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Production potential, soil health, water productivity and economics of rice (*Oryza sativa*)–based cropping systems under different nutrient sources

V.B. UPADHYAY*, VIKAS JAIN, S.K. VISHWAKARMA AND A.K. KUMHAR

Jawaharlal Nehru Krishi Vishwa Vidyhalaya, Jabalpur, Madhya Pradesh 482 004

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ABSTRACT

A field experiment was conducted during 2004–05 to 2008–09 at Jabalpur, Madhya Pradesh to study the effect of chemical fertilizers, organic manures (ONM) and integrated (50:50) nutrient management (INM) practices on the production potential, soil fertility, water productivity and economics of 4 rice (*Oryza sativa* L.)- based cropping systems involving *durum* wheat (*Triticum durum* Desb.)-sunhemp (*Crotolaria juncea* L.), potato (*Solanum tuberosum* L.)-okra (*Abelmoschus esculentus* L.), berseem (*Trifolium alexandrium* L.) and vegetable pea (*Pisum sativum* L.) and sorghum (*Sorghum bicolor* L. Moench). The productivity of crops in these cropping systems was higher when chemical fertilizer was used compared to ONM or INM in all the years of experimentation. In the initial years, ONM recorded a significant reduction in yield. Of the different rice based cropping systems, rice-potato-okra gave the highest rice equivalent (REs), while rice-wheat-GM gave the least REs. At the end of 5 cropping cycles, application of organic manures resulted in higher soil organic carbon, available N, P and K than the chemical fertilizers. Maximum beneficial micro-organisms were recorded under organic nutrient management (ONM) after completion of 5 crop cycles and the bulk density of soil was also lowered significantly in ONM. The B:C ratio was higher for chemical fertilizers in case of rice-*durum* wheat-green manuring (3.6) and rice-potato-okra (3.1) due to lesser cost of cultivation.

Key words: Consumptive use, Cropping system, Integrated nutrient management, Organic farming, Soil health

After green revolution substantial increase in the production of food grains was achieved through the use of improved crop varieties and higher levels of input specially fertilizers and plant protection chemicals. However, it has now been realized that this increase in production was achieved at the cost of soil health and may not be sustainable (Prasad *et al*., 2005a). On the other hand organic farming may be a better option for maintaining soil health (Ramesh *et al*., 2009) but has low productivity. A resource-poor, highly populated country like India with ever-growing demand for food, fuel, fibre and shelter can thus ill afford to go all the way for organic farming (Prasad, 2005b). An integrated nutrient management appears to be an appropriate approach (Prasad 2002). The present experiment was therefore conducted with an objective to study the effect of organic (ONM), inorganic and integrated nutrient management (INM) practices on the productivity, soil fertility, water productivity and economics in four rice-based cropping systems on sandy clay loam of Kymore Plateau and Satpura Hills zone of Madhya Pradesh.

***Corresponding author Email:** vbujbp1956@rediffmail.com

MATERIALS AND METHODS

A field experiment was conducted during 2004-05 to 2008-09 at the research farm of Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur on a sandy clay loam soil. The soil of the experimental site had a pH 7.4, EC 0.51 dS/m and organic carbon 0.7 %. The available soil nitrogen, phosphorus and potash were 264, 12.6 and 282 kg/ha, respectively. The bulk density of the soil was 1.35 Mg/m^3.

The factors studied included 3 nutrient management practices viz. organic manures (ONM), chemical fertilizers and integrated nutrient (50:50) (INM) and 4 cropping systems viz. rice-*durum* wheat-green manuring, rice-potato-okra, rice-berseem(fodder+seed) and rice-vegetable pea-sorghum(fodder) in strip plot design with four replications .The crop varieties grown were Pusa Basmati-1 in rice; HD 4672 in *durum* wheat, Kufri Sinduri in potato, JB 1 in berseem and Arkel in vegetable pea during winter season and Parbhani Kranti in Okra and MP Chari in sorghum during summer season. These crops were raised with recommended agronomic practices.

In organic manure treatment nutrients were applied through farm yard manure. The manure was applied on the nitrogen equivalent basis for each crop. The nutrient composition of FYM, was 0.5,0.25,0.5 % N,P_2O_5 and K_2O, respectively. For the weed management, mechanical measures were adopted and for insect pest management, neem oil (Azadiractin 0.03%) was applied as and when required under organic nutrient management. In chemical fertilizer treatment, nutrients were applied through chemical fertilizers viz. urea, single superphosphate and muriate of potash while plant protection was done through recommended pesticides, when required. The recommended dose of fertilizers for rice, wheat, potato, okra, vegetable pea, sorghum and berseem were 120:26.4:33.3, 120:26.4:33.3, 120:26.4:33.3, 120:26.4:33.3, 20:26.4, 16.6, 100:22:25 and 20:26.4: 16.6 kg N:P:K/ha, respectively. In integrated nutrient management (INM) treatment 50% of nitrogen was supplied through farmyard manure and the rest 50% through chemical fertilizers and the plant protection was done by adopting integrated pest management (IPM) practices. In rice-*durum* wheat-green cropping system, sumhemp (*Crotolaria* sp.) was grown before rice and 35 days old crop was incorporated in soil as green manure. Phosphorus solubilizing bacteria (PSB) was used for inoculation in all the crops.

Rice was transplanted in the first week of July and harvested in the second week of October. The winter crops (wheat, potato, vegetable pea and berseem) were sown in the second week of October and harvested in second week of February. The summer crops (okra and sorghum) were sown in third week of February and harvested in first/second week of June. The calculated dose of organic manures was applied 2-3 weeks prior to sowing of *kharif* crops, 1 week prior to rabi and summer crops. The rainfall received during the experimental period was 1063, 1829, 985.3, 1064.2 and 1434.1 mm in 2004-05, 2005-06,2006-07,2007-08 and 2008-09, respectively. During *kharif,* rice received 3 irrigations (each of 7.5 cm depth) each year. During *rabi* 5,8,12 and 3 irrigations were provided for wheat, potato, berseem (fodder+seed) and vegetable pea, respectively each year except during 2007-08 and 2008-09. During these 2 years 1 additional irrigation was provided to *rabi* crops due to long break in the rainfall from October to February. During summer, okra and sorghum received 6 and 4 irrigations, respectively each year except during 2006-07 when one additional irrigation was provided to both the crops. The total productivity of the system was expressed in terms of rice equivalent yield. The market price (₹/t) of rice, *durum* wheat, potato, okra, vegetable pea, sorghum (fodder) and berseem were ₹ 20000, 15000,10000,12000,2000 and 2000 under organic manures and ₹ 16000, 13000, 8000, 10000,10000,1500 and 15000 under chemical fertilizer and INM (50:50), respectively. The market price of berseem seed was ₹ 100000 and 80000/t under organic and chemical fertilizers and INM (50:50), respectively (JNKVV, 2009).

RESULTS AND DISCUSSION

Productivity of crops

During *kharif* season, the effective tillers/m^2 were significantly higher under fertilizer application than under integrated nutrient management (INM) and organic nutrient management (ONM) (Table 1). However, grains/panicle was significantly higher under fertilizer application only over ONM. The yield attributes of rice viz. effective tillers/m^2, panicle length and grains/panicle were not affected due to cropping systems. The yield of rice was significantly higher under fertilizer application treatment during initial 3 years but was not significant during last 2 years. This may be attributed to good long term impact of INM and ONM. Since the nutrient release from organic source is slow (Bhardwaj and Omanwar, 1994) the crops which require higher rates of nitrogen application like rice respond better to chemical fertilizer than organic manures. Organic nitrogen applied as manure is slowly available over a long period as compared to chemical fertilizers. On an average the difference between rice yields due to nutrient management was not significant. The mean grain yield of rice was not affected due to cropping systems also. However, the productivity of rice was slightly higher where green manuring was done and durum wheat followed it. This may be due to higher amount of nutrients released from incorporation of green manuring crop and higher amount of fertilizers applied to both rice and wheat (Table 1).

During *rabi* season, the mean productivity of *durum* wheat, potato and vegetable pea were higher in the fertilizer application treatment as compared to either INM or ONM, however, nutrient management practices did not differ significantly in *berseem*. On an average, organic manure treatment resulted in the reduction in yields of wheat, potato and vegetable pea yields by 16.0, 16.8 and 12.5%, respectively than the fertilizer application treatment (Table 2).

During summer the productivity of okra was minimum in 2005-06 due to adverse effect of heavy downpour at the flowering time. The mean yield of okra was higher by 13.0 % under fertilizer treatment over ONM (Table 3). The productivity of berseem was almost similar under fertilizers, INM and ONM. Sorghum (fodder) yield was minimum during 2008-09 due to late sowing. The mean productivity of sorghum (fodder) was 11.6 and 7.5% higher under fertilizer management treatment than under ONM and INM, respectively.

Table 1. Yield and yield attributes of rice as influenced by nutrient sources and cropping systems

Treatment	Yield attributes*			Grain yield (t/ha)					
	Effective tillers/m^2	Panicle length (cm)	Grains/ panicle	2004-05	2005-06	2006-07	2007-08	2008-09	Mean
Nutrient Sources									
Organic	272	14.10	72	3.78	3.51	3.31	3.28	3.49	3.47
Inorganic	295	14.82	76	4.76	4.10	3.79	3.46	3.66	3.95
Integrated (50:50)	288	14.75	74	4.45	3.85	3.55	3.38	3.59	3.77
SEm±	1.7	0.3	0.8	0.18	0.19	0.14	0.21	0.23	0.20
CD (P=0.05)	5.3	NS	2.6	0.58	0.54	0.45	NS	NS	NS
Cropping System									
Rice-*durum* wheat-GM	287	14.80	75	4.30	4.27	3.62	3.73	3.90	3.96
Rice-potato-okra	283	14.51	72	4.14	3.70	3.54	3.23	3.45	3.62
Rice-berseem (fodder + seed)	283	14.71	75	4.44	3.62	3.53	3.29	3.47	3.67
Rice-vegetable pea-sorghum (fodder)	285	14.61	74	4.33	3.68	3.51	3.25	3.46	3.65
SEm±	1.4	0.2	1.3	0.18	0.24	0.14	0.19	0.17	0.13
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

*Pooled data of 5 years

Table 2. Productivity of crops (t/ha) during *rabi* as influenced by nutrient management

Nutrient Sources	2004-05	2005-06	2006-07	2007-08	2008-09	Mean	2004-05	2005-06	2006-07	2007-08	2008-09	Mean
	Durum wheat						Potato					
Organic	2.68	2.52	2.24	2.51	3.13	2.62	18.10	15.30	14.70	15.40	13.90	15.48
Inorganic	3.10	2.90	3.31	2.85	3.40	3.12	21.80	17.10	17.90	20.70	15.60	18.62
Integrated (50:50)	2.94	2.72	3.13	2.85	3.63	3.05	21.60	17.50	17.30	20.50	15.40	18.46
SEm±	0.12	0.13	0.31	0.13	0.18		1.20	0.67	0.98	1.53	0.59	
CD (P=0.05)	0.33	0.36	0.89	NS	NS		3.40	2.00	3.00	4.81	NS	
	Berseem (fodder)						Vegetable pea					
Organic	58.20	46.70	52.70	46.60	39.70	48.78	5.40	6.60	6.30	5.80	5.80	5.98
Inorganic	58.70	47.90	50.60	46.70	36.20	48.02	7.50	7.70	6.40	5.70	6.90	6.84
Integrated (50:50)	58.40	47.20	54.50	46.70	36.00	48.56	6.30	6.80	5.90	5.80	6.90	6.34
SEm±	0.19	0.32	1.15	0.09	0.91		0.62	0.34	0.13	0.05	0.41	
CD (P=0.05)	NS	0.98	3.51	NS	2.81		1.81	0.92	0.42	NS	NS	

System productivity

While comparing the total productivity of cropping systems in terms of rice equivalents (REs), rice-wheat-green manuring was the least productive among all cropping systems and under all the 3 nutrient management practices. It was due to less price of cereals in the prevailing markets as compared to higher prices obtained for vegetables and fodder. Rice-potato-okra gave the highest RE than other cropping systems, which may be attributed to inclusion of 2 vegetables in the system. In this system 100% fertilizer management practices produced 9.7% and 2.5% higher REs than ONM and INM. Timely N availability could be a major factor in limiting crop yields (Pang and Letey,2000). The production efficiency (kg/ha/day) followed the same trend as that of REs (Table 7).

Consumptive use of water and water productivity

The total consumptive use of water under rice-potato-okra system was maximum and was very close to rice-berseem (fodder+seed) which is because of inclusion of 2 vegetables and long duration fodder i.e. berseem in the respective cropping systems. Minimum consumptive use of water was recorded under rice-vegetable pea-sorghum (fodder) cropping system. Under different nutrient management practices the consumptive use of water was almost same.

The water productivity under different nutrient management it was maximum with fertilizer management and was reduced under INM (50:50) and ONM (Table 4). Among the 4 crop sequences, rice-vegetable pea-sorghum (fodder) and rice-potato-okra had significantly higher water productivity than the rest 2 cropping systems due to high yield of potato and sorghum in the respective cropping systems.

Nutrient uptake

The total uptake of nutrients (N, P and K kg/ha) was found to be significantly higher in case of fertilizer application than ONM. The results are in conformity with the findings of Ramesh *et al.* (2009). Among the cropping systems the total uptake of nutrients for N was significantly highest in case of rice-berseem (fodder+seed) which was due to higher amount of biomass produced (Sharma and Sharma, 2002). The P and K uptake was significantly higher in case of rice-vegetable pea-sorghum (fodder) than other cropping systems due to higher concentration of P and K in sorghum and higher biomass production (Table 5).

Table 3. Productivity of crops (t/ha) during summer as influenced by nutrient management

Nutrient Sources	2004-05	2005-06	2006-07	2007-08	2008-09	Mean	2004-05	2005-06	2006-07	2007-08	2008-09	Mean
	Green manuring						Okra					
Organic	-	-	-	-	-	-	4.27	2.62	7.40	6.92	11.49	6.52
Inorganic	-	-	-	-	-	-	5.12	3.59	7.50	6.85	13.79	7.37
Integrated (50:50)	-	-	-	-	-	-	4.83	2.88	7.39	7.05	14.71	7.73
SEm±							0.24	0.29	0.04	0.08	1.01	
CD (P=0.05)							0.71	0.91	NS	NS	3.10	
	Berseem (seed)						Sorghum (fodder)					
Organic	0.13	0.25	0.19	0.20	0.17	0.18	31.00	23.60	18.50	24.10	11.50	21.74
Inorganic	0.16	0.27	0.20	0.21	0.18	0.21	34.40	25.90	22.40	25.50	13.10	24.26
Integrated (50:50)	0.15	0.26	0.21	0.20	0.17	0.19	31.20	23.80	21.30	25.10	11.40	22.56
SEm±	0.01	0.02	0.01	0.02	0.01		1.10	0.80	1.19	0.52	0.44	
CD (P=0.05)	NS	NS	NS	NS	NS		3.10	NS	3.61	NS	1.30	

Table 4. Consumptive use of water (cm/ha) and water productivity (kg/ha-cm) under different nutrient management and cropping systems (pooled data of 5 years)

Nutrient Sources	Cropping System				
	Rice-*durum* wheat-GM	Rice-potato-okra	Rice-berseem (fodder+seed)	Rice-vegetable pea-sorghum (fodder)	Mean
Organic	193.4(79.7*)	214.8(184.5)	214.4(77.9)	190.9(180.0)	203.3(130.5)
Inorganic	192.9(90.2)	214.9(206.5)	213.5(74.4)	191.3(214.5)	203.2(146.4)
Integrated (50:50)	192.3(95.0)	214.6(204.8)	213.9(72.1)	191.0(209.2)	202.9(145.3)
Mean	192.9(88.3)	214.8(198.6)	213.9(74.7)	191.1(201.2)	
	Nutrient Sources		Cropping System	Interaction	
SEm±	0.20(3.86)		3.42(11.60)	7.18(41.3)	
CD (P=0.05)	NS(12.1)		10.1(36.1)	NS (NS)	

*Values in parenthesis indicate water productivity

Table 5. Total uptake of nutrients and changes in physico-chemical properties of soil at the end of 5 crop cycles

Treatment	Total uptake of nutrients (kg/ha/annum) N	P	K	pH	EC (dS/m)	Bulk density (Mg/m^3)	OC (%)	Available nutrients (kg/ha) N	P	K
Nutrient Sources										
Organic	115.0	30.8	168.0	7.20	0.50	1.34	0.78	287.3	12.9	289.5
Inorganic	123.1	33.9	186.5	7.23	0.51	1.39	0.73	270.5	12.3	270.0
Integrated (50:50)	120.7	32.8	177.5	7.20	0.50	1.37	0.74	276.8	12.7	277.5
SEm±	1.89	0.85	3.38	0.02	0.02	0.01	0.01	3.49	0.17	3.97
CD (P=0.05)	5.6	2.5	10.3	NS	NS	0.04	0.04	10.1	0.51	11.6
Cropping System										
Rice-*durum* wheat-GM	173.2	30.6	179.1	7.23	0.50	1.35	0.77	279.3	12.6	283.0
Rice-potato-okra	252.6	32.6	169.5	7.13	0.51	1.37	0.72	273.3	12.5	285.3
Rice-berseem (fodder + seed)	490.9	48.2	245.8	7.17	0.49	1.36	0.74	277.3	12.4	261.7
Rice-vegetable pea-sorghum (fodder)	451.5	58.2	447.5	7.30	0.51	1.39	0.75	282.7	13.0	286.0
SEm±	14.21	3.18	24.56	0.07	0.04	0.06	0.02	2.79	0.17	2.51
CD (P=0.05)	41.6	9.5	76.3	NS	NS	NS	NS	8.3	0.49	7.6
Initial soil fertility				7.4	0.51	1.35	0.70	264	12.6	282

Table 6. Effect of different nutrient management with various cropping systems on changes in biological properties of soil at the end of 5 crop cycles

Nutrient Sources	Fun ($\times 10^4$g)	Bac ($\times 10^6$ g)	AZB ($\times 10^6$ g)	PSB ($\times 10^6$ g)	ACT ($\times 10^6$ g)	Fun ($\times 10^4$ g)	Bac ($\times 10^6$ g)	AZB ($\times 10^6$ g)	PSB ($\times 10^6$ g)	ACT ($\times 10^6$ g)
	Rice-*durum* wheat-GM					Rice-potato-okra				
Organic	48.1	56.9	32.0	20.6	16.6	45.2	55.6	31.7	19.0	14.7
Inorganic	38.0	35.6	25.7	13.0	8.0	38.2	35.6	20.4	11.7	7.4
Integrated (50:50)	43.8	45.2	24.3	15.8	11.5	42.3	45.2	24.8	15.0	11.3
SEm±	1.37	3.51	1.94	2.24	2.45	2.09	2.61	3.44	2.33	2.23
CD (P=0.05)	4.1	10.8	6.1	6.5	7.1	6.2	8.1	10.4	6.9	7.1
	Rice-berseem (fodder+seed)					Rice-vegetable pea-sorghum (fodder)				
Organic	46.0	55.8	31.8	19.6	14.1	46.6	58.1	33.0	19.8	14.6
Inorganic	38.0	35.0	20.5	12.0	7.2	38.1	32.6	25.3	12.6	8.0
Integrated (50:50)	43.0	45.3	26.1	15.5	11.2	44.0	45.6	25.5	15.8	11.4
SEm ±	1.07	3.67	1.97	1.52	1.04	0.97	4.17	2.67	1.45	1.19
CD (P=0.05)	3.2	10.8	6.1	4.8	3.1	2.9	13.1	7.9	4.3	3.5
Initial	33.7	35.7	17.5	9.7	5.9					

Table 7. Rice equivalents (t/ha), production efficiency (kg/ha/day) and economics of various cropping systems under different nutrient management*

Nutrient Sources	Rice equivalent (t/ha)	Production efficiency (kg/ha/ day)	Cost of cultivation ($\times 10^3$ ₹/ ha/yr)	Net returns ($\times 10^3$ ₹/ ha/yr)	B:C ratio	Rice equivalent (t/ha)	Production efficiency (kg/ha/ day)	Cost of cultivation ($\times 10^3$ ₹/ ha/yr)	Net returns ($\times 10^3$ ₹/ ha/yr)	B:C ratio
	Rice-*durum* wheat-GM					Rice-potato-okra				
Organic	6.1	19.2	46.2	110.5	3.4	10.3	29.6	70.3	142.2	3.0
Inorganic	6.7	21.1	39.0	99.8	3.6	11.4	32.5	59.2	126.4	3.1
Integrated (50:50)	6.9	21.8	42.0	99.2	3.4	11.1	31.7	67.5	113.7	2.7
SEm±	0.29	0.96				0.29	0.81			
CD (P=0.05)	NS	NS				1.0	2.5			
	Rice-berseem (fodder+seed)					Rice-vegetable pea-sorghum (fodder)				
Organic	8.2	28.5	47.1	146.5	4.1	6.9	20.3	47.4	96.1	3.0
Inorganic	7.9	27.2	47.4	102.1	3.2	7.8	23.0	47.5	81.1	2.7
Integrated (50:50)	7.6	26.4	47.1	95.9	3.0	7.7	22.8	47.5	80.1	2.7
SEm±	0.17	0.55				0.25	0.63			
CD (P=0.05)	0.45	1.75				0.78	2.1			

*Mean of 5 years

Soil health

Bulk density was found to be significantly lowest (1.34 Mg/m^3) in organic nutrition treatment as compared to fertilizer application (Table 5). The bulk density was also slightly lower as compared to initial soil values in case of ONM. Soil organic carbon (0.78%), available N (287.3 kg/ha), available P (12.9 kg/ha) and available K (289.5) was higher over initial soil status in ONM. Other soil chemical properties i.e. pH and EC remained unaffected due to nutrient management and cropping systems. Among the cropping systems rice-vegetable pea-sorghum (fodder) recorded the highest soil organic carbon (0.75%), available N,P and K (282.7, 13.0 and 286.0 kg/ha, respectively). This increase may be attributed to the effect of vegetable pea (legume crop) and addition of high amount of residues of sorghum (fodder).

Organic nutrient management under each cropping system had significantly higher microbial population (total fungi, bacteria, azotobacter, phosphorus solubilizing bacteria and actinomycetes) than the fertilizers treatment (Table 6).

Economics

Higher net returns were recorded in organic nutrition management due to premium prices for organic products in all cropping systems. The B:C ratio was higher for fertilizer treatment in case of rice-wheat- green manuring and rice-potato-okra due to lesser cost of cultivation. The fertilizer requirement for the constituent crops in both systems are higher, which led to use of higher quantity of organic manure that raised cost of cultivation for ONM. It was the reverse in the case of cropping systems including pulse crops (low fertilizer consumers) which resulted in higher B:C ratio in ONM (Table 7).

It can be concluded from the study that ONM may be followed in rice-based cropping systems, where the input costs are low and market prices for the produce are higher. Organic nutrient management improves soil fertility.

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