and irrigating the rainy-season and summer crops at 0.75 and 0.60 irrigation water depth : cumulative pan evaporation (IW : CPE) ratios respectively gave highest rice-grain yield equivalence. Recommended level of irrigation and fertilizer NPK based on soil test enabled higher utilization of solar energy.

In search for methods of attaining sustainable higher agricultural production by keeping the photosynthetic factory of crop plants operative at higher efficiency, various cropping systems have been studied, where total production from unit area of land can be increased.

Intensive cropping is one mechanism by which maximum harvest of solar energy could be achieved. Nair (1973) reported the photosynthetic efficiency 1.58–2.02% of photosynthetically active radiation in a rice (*Oryza sativa* L.)-based cropping system. Hence this experiment was conducted.

MATERIALS AND METHODS

The field experiment was conducted during 1986–88 at Madurai with 5 cropping systems, 2 fertilizer levels and 2 irrigation regimes in split-plot design with 3 replications. The main plot comprised 5 cropping systems, viz. C_1, 'CO 37' rice–'IR 20' rice–fallow; C_2, rice – rice – 'KM 2' greengram (*Phaseolus radiatus* L.); C_3, 'CO 24' sorghum [*Sorghum bicolor* (L.) Moench] + 'CO 2' vegetable cowpea [*Vigna unguiculata* (L.) Walp.] – rice – 'CO 1' soybean [*Glycine max* (L.) Merr.]; C_4, 'COH 1' maize (*Zea mays* L.) + soybean – rice – vegetable cowpea; and C_5, 'CO 1' groundnut (*Arachis hypogaea* L.) + 'CO 4' blackgram (*P. mungo* L.) – rice –'CO 1' sesame (*Sesamum indicum* L.). The subplot comprised 2 fertilizer levels – F_1, N, P and K as per soil-test values; F_2, F_1 for all crops except for rice to which P and K alone skipped – and 2 irrigation regimes. The irrigation regimes for rice were: I_1, irrigation of 5 cm depth on the day of disappearance of ponded water (recommended); and I_2, maintaining submergence to 5 cm depth at reproductive stage (critical stage). In other stages, the irrigation was

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Table 1. Water use (cm) by different cropping systems

Cropping system and irrigation level	1986–87			1987–88			Mean water use by croping system
	Water applied	Effective rainfall	Total	Water applied	Effective rainfall	Total	
$C_1 I_1$	180.0	32.15	212.15	170.0	47.05	217.05	225.58 (C_1)
$C_1 I_2$	213.5	32.15	245.65	180.4	47.05	227.45	
$C_2 I_1$	210.0	32.75	242.75	194.0	48.25	242.25	264.03 (C_2)
$C_2 I_2$	225.5	32.75	258.25	192.6	48.25	240.85	
$C_3 I_1$	163.0	38.19	201.19	129.0	62.02	191.02	183.28 (C_3)
$C_3 I_2$	129.5	38.19	167.69	111.2	62.02	173.22	
$C_4 I_1$	157.0	38.89	195.89	135.0	58.32	193.32	184.78 (C_4)
$C_4 I_2$	135.5	38.89	174.39	117.2	58.32	175.52	
$C_5 I_1$	169.0	37.09	206.09	141.0	64.02	205.02	188.23 (C_5)
$C_5 I_2$	129.5	37.09	166.59	111.2	64.02	175.22	

Details of treatments are given under Materials and Methods

given as in I_1. Depth of irrigation was 6 cm for sorghum, maize and groundnut with 2 irrigation regimes, viz. I_1, irrigation at 0.75 IW : CPE ratio (recommended); and I_2, irrigation at critical stages. The irrigation regimes for greengram, soybean, vegetable cowpea and sesame were: I_1, irrigation at 0.60 IW : CPE ratio (recommended); and I_2, irrigation at critical stages.

Water use by different cropping systems is given in Table 1. Production potential in terms of rice-yield equivalent was worked out by converting the economic yield of different crops in the cropping systems in terms of rice-grain yield on the basis of marketable price ratio.

RESULTS AND DISCUSSION

Groundnut + blackgram – rice – sesame cropping system recorded higher rice-yield equivalent of 18.04 and 18.58 tonnes/ha during first and second year respectively, followed by maize + soybean – rice – vegetable cowpea. The least rice-yield equivalent was 9.71 and 9.78 tonnes/ha in first and second year respectively, in rice–rice–fallow system (Table 2).

Cropping sequences of rice–rice– greengram and sorghum + vegetable cowpea–rice–soybean were comparable during 1986–87 (Table 3).

Recommended level of irrigation recorded higher rice-yield equivalent, which might be due to higher availability of plant nutrients as a result of higher residual effect of applied nutrients and biologically fixed N. The different fertilizer levels did not exert any differential influence. The interaction between cropping system and irrigation levels was significant. Recommended level of irrigation in cropping of sorghum + vegetable cowpea – rice – soybean, maize + soybean – rice – vegetable cowpea and groundnut + blackgram – rice – sesame was responsible for the higher rice-yield equivalent. At both the levels of irrigation, groundnut + blackgram – rice – sesame cropping system gave higher rice-yield

Table 2. Rice-yield equivalent (tonnes/ha) as affected by cropping system, fertilizer and irrigation

Cropping system	I_1						I_2						Mean					
	1986–87			1987–88			1986–87			1987–88			1986–87			1987–88		
	F_1	F_2	Mean	F_1	F_2	Mean	F_1	F_2	Mean	F_1	F_2	Mean	F_1	F_2	Mean	F_1	F_2	Mean
C_1	9.59	9.11	9.35	9.54	9.30	9.42	10.26	9.88	10.07	10.32	9.98	10.15	9.93	9.50	9.71	9.93	9.64	9.78
C_2	13.88	13.39	13.64	13.93	13.60	13.76	13.41	12.89	13.15	13.45	12.90	13.17	13.65	13.14	13.39	13.69	13.25	13.47
C_3	13.70	14.27	13.99	14.91	15.01	14.96	12.44	12.16	12.30	12.92	12.76	12.84	13.07	13.22	13.14	13.91	13.88	13.90
C_4	14.73	14.55	14.64	15.20	16.11	15.66	13.27	13.04	13.15	13.44	13.29	13.36	14.00	13.80	13.90	14.32	14.70	14.51
C_5	19.25	18.51	18.88	19.32	19.41	19.37	17.04	17.35	17.19	17.85	17.73	18.79	17.15	18.93	18.04	18.59	18.57	18.58
Mean	14.23	13.97	14.10	14.58	14.69	14.63	13.28	13.06	13.17	13.60	13.33	13.46	13.76	13.51	13.64	14.09	14.01	14.05

CD (P = 0.05)

	1986–87	1987–88
C	0.37	0.44
I	0.60	0.39
F	NS	NS
C at I	1.06	0.78
I at C	0.84	0.71

Details of treatments are under Materials and Methods

Table 3. Yield of individual component crops (kg/ha) in different rice-based cropping systems

Cropping system	1986–87	1987–88
C_1	4,893	4,878
	4,919	5,119
C_2	4,819	4,987
	4,936	5,216
	1,528	1,820
C_3	4,528	4,707
	2.093	2,138
	5,076	5,373
	2,523	2,893
C_4	3,806	3,955
	818	336
	5,270	5,573
	7,191	7,357
C_5	3,507	3,728
	599	605
	5,639	5,881
	683	729

Details of cropping systems are given under Materials and Methods

Table 4. Energetics in different rice-based cropping systems

Treatment	Total energy output (10^6 K cal/ha)		Solar-energy utilization (%)	
	1986–87	1987–88	1986–87	1987–88
C_1	35.83	26.89	1.028	1.084
C_2	49.12	49.17	1.014	1.016
C_3	48.69	52.26	1.378	1.399
C_4	51.28	51.80	1.198	1.283
C_5	66.65	70.58	0.864	0.927
CD	1.42	4.94	0.058	0.053
F_1	50.68	51.73	1.112	1.152
F_2	49.87	52.55	1.081	1.131
CD	NS	NS	0.009	0.011
I_1	51.91	54.15	1.145	1.200
I_2	48.64	50.13	1.048	1.083
CD	NS	1.72	0.009	0.011

Details of treatments are given under Materials and Methods

equivalent because of its higher yield and higher economic values recorded in our experiment.

Total energy output in cropping system

In both the years, highest total energy was recorded by cropping of groundnut + blackgram – rice – sesame and the least by the cropping of rice – rice – fallow (Table 4). Higher total energy in cropping system of groundnut + blackgram – rice – sesame was due to the higher market price of the produce obtained in this system, as it was worked out on the basis of rice-yield equivalent. Dazhong (1988) reported the consumption of total energy for a rice-based cropping system 2.76×10^3 K cal/ha. Higher total energy output in recommended level of irrigation during 1987–88 might be attributed due to the production of economic yield as a result of higher water use by irrigating the dry crops. During 1986–87 higher total energy output could be obtained under the recommended level of irrigation in of rice – rice – greengram, sorghum + vegetable cowpea, and groundnut – blackgram – rice – sesame cropping systems. At both the irrigation levels, the cropping system of groundnut + blackgram – rice – sesame produced higher total energy in the present investigation.

Solar-energy utilization

Highest solar energy fixation by cropping system of sorghum + vegetable cowpea – rice – soybean was possible, owing to inclusion of photosynthetically efficient C 4 crop like sorghum. This crop is a very efficient convertor of solar energy into chemical energy. This may also be ascribed to the inclusion of 2 pulse crops in the system, viz. vegetable cowpea in the rainy season as an

Table 5. Labour and energy requirement of cropping system (mean data of 2 years)

Croping system	Labour involvement		Labour generation or labour requirement (Man-days)	Energy requirement (HP hr)		
	Men (A type)	Women (B type)		Energy through human labour	Energy through bullock	Total energy input
C	85	234	241	192.8	360	552.8
C_2	95	306	298	238.4	360	598.4
C_3	98	380	351	280.8	292	572.8
C_4	108	360	348	278.4	332	610.4
C_5	136	398	401	320.8	476	796.8

Details of cropping systems are given under Materials and Methods

intercrop and soybean in summer season. It thus indicated that not only a protracted field duration but also an accelerated ground coverage is required for better harvest of solar radiation. The greater solar radiation during dry season provides more photosynthetic energy and allows larger N response and yields (De Datta and Zorte, 1970). Cropping system of sorghum + vegetable cowpea – rice – soybean system was followed by that of maize + soybean – rice – vegetable cowpea. Though maize as C 4 plant is efficient in utilizing solar energy, the higher dry matter obtained in cropping system of sorghum + vegetable cowpea – rice – soybean, might be the outcome of higher solar-energy utilization. Higher moisture availability throughout the crop period in recommended level of irrigation for irrigated dry crops and application of fertilizer as per soil-test recommendations facilitated higher canopy coverage and might be the reason for higher solar-energy fixation.

Labour and energy requirement

Labour utilization and energy requirement were higher in groundnut + blackgram– rice – sesame cropping system (Table 5). Groundnut in groundnut + blackgram – rice – sesamum cropping system utilized more labour for cultivation operations. The groundnut + blackgram – rice – sesame cropping system was followed by sorghum + vegetable cowpea – rice – soybean due to periodical pickings of vegetable cowpea in intercrop situation. Cropping of groundnut + vegetable cowpea – rice – sesame and sorghum + vegetable cowpea – rice– soybean systems would provide increased employment opportunity to the family labour of small farmers. Labour utilization was least in rice – rice – fallow system, as the post-planting operations required less labour in rice compared with the other crops.

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