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Effect of irrigation and nitrogen on yield, water use efficiency and nutrient balance in rice (*Oryza sativa*)- based cropping system

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ABSTRACT

An experiment was conducted at ICAR- RCER, Patna during 2001–02 to 2003–04 to study the effect of irrigation and nitrogen on yield, water-use efficiency and nutrient balance in rice (*Oryza sativa* L.)-based cropping system. Application of optimum level of irrigation and nitrogen fertilization increased the rice-equivalent yield by 8.40, 6.38 and 6.90 % over the sub-optimum level in both the cropping systems. Among cropping systems, total water-use efficiency was higher in rice-lentil (*Lens culinaris* Medikus)–greengram (*Vigna radiata* L. Wilczek), followed by rice–wheat (*Triticum aestivum* L. emend. Fiori & Paol.)–greengram. However, total water- use efficiency was more at optimum level of irrigation during first year, whereas during second and third year reverse was the case. There was a negative balance in nitrogen and phosphorus in both the cropping systems as well as levels of irrigation and nitrogen. Among the cropping system, maximum negative balance (–564 kg N/ha) was recorded in rice–wheat –greengram, followed by rice–lentil– greengram (–350 kg N/ha). Available phosphorus balance was also negative in both the cropping systems, levels of irrigation and nitrogen. Maximum available phosphorus balance was recorded in cereal dominated cropping system (–244 kg P/ha), followed by pulse dominated cropping system (–238 kg P/ha). There was a positive balance in potassium in both the cropping systems and levels of irrigation and nitrogen.

Key words: Rice-based cropping system, Rice-equivalent yield, Water-use efficiency, Cereal pulse

Rice (*Oryza sativa* L.) – wheat (*Triticum aestivum* L. emend. Fiori & Paol) system occupies an area of 10.5 million ha in the Indo-Gangetic plains of India (Singh *et al.* 2003). Efficient use of applied water and nutrient under adequate and inadequate supply condition are crucial for the crop production. Crops in a sequence may modify the water and nutrient use efficiencies of other crops due to differences in their genetic make up and physiological behaviour. Limited informations are available on nutrient uptake in cropping system as well as variable water and nitrogen. Sharma and Sharma (2002) reported that high yielding varieties grown in multiple crop sequences with recommended package of practices remove considerable amount of nutrients from soil and thus information is urgently needed to understand the mining of soil nutrients and to work out the nutrient balance over a period of time. Indian soils are generally deficient in available N and all cereal crops including rice and wheat show significant response to applied N. Patro *et al.* (2005) reported both rice and wheat are heavy feeders of nutrients and rapid spread of rice-wheat system in India caused an unfavourable effect on sustainability of soil productivity. Hence inclusion of legume crops in the system is must to improve soil physical condition and its productivity. Since the information on water-use efficiency and nutrient uptake in rice-based cropping system is not available under optimum and sub-optimum levels of supply conditions in central Bihar, a field experiment was undertaken with the objective to evaluate the effects of optimum and sub-optimum supply of water and nutrients on yield equivalent, water-use-efficiency and nutrient balance in rice-based cropping systems.

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MATERIAL AND METHODS

A field experiment was conducted in split plot design replicated thrice allocating cropping systems rice – wheat – greengram (C_1) and rice – lentil – greengram (C_2) in main plots and a combination of optimum and sub-optimum levels of irrigation and nutrients in sub-plots at Sabajpura Farm of ICAR- RCER, Patna during 2001–02, to 2003–04. There were 2 levels of irrigation for rice, i e irrigation at 3 days after disappearance of ponded water under optimum condition (I_1) and irrigation at 5 days after disappearance of ponded water under sub-optimum condition (I_2). In wheat there were 2 levels of irrigations: optimum level (I_1)–4 irrigations (CRI +tillering+ flowering +milking) and sub-optimum level (I_2) –3 irrigations (CRI+ flowering+ milking). In lentil and greengram optimum level: 1 irrigation and sub-optimum level: - no irrigation was applied in 2001–02 and 2003–04 but in 2002–03 greengram received 2 irrigations as optimum level and 1 irrigation as sub-optimum level. The 6 cm depth of water was applied in each irrigation as per treatment besides 93 cm, 120 cm and 117 cm rainfall during the first, second and third year of experimentation respectively. Recommended dose of nitrogen was considered as optimum level (N_1) and 50% of the recommended dose as sub-optimum level (N_2) in all the crops. An 100 kg N/ha was applied to rice and wheat as optimum dose and 50 kg N/ha as sub-optimum dose. An 30 kg N/ha was applied to lentil and greengram as optimnm dose and 15 kg N/ha as sub-optimum dose. Recommended dose of phosphorus (60 kg P_2O_5/ha in rice & wheat, 40 kg P_2O_5/ha in lentil and greengram) and potash (40 kg K_2O/ha in rice and wheat only) was applied in all the crops at both the levels of nitrogen. The water table was 2.0 – 6.1 m below ground level during the crop season. The texture of soil was silty clay loam, pH 7.4, electrical conductivity 0.026 dS/m, bulk density 1.44 Mg/m^3, particle density 2.71 Mg/m^3, organic carbon 0.65%, available nitrogen 290 kg N/ha, available phosphorus 32 kg P/ha and available potash 398 kg K/ha of initial soil sample (0–30 cm).

RESULTS AND DISCUSSION

Rice equivalent yield

Yield of wheat, lentil and greengram was converted into rice equivalent yield. There was significant variation among levels of nitrogen during all the 3 years of experimentation but among the cropping system and levels of irrigation, the significant variation was only during first year. Results of all the 3 years revealed that among cropping systems, maximum rice yield equivalent was recorded in rice-wheat-greengram (12.39, 12.50 and 11.16 t/ha), followed by rice–lentil–green gram (11.43, 11.75 and 10.44 t/ha) during 2001–02, 2002–03 and 2003–04 respectively. Among levels of irrigation, maximum rice yield equivalent was recorded at optimum level (12.89, 12.42 and 11.08 tonnes/ha), followed by sub - optimum level (11.01, 11.83 and 10.52 tonnes/ha) and the increase was to the tune of 16.44, 4.98 and 5.52% respectively over the sub-optimum level of irrigation. Similar trend was observed in case of levels of nitrogen. Optimum level of irrigation and nitrogen fertilizatiou produced higher rice equivalent yield than the sub-optimum level of irrigation and nitrogen in all the systems (Table 1). The results are in conformity with the results of Kumar and Prasad (2002). The interaction effect of different treatments did not show any significant variation on rice yield equivalent.

Table 1 Effect of optimum and sub-optimum levels of irrigation and nitrogen on yield of individual crops and rice equivalent yield (tonnes/ha).

Treatment	Rice	Winter crops	Green-gram	Total rice equivalent yield
	2001–02			
Cropping system				
Rice–wheat–greengram	6.51	2.32	0.54	12.39
Rice–lentil–greengram	6.29	0.51	0.62	11.43
CD (*P*=0.05)	NS	0.45	NS	0.32
Irrigation levels				
Optimum	6.56	1.36	0.64	12.82
Sub-optimum	6.24	1.47	0.52	11.01
CD (*P*=0.05)	NS	NS	0.14	0.84
Nitrogen levels				
Optimum	6.68	1.64	0.61	12.89
Sub-optimum	6.12	1.19	0.55	10.93
CD (*P*=0.05)	NS	0.33	0.09	0.84
	2002–03			
Cropping system				
Rice–wheat–greengram	6.87	2.68	0.43	12.50
Rice–lentil–greengram	8.18	0.59	0.42	11.75
CD (*P*=0.05)	NS	0.40	NS	NS
Irrigation levels				
Optimum	7.92	1.66	0.42	12.42
Sub-optimum	7.13	1.61	0.43	11.83
CD (*P*=0.05)	NS	NS	NS	NS
Nitrogen levels				
Optimum	7.74	1.76	0.42	12.65
Sub-optimum	7.31	1.51	0.43	11.60
CD (*P*=0.05)	NS	0.34	NS	0.41
	2003–04			
Cropping systems				
Rice–wheat–greengram	5.39	2.95	0.39	11.16
Rice–lentil–greengram	5.66	0.51	0.42	10.44
CD (*P*=0.05)	NS	0.32	NS	NS
Irrigation level				
Optimum	5.41	1.68	0.39	11.08
Sub-optimum	5.64	2.49	0.42	10.52
CD (*P*=0.05)	NS	NS	NS	NS
Nitrogen level				
Optimum	5.75	1.89	0.41	11.49
Sub-optimum	5.30	1.57	0.40	10.10
CD (*P*=0.05)	NS	NS	NS	0.70

Water-use efficiency

Among cropping systems, total water-use efficiency was higher in rice–lentil–greengram, followed by rice–wheat–greengram (Table 2) in all the 3 years of experimentation. Total water-use efficiency was more at optimum level of irrigation (89.03 kg/ha-cm) than sub-optimum level during first year of experimentation. Whereas during second and third year of experimentation, water-use efficiency was higher at sub-optimum level (77.32 and 67.43 kg/ha-cm) followed by optimum level (69.0 and 65.95 kg/ha-cm) of irrigation. Among levels of nitrogen, maximum water-use efficiency

Table 2 Total water applied and water-useefficiency of individual crop in rice based cropping system under optimum and sub-optimum levels of irrigation.

Treatment	Total water applied (cm)			Water-use efficiency (kg/ha/cm)			Mean WUE (kg/ha/cm)
	Rice	Winter crops	Greengram	Rice	Winter crops	Greengram	
			2001–02				
Cropping system							
Rice–wheat–greengram	102	21.70	23.30	36.82	106.91	23.18	83.28
Rice–lentil–greengram	102	3.70	23.30	61.67	137.84	26.61	88.60
Irrigation level							
Optimum	102	15.70	26.3	64.31	86.62	24.33	89.05
Sub-optimum	102	9.70	20.3	61.18	151.54	25.61	83.41
Nitrogen level							
Optimum	102	12.70	23.3	65.49	129.13	26.18	93.40
Sub-optimum	102	12.70	23.3	60.00	93.70	23.60	79.20
			2002–03				
Cropping system							
Rice–wheat–greengram	123.38	32.57	21.05	55.68	82.03	20.43	70.62
Rice-lentil-green gram	123.38	11.57	21.05	66.30	50.99	19.95	75.32
Irrigation level							
Optimum	129.38	26.57	24.05	61.21	62.48	17.47	69.00
Sub-optimum	117.38	17.57	18.05	64.01	91.65	23.82	77.32
Nitrogen level							
Optimum	123.38	22.07	21.05	62.73	79.75	19.95	75.97
Sub-optimum	123.38	22.07	21.05	59.24	68.42	20.42	69.67
			2002–03				
Cropping system							
Rice–wheat–greengram	128.87	24.79	17.34	41.82	118.99	22.91	65.26
Rice–lentil–greengram	128.87	6.79	17.34	43.92	75.11	24.22	68.23
Irrigation level							
Optimum	128.87	18.79	20.34	42.98	89.41	19.17	65.95
Sub-optimum	128.87	12.79	14.34	43.76	194.68	29.29	67.45
Nitrogen level							
Optimum	128.87	15.79	17.34	44.62	119.70	23.64	70.92
Sub-optimum	128.87	15.79	17.34	41.13	99.43	23.06	62.34

was recorded at optimum level of nitrogen application as compared to sub-optimum level. It is evident from the result that water was used more efficiently under rice–lentil–greengram than rice–wheat–greengram in all the 3 years of experimentation. The results are in conformity with the results of Tiwari *et al.* (2002). Parihar *et al.* (1999) also reported that inclusion of legumes in the system increase water-use efficiency. In general water-use efficiency was higher under optimum level of nitrogen than sub-optimum level of nitrogen, whereas reverse is the case with irrigation.

Nitrogen balance

There was a decrease in available N after harvest of the third crop in both the systems in all three years of experimentation. The reduction in the available soil N was due to adoption of intensive cropping system, which ultimately depleted more N from the soil (Verma *et al.* 2003). Maximum post-harvest soil-available N was recorded under rice–lentil–greengram (211 kg N/ha), followed by rice–wheat–greengram (190 kg N/ha). Variation in nutrient status was also observed due to optimum level of irrigation over sub-optimum level because increased moisture availability favoured bio-degradation of organic matter and mineralization of N in soil. Secondly in the plots having less soil moisture, there was more volatilization loss of N leading to further reduction in available soil nitrogen under less frequent irrigations. Nutrient uptake was positively influenced by levels of irrigation and nitrogen (Parihar and Tiwari 2003). Maximum N uptake was recorded in rice–wheat–greengram (571 kg N/ha) due to higher biological yield of wheat, which consequently increased total N uptake. Sharma and Sharma (2002) also reported higher N uptake under cereal dominated

Table 3 Balance sheet of available nitrogen in the soil as effected by cropping system, optimum and sub-optimum levels of irrigation and nitrogen (2001-04)

Treatment	Initial available soil nutrient (A)	Amount of nitrogen added in different crops (kg/ha) – (B)				Amount of N removed by the different crops (kg/ha) – (C)				Available N (kgha)		
		Rice	Winter crops	Green-gram	Total	Rice	Winter crops	Green-gram	Total	Nutrient in balance (expected value)- A+B-C= (D)	Final avaiable soil nutrients (actual values) (E)	Net loss (-)/ gain (+) E-D = (F)
Cropping system												
C_1	290	450	450	135	1035	363	174	34	571	754	190	–564
C_2	290	450	135	135	720	377	36	36	449	561	211	–350
Irrigation												
I_1	290	450	293	135	878	385	104	35	524	644	207	–437
I_2	290	450	292	135	877	355	106	35	496	671	194	–477
Nitrogen												
N_1	290	600	390	180	1170	406	120	38	564	896	198	–698
N_2	290	300	195	90	585	334	90	32	456	419	203	–216

cropping system.

Nitrogen balance indicated a negative balance of available N in the soil in both the cropping systems, being higher under rice–wheat–greengram (–564 kg/ha) followed by rice–lentil–greengram (–350 kg N/ha). This was evidently due to N fixation by legumes. Optimum and sub-optimum level of irrigation and nitrogen had also negative balance of available N in the soil. More gain in available soil N under optimum level (bigher frequency of irrigation) may be due to favourable soil moisture condition for bio-degradation of organic matter and mineralization of N than sub-optimum level. Moreover the organic matter added to the soil in the form of root mass and senescent leaves was more under optimum level of irrigation and nitrogen due to higher biological yield.

Phosphorus balance

Cereal-dominated cropping system indicated slightly higher available P in soil than the legume dominated ones (Table 4). The results confirm the findings of Kumar and Prasad (2002), which may be attributed to higher CO_2 pressure, addition of high organic matter to the soil system by cereals and high phosphate requirement of legumes. Maximum available P was recorded with sub-optimum levels of irrigation but in case of nitrogen the trend was in reverse order. Higher hydration resulted in solubilization of P, mineralization of organic matter, providing complete chelate for soluble Ca^{2+} and thereby reduced phosphate fixation. Higher CO_2 pressure might also be an added advantage. Soil availability of P_2O_5 depends upon plant, soil fixation and the rate of application. It seems that legume crop increased P availability. Such differential pattern of cereals and legumes with water and nitrogen ultimately resulted in an interaction effect between these two variables.

Maximum P uptake was recorded in rice–wheat – greengram followed by rice–lentil–greengram because of higher by product production. Sharma and Sharma (2002) also reported higher uptake of P by cereals as compared to pulses. Optimum level of irrigation and nitrogen had a positive effect in influencing the P_2O_5 uptake by crops. Phosphorus-balance sheet indicated its balance on negative side as compared to expected available P value in the soil. Among the cropping systems, maximum negative balance in available P was recorded under rice–wheat–greengram (–244 kg P/ha) followed by rice–lentil– greengram (–238 kg P/ha). Amoug different levels of irrigation, maximum negative balance was recorded at optimum level (–242 kg P/ha) as compared to sub-optimum level (–240 kg P/ha). whereas in case of different levels of nitrogen maximum negative balance was recorded at sub-optimum level (–265 kg P/ha) compared to optimnm level (–217 kg P/ha). This may be attributed to higher P fixation in the soil due to lesser number of irrigation.

Potassium balance

Maximum post-harvest soil-available K was recorded in the plots. having rice–lentil–greengram (307 kg K/ha), followed by rice–wheat–greengram (282 kg K/ha). This was partly due to the fact that cereal dominated cropping system removed more K from the soil. It is an established fact that cereals and grasses having low root exchange capacity utilize more soil potassium from the exchange complex than other crops. Maximum available K was recorded at optimum levels

Table 4 Balance sheet of available phosphorus in the soil as effected by cropping system, optimum and sub-optimum levels of irrigation and nitrogen (2001-04)

Treatments	Initial available soil nutrient (A)	Amount of P added in different crops (kg/ha) –B				Amount of P removed by the different crops (kg/ha) –C				Available P (kg/ha)		
		Rice	Winter crops	Green-gram	Total	Rice	Winter crops	Green-gram	Total	Nutrient in blance (expected value)- A+B-C= (D)	Final available soil nutrients (actual values) (E)	Net loss (-)/ gain (+) E-D= (F)
Cropping system												
C_1	32	157	157	105	419	107	64	12	183	268	24	-244
C_2	32	157	105	105	367	115	13	11	139	260	22	-238
Irrigation												
I_1	32	157	131	105	393	112	37	12	161	264	22	-242
I_2	32	157	131	105	393	110	40	11	161	264	24	-240
Nitrogen												
N_1	32	157	131	105	393	125	46	13	184	241	24	-217
N_2	32	157	131	105	393	97	31	10	138	287	22	-265

of irrigation and nitrogen and minimum at sub-optimum level. The total uptake of K_2O was more in cereal dominated cropping system as compared to pulse dominated cropping system (Table 5). The value was much higher than the applied K, indicating thereby that the uptake was higher due to release of fixed potassium at clay complex. Optimum level of irrigation and nitrogen helped in good plant stand, resulting in increased K_2O uptake.

Potassium balance sheet indicated that there was positive balance of available K in the soil under both the cropping systems. Maximum positive available K was recorded in rice–lentil–greengram (+122 kg K/ha) followed by rice–wheat–greengram (+20 kg K/ha). Among levels of irrigation and nitrogen, maximum available K was recorded in optimum

Table 5 Balance sheet of available potash in the soil as effected by cropping system, optimum and sub-optimum levels of irrigation and nitrogen (2001-04)

Treatment	Initial available soil nutrient (A)	Amount of potash added in available				Amount of K removed by the different crops (kg/ha) (B)				Available K (kg/ha) different crops (kg/ha)– (c)		
		Rice	Winter crops	Green-gram	Total	Rice	Winter crops	Green-gram	Total	Nutrient in blance (expected value)- A+B-C = (D)	Final available nutrients (actual value) (E)	Net loss (-)/ gain (+) E-D = (F)
Cropping system												
C_1	398	199	199		398	365	158	11	534	262	282	+20
C_2	398	199			199	383	17	12	412	185	307	+122
Irrigation												
I_1	398	199	100		299	392	89	12	493	204	342	+138
I_2	398	199	100		299	356	86	11	453	244	248	+4
Nitrogen												
N_1	398	199	100		299	417	104	13	534	163	299	+136
N_2	398	199	100		299	331	71	10	412	285	291	+6

level (+138 kg K/ha and +136 kg K/ha) as compared to sub-optimum level (+4 kg K/ha and +6 kg K/ha) respectively. This was because of the fact that the crop might have derived K from unavailable source through the exchange equilibrium. The positive K balance in the soil indicated that non-exchangeable form of K was released as a result of priming action of applied K, possibly to maintain the soil K equilibrium (Kumar and Prasad 2002).

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