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Effect of varying level of diversification and intensification of rice-wheat cropping system on the production potential and nutrient balance of soil in Indo-Gangetic Plain of India

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ABSTRACT

Since few decades, continuous practice of Rice-Wheat Cropping System (RWCS) has been led to depletion of inherent soil fertility and thereby productivity, resulting in a serious threat to its sustainability in the Indo- Gangetic Plain Region (IGPR) of India. Unfortunately, farmers in the region rarely introduce legumes in the systems which have great significance to restore fertility and productivity of soil. Keeping these aforesaid facts in view, a long-term field experiment initiated during 2000-01 to assess the impact of rice based cropping sequences. The data of the experimental year 2002-03 and 2003-04 showed that addition of one more crop in rice-wheat cropping system either summer grain/ fodder legumes or Sesbania (green manure) resulted higher Economic Rice Yield Equivalent (EREY), protein yield, nutrient uptake vis a vis increased soil nutrient balance due to improvement in physico-chemical properties of soil. Among different cropping system under study, rice-potato-green gram gave highest EREY whereas highest protein recovery and nutrient (N, P and K) uptake were associated with rice-maize (cob) + veg. pea (1:1)-cowpea (fodder). Conclusively, Rice-potato-green gram and rice-maize (cob) + veg. pea (1:1)-cowpea (fodder) appeared promising alternatives to replace the rice-wheat cropping system in IGPR.

Key word: cropping system, rice equivalent yield, soil productivity, nutrient balance, diversification and intensification

INTRODUCTION

The introduction of short duration, photo-insensitive, dwarf and input responsive high yielding varieties of rice and wheat in the mid-1960s has led to adoption of rice-wheat cropping system (RWCS) in India and more particularly in the entire Indo-Gangatic Plain Region (IGPR). In recent years, the productivity of this sequences decreases drastically (Anon 1991) due to the degradation of soil fertility by the intensive cereal-cereal production systems and is considered a major cause of the decline yield in the region. A rice-wheat system yielding 7 t ha^{-1} of rice and 4 t ha^{-1} of wheat removes 315 kg nitrogen (N) ha^{-1}, 28 kg phosphorus (P) ha^{-1} and 333 kg potassium (K) ha^{-1}, and significant amount of micronutrients (Hegde and Dwivedi 1992). Therefore, for sake of food security, farmers are being compelled to apply higher rates of the fertilizers every years in incremental fashion (particularly N fertilizer) to maintain the same yield levels as it was attained previous year with less fertilizer use.

During the rice-wheat cropping cycle, soil under goes drastic change *i.e.* anaerobic to aerobic environment, leading to several chemical and electro-chemical transformations. Besides the contrasting need of each crop, continuous practice of rice-wheat cropping system for longer period with least system diversity and often with poor crop management practices, resulted in loss of soil fertility due to emergence of multiple nutrient deficiency (Singh and Singh 1995), deterioration of soil physical properties (Tripathi 1992) and decline in factor productivity and crop yields in high productivity areas (Yadav et al. 1998). Certainly, refinement of nutrient management strategies helps to maintain the crop productivity and soil fertility, but other rotational strategies could help especially in situation where greater fertilizer use may be uneconomic or environmentally unacceptable. In this manner, a nutrient cycling mechanism that is essential for the sustainability of the production system can be established. Inclusion of pulses, oilseeds and vegetables in the system is more beneficial than cereal after cereal (Raskar

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and Bhoi 2001). Introduction of a legume crop in RWCS may have advantages well in the improvement in physic-chemical properties of soil, beyond the N addition through biological nitrogen fixation (BNF) including nutrient recycling from deeper soil layers, minimizing soil compaction, increase in soil organic matter, breaking of weed and pest cycles and minimizing harmful allelopathic effects (Sanford and Hairston 1984, Wani et al. 1995). Soil organic carbon and available N, P and K increased markedly, when the wheat in rice-wheat cropping system was substituted with a legume (Hegde and Dwivedi 1992). Growing of legumes as green manure can provide the equivalent of 60 kg of urea N ha^{-1} to following rice with little or no residual effect on a succeeding wheat crop (Kolar and Grewal 1988). Mandal and Chatterji (1998) documented that N, P and K uptake by crops and soil fertility improved significantly due to inclusion of legume as green manure before transplanting of rice in the rice based cropping sequences. In addition, it is also reported that legumes are favorable for increasing the yield of succeeding rice crops (Quayyam and Maniruzzaman 1996). As much as 10% of the rotation effect on grain yield of a subsequent cereal may be due to N benefits from the legume crop in the rotation (Stevenson and Van Kessel 1996). Hargrove (1986) estimated that contribution of legume cover crop as source of N to subsequent non leguminous crops may be as high as 120 kg N ha^{-1}. In another long term experiment at Saskatchewan, Campbell et al. (1991) reported increasing soil organic matter content with increasing frequency of cropping and especially inclusion of legumes as green manure in the rotation. On the other hand, Soil N content under crop rotation is increased in two major ways: N input as atmospheric fixation during rotation of legume and secondly reducing leaching loss due to increasing soil organic matter (Arshad et al. 1998).

Most of the micro and macro level previous studies on cropping systems in the IGPR have focused mainly on specific aspects of rice-wheat cropping system. Studies providing an integrated assessment of more diversified intensive double and tripal cropping systems have remained relatively less studied but such studies are needed for understanding options for diversification and intensification of the rice-wheat system in IGPR. The present investigation was therefore undertaken to study the system production potential, soil nutrient balance as well as changes in physico-chemical properties of soil under varying levels of intensification and diversification in traditional rice-wheat cropping system.

MATERIAL AND METHODS

A long term field experiment entitled "Effect of diversification and intensification of rice-wheat cropping system on the productivity and nutrient balance of soil in Indo-Gangetic Plain" was initiated under All India Coordinated Research Project on Cropping Systems during 2000-2001 at Agricultural Research Farm, Banaras Hindu University, Varanasi, India but data of experimental year 2002-03 and 2003-04 only compiled for current research paper.

Varanasi is situated at 25^0 18' N latitude, 83^0 03' E longitude and at an elevation of 128.93 m. It falls under middle Gangetic plain zone of the IGPR. The climate is semi arid to sub humid with hot dry summer and cold winters. The soil was sandy loam and classified as Ustochrep. The top soil (0-15 cm layer) at the start of experiment was non saline (EC 0.34 dS m^{-1}) of neutral reaction (pH 7.3) and contained 0.34 % organic carbon, 192.0 kg ha^{-1} available N, 21.4 kg ha^{-1} available P and 224.0 kg ha^{-1} available K. The treatments consisting of ten crop sequences were arranged in four randomized blocks. The crop sequences were:

1. S_1: Rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.)
2. S_2: Rice-chickpea (*Cicer arietinum* L.)
3. S_3: Rice-wheat-green gram (*Vigna radiata* L.)
4. $S_{4:}$ Rice-wheat-*Sesbania* (*Sesbania aculeata* L.) for green manuring
5. S_5: Rice-mustard (*Brasica juncea*)-green gram
6. S_6: Rice-lentil (*Lens culinaris* L.)-cowpea fodder (*Vigna unguiculata* L.)
7. S_7: Rice-pea (*Pisum sativum* L.)
8. S_8: Rice-lentil+mustard (3:1)-cowpea fodder
9. S_9: Rice-maize (*Zea mays* L.) for green cob+vegetable pea (1:1)-cowpea fodder
10. S_{10}: Rice-potato (*Solanum tuberesum*)-green gram

The details of the varieties used and cultural operations adopted in different crop sequences are given in Table 1. The gross plot size was 7 x 6 m with one meter plot border. With a view to avoid the mixing of soil in different treatments, individual plots were thoroughly prepared by power tiller in each season. Before sowing of any legumes component, they were treated with appropriate strain of *Rhizobium spp*.as seed treatment. *Sesbania aculeata* as green manure and green gram after last picking were cut from the ground level and green biomass so obtained was weighed and incorporated *in situ.* The cowpea for green fodder was harvested from the ground level. The rest of the crop was harvested at maturity. However, harvesting of maize for green cob, vegetable pea and cowpea for green fodder was done at proper stage.

To study changes in soil fertility, initial soil samples were collected at beginning of the experiment (2000) with auger from 0-15 cm soil depth at 20 locations of the experimental area as per standard procedure. The samples were thoroughly mixed, dried and passed through 100 mesh sieve and kept in poly bags for chemical analysis of organic carbon (rapid titration method), pH (1: 2.5 soil : water), available N (alkaline permanganate method), available P (0.5N $NaHCO_3$ extractable) and available K (Flame photometric method). Soil samples were also analyzed treatment-wise at the completion of each cycle. The changes in soil organic carbon and available N, P and K in different crop sequences were worked out on the basis of initial soil nutrient status and nutrient status of soil at termination of the experiment (2003-04).

Representative samples of harvested grain/ seed/ cob/ tuber and straw/ stover/ fodder were also taken for chemical analysis. The plant samples were successively wash thoroughly with tap water, 0.05M HCl solution and deionized water, and dried at 70^0 C in a hot air oven. The dried samples were milled in a stainless steel Wiley mill and wet- digested in a 4:1 mixture of nitric and perchloric acid, and aqueous extracts prepared for the determination of total P Spectro-photometrically (using vandomolybdate yellow colour method), and of total

Table 1: Describing different systems with level, rate and desired state

Crop in rotation	Cultivar	Seed rate (kg ha^{-1})	Spacing (cm)	Date of sowing 2002-03	Date of harvesting 2002-03 2003-04	Rate of fertilizer application(kg ha^{-1})		
						N	P	K
2002-03								
Rice	NDR 97	30	20	15 July 02	14 Oct 02	120	60	60
Wheat	HUW 468	100	20	25 Nov 02	4 April 03	120	60	60
Chickpea	Avarodhi	80	30	14 Nov 02	28 March 03	18	46	20
Mustard	PRO 4001	5	45	14 Nov 02	16 March 03	90	45	45
Lentil	Pant 209	40	30	14 Nov 02	22 March 03	18	46	20
Pea(grain)	HUP 15	80	30	14 Nov 02	22 March 03	18	46	20
Veg. pea	Arkel	80	25	15 Nov 02	15/26 Feb 03	18	46	20
Maize(cob)	Decan 103	20	75	15 Nov 02	16 April 03	120	60	40
Potato	Kufari Badshah	2000	50	15 Nov 02	16 March 03	120	60	80
Green gram(S_3)	Jyoti	25	30	8 April 03	6 July 03*	18	46	0
Green gram (S_5)	Jyoti	25	30	26 March 03	21 June 03*	18	46	0
Green gram(S_{10})	Jyoti	25	30	26 March 03	21 June 03*	18	46	0
Sesbania(GM)	-	60	-	-	-	0	0	0
Cowpea (F) (S_6)	Local	40	30	2 April 03	28 June 03	18	46	0
Cowpea (F) (S_8)	Local	40	30	2 April 03	28 June 03	18	46	0
Cowpea (F) (S_9)	Local	40	30	18 April 03	28 June 03	18	46	0
2003-04								
Rice	NDR 97	30	20	25 July 03	13 Oct 03	120	60	60
Wheat	HUW 468	100	20	27 Nov 03	8 April 04	120	60	60
Chickpea	Avarodhi	80	30	13 Nov 03	2 April 04	18	46	20
Mustard	PRO 4001	5	45	13 Nov 03	18 March 04	90	45	45
Lentil	Pant 209	40	30	13 Nov 03	18 March 04	18	46	20
Pea(grain)	HUP 15	80	30	13 Nov 03	18 March 04	18	46	20
Veg. pea	Arkel	80	25	14 Nov 03	13/24 Feb 04	18	46	20
Maize(cob)	Decan 103	20	75	14 Nov 03	9 April 04	120	60	40
Potato	Kufari Badshah	2000	50	14 Nov 03	12 March 04	120	60	80
Green gram(S_3)	Jyoti	25	30	16 April 04	29 June 04*	18	46	0
Green gram (S_5)	Jyoti	25	30	30 March 03	15 June 04*	18	46	0
Green gram(S_{10})	Jyoti	25	30	23 March 03	11 June 04*	18	46	0
Sesbania(GM)	-	60	-	-	-	0	0	0
Cowpea (F) (S_6)	Local	40	30	5 April 04	30 June 04	18	46	0
Cowpea (F) (S_8)	Local	40	30	5 April 04	30 June 04	18	46	0
Cowpea (F) (S_9)	Local	40	30	17 April 04	30 June 04	18	46	0

*Green gram after last picking the biomass cut from the ground level and incorporated *in situ.*

K content (Flame photometrically). For the determination of N, the ground material was digested separately in a 4:1 mixture of H_2SO_4 and $HClO_4$ and analyzed by the micro Kjeldahl method (Piper 1966). Protein content in economic produces of different crops was estimated by multiplying 6.25 with nitrogen content in economic produces of respective crop.

The productivity of different crop sequences was compared by calculating their Economic Rice Equivalent Yield (EREY) using formula given by Ahlawat and Sharma (1993). Where,

$$EREY = \frac{\text{Yield of each crop (t ha}^{-1}\text{) x Economic value of respective crop (Rs. t}^{-1}\text{)}}{\text{Price of rice grain (Rs. t}^{-1}\text{)}}$$

For this the price of individual output were assumed to be stable during the experimental period. The economic values of the produce from different crops were taken as Rs. 6500.0 t^{-1} for rice, Rs. 10000.0 t^{-1} for wheat, Rs. 27000.0 t^{-1} for chickpea, Rs. 20000.0 t^{-1} for mustard, Rs. 22000.0 t^{-1} for lentil, Rs. 19000.0 t^{-1} for field pea, Rs. 4500.0 t^{-1} for maize (cob), Rs. 6000.0 t^{-1} for vegetable pea, Rs. 4000.0 t^{-1} for potato tuber, Rs. 32000.0 t^{-1} for green gram and Rs. 800.0 t^{-1} for cowpea fodder.

The data were analyzed statistically by analysis of variance (Cochran and Cox 1957) to ascertain statistical differences between cropping systems, and level of significance was calculated by two way ANOVA and expressed as $p < 0.05$.

RESULTS AND DISCUSSION

As evident from table 2, in the rainy season, crop sequences involving summer grain/ fodder legume or *Sesbania* for green manuring tended to be greater rice yield than rice grown in rice - wheat cropping system. However, the differences were significant only 2003-04. As the experiment was initiated in 2000 - 2001, it took four years to become legume effect significant in terms of rice yield. The crop sequences, *viz.* S_4, S_8, S_{10}, S_9 and S_3 though remained at par among themselves, produced significantly greater grain yield of rice than rice-wheat system. In winter season, potato out yielded other crops and the next best was maize (cob) + vegetable pea (1:1) as intercropping. This could be ascribed to their high production potential and harvesting of the economic produce fresh at high moisture contents. Among three sequences involving wheat as winter crop, the greater wheat yield was recorded in rice-wheat-*Sesbania* (5.68 and 9.58%) followed by rice-wheat-green gram (1.8 and 7.25%) over rice-wheat system during 2002-03 and 2003-04, respectively. This is due to improvement in soil physico-chemical properties (Table 5) in these treatments by inclusion of *Sesbania* as green manuring (S_4) and templing of green gram after last pecking. Sharma et al. (1995) also advocated the benefit of green manure before the rice in rice-wheat system for enhancing the wheat yield. Out of the two summer crops that are green gram and cowpea fodder grown in different crop sequences, green gram performed better when taken after potato (S_{10}) and mustard (S_5) than after wheat in S_3. This was mainly due to timely sowing of green gram after potato and mustard (Table-1) that provided favorable weather conditions for initial growth and development as well as sufficient period for three picking before onset of mansoon. Whereas, only two picking were possible in green gram taken after wheat due to delayed sowing of green gram (S_3). In contrast, there was not much variation in fodder yield of cowpea taken in different sequences *viz.* S_6, S_8 and S_9. This indicates that timely sowing of summer green gram is more important than that of cowpea fodder. Considering system wise REY, sequences having three crops each year produced significantly greater REY than rice-wheat system during both the years. The highest REY was recorded from rice-potato-green gram rotation possibly due to besides, higher production potential of potato, higher grain yield of green gram after potato were instrumental for attaining maximum REY than rest of the sequences. The rice-maize (cob) + veg. pea (1:1)-cowpea (fodder) and rice-mustard-green gram sequences ranked second and third respectively, recorded significantly greater REY than rice-wheat. This might be due to higher production potential of maize (cob) along with good market price of vegetable pea and mustard that fetched better returns of these two sequences. Green gram in S_3 markedly contributed to system besides enhancing the productivity of succeeding crops and consequently resulted in significantly higher REY than rice-wheat system (S_1). The improvement of soil structure following legume (Wani et al. 1995), breaking of cycle of the pest and diseases and allelopathic effect of residue of legume crops (Sanford and Harison 1984) may be additional reason for extra yield from these sequences.

The crop sequences with summer grain/ fodder legumes resulted better protein recovery (Table 3), produced 808.8 and 1369.6 kg ha^{-1} in 2002-03 and 983.8 and 1427.4 kg ha^{-1} in 2003-04, it was significantly greater than the protein production under traditional rice-wheat cropping system, produced 708.1 and 726.8 kg ha^{-1} in 2002-03 and 2003-04, respectively. Besides direct contribution of summer legume in total system protein production, its residual effect on succeeding rice, obviously improved its yield and N uptake (Table 2 and 4) due to nitrogen being an important component of protein resulted greater protein production. The maximum protein yield of rice-maize (cob) + veg. pea (1:1)-cowpea (fodder) rotation was due to higher biological yield of maize as well as inclusion of two leguminous crop *i.e.* vegetable pea and cowpea fodder, in the sequence. Tripathi et al. (1987) also reported intensification of crop sequences with pulses considerably increased the production of protein. However, the poor performance of chickpea and pea (Table 2) caused lower protein production of rice-chickpea and rice-pea sequences.

In general, sequences involving summer grain/fodder legume or *Sesbania* as green manure, one extra crop taken during summer season of experiment results greater N, P and K uptake by sequences during both the years of experimentation (Table 4). The N uptake of the sequences having cowpea fodder *viz.* S_6, S_8 and S_9, were higher than the sequences *viz.* S_3, S_5 and S_{10} comprising green gram. This was due to fact that in green gram only pods were picked up but for cowpea fodder, the entire crop was cut at the ground level. Nevertheless, all the crop sequences having summer green gram, cowpea fodder or *Sesbania* for green manuring resulted significantly higher nutrient (N, P and K) removal than standard rice-wheat cropping system. Here it may be pointed out that in present investigation, besides the direct contribution of green gram/cowpea fodder in nutrient uptake, it improved the productivity (Table 2) and nutrient concentration in component crops in respective sequence were responsible for this result. However, *Sesbania* as green manure in rice-wheat-*Sesbania*, not directly involved in nutrient uptake, but it enhanced the productivity and nutrient content of component crops, which resulted in higher nutrient uptake of this sequence. This result corroborates the findings of Chandrasekharan and Sankaran (1995). Sequence S_9 removed highest amount of N, P and K, and proved significantly greater N and P uptake than other sequences but in respect to K uptake it remained at par to all the triple cropping systems. This could be ascribed mainly to its maize (cob) + vegetable pea (1:1) intercropping with good productivity. Similarly, due to lentil + mustard (3:1) intercropping, sequence S_8 was next to S_9 and significantly higher N and P uptake than other sequences. Due to poor performance of chickpea and pea, the rice-chickpea and rice-pea sequences recorded significantly lower nutrient uptake than rice-wheat system, indicating major cause of decline in fertility of soil under traditional rice-wheat system.

Soil pH declined in all the sequences except rice-wheat, which remained increase from initial 7.30 to 7.43. The maximum reduction in pH value was recorded under rice-

Table 2: Economic yield and economic rice equivalent yield (t ha^{-1}) of different cropping systems

Treatments	Rice crop		Winter crops		Summer crops		Economic rice equivalent yield	
	2002-03	2003-04	2002-03	2003-04	2002-03	2003-04	2002-03	2003-04
S_1- Rice-Wheat	3.60	4.01	3.87	3.86	-	-	9.53	9.95
S_2- Rice-Chickpea	3.64	4.12	0.83	1.19	-	-	7.06	9.06
S_3- Rice-Wheat-Green gram	3.73	4.46	3.94	4.14	0.75	0.62	13.47	13.89
S_4- Rice-Wheat-*Sesbania* (GM)	3.84	4.59	4.09	4.23	-	-	10.13	11.10
S_5- Rice-Mustard-Green gram	3.85	4.26	1.29	2.12	0.95	1.06	12.52	16.02
S_6- Rice-Lentil-Cowpea (F)	3.92	4.34	1.05	1.01	24.30	23.56	10.47	10.65
S_7- Rice-Pea	3.75	4.27	1.48	1.16	-	-	8.06	7.67
S_8- Rice-Lentil+ Mustard (3:1)-Cowpea(F)	3.76	4.55	0.69 (0.67)*	0.62 (1.04)	23.52	24.66	11.05	12.89
S_9- Rice-Maize (cob)+ veg. Pea (1:1)-Cowpea (F)	3.83	4.53	9.22 (2.01)	9.87 (1.99)	24.65	24.04	14.67	16.16
S_{10} - Rice-Potato-Green gram	3.85	4.53	17.77	23.66	1.27	1.25	21.02	25.23
SEm ±	0.12	0.13	-	-	-	-	0.35	0.42
CD (P = 0.05)	N.S	0.38	NA	NA	NA	NA	1.01	1.23

*Figures in parentheses shows the value in intercrop, SEm = Standard Error of Mean and CD = Critical difference = Least significant difference

Table 3: Protein yield (kg ha^{-1}) from economic produce of different crop sequences

Treatments	Rice		Winter crops		Summer crops		Total system	
	2002-03	2003-04	2002-03	2003-04	2002-03	2003-04	2002-03	2003-04
S_1- Rice-Wheat	277.8	305.0	430.3	421.9	-	-	708.1	726.8
S_2- Rice-Chickpea	288.8	327.3	173.1	241.4	-	-	461.9	568.7
S_3- Rice-Wheat-Green gram	299.9	361.4	449.0	470.3	180.9	152.0	929.8	983.8
S_4- Rice-Wheat-*Sesbania* (GM)	315.2	382.7	471.7	483.9	-	-	787.0	866.6
S_5- Rice-Mustard-Green gram	312.3	345.0	266.5	428.1	230.0	254.8	808.8	1027.8
S_6- Rice-Lentil-Cowpea (F)	326.0	365.3	228.0	221.2	699.2	682.3	1253.2	1268.8
S_7- Rice-Pea	297.7	341.9	297.3	235.5	-	-	595.0	577.4
S_8- Rice-Lentil+ Mustard (3:1)-Cowpea (F)	305.1	373.5	287.8	341.6	666.6	706.4	1259.5	1421.5
S_9- Rice-Maize (cob)+ veg. Pea (1:1)-Cowpea (F)	313.4	372.8	355.9	368.2	700.3	686.4	1369.6	1427.4
S_{10} - Rice-Potato-Green gram	303.3	356.7	444.2	563.3	302.2	298.2	1049.7	1218.2
SEm ±	11.0	11.5	11.8	21.7	25.0	17.7	25.5	31.2
CD (P = 0.05)	NS	33.3	34.1	62.8	75.3	53.3	73.9	90.7

Table 4: Total N, P and K uptake (kg ha^{-1}) by different crop sequences

Treatments	N		P		K	
	2002-03	2003-04	2002-03	2003-04	2002-03	2003-04
S_1- Rice-Wheat	173.45	176.91	28.69	29.46	182.29	185.70
S_2- Rice-Chickpea	130.19	158.90	17.38	20.81	116.90	138.63
S_3- Rice-Wheat-Green gram	211.25	225.77	32.95	35.62	200.73	223.50
S_4- Rice-Wheat-*Sesbania* (GM)	192.21	208.77	32.35	34.94	213.46	228.47
S_5- Rice-Mustard-Green gram	199.34	244.81	29.93	37.78	188.37	218.40
S_6- Rice-Lentil-Cowpea (F)	272.35	268.98	36.04	35.82	215.46	211.16
S_7- Rice-Pea	163.97	150.06	21.05	20.04	142.93	135.40
S_8- Rice-Lentil+ Mustard (3:1)-Cowpea(F)	277.00	300.70	38.48	42.36	227.70	233.58
S_9- Rice-Maize+ Pea (1:1)-Cowpea (F)	329.54	332.00	46.03	45.57	229.96	228.36
S_{10} - Rice-Potato-Green gram	208.56	248.03	33.48	39.83	195.26	216.67
SEm ±	5.33	7.03	0.82	0.86	6.15	5.2
CD (P = 0.05)	15.46	20.39	2.39	2.49	17.85	16.88

Table 5: Physico-chemical properties of soil and nutrient balance after four year completion of experiment under different crop sequences

Treatments	pH	BD (Mg m^{-3})	O. C. (%)	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})	Nutrients balance (kg ha^{-1})		
							N	P	K
S_1- Rice-Wheat	7.43	1.46	0.34	186.2	21.70	194.2	-5.8	0.3	-29.8
S_2- Rice-Chickpea	7.29	1.43	0.36	200.4	24.70	209.4	8.4	3.3	-14.6
S_3- Rice-Wheat-Green gram	7.00	1.34	0.37	206.1	22.20	218.7	14.1	0.8	-5.3
S_4- Rice-Wheat-*Sesbania* (GM)	6.97	1.31	0.39	218.6	23.20	219.5	26.6	1.8	-4.5
S_5- Rice-Mustard-Green gram	7.03	1.35	0.38	205.4	22.80	216.2	13.4	1.4	-7.8
S_6- Rice-Lentil-Cowpea (F)	7.06	1.33	0.37	212.5	23.00	211.6	20.5	1.6	-12.4
S_7- Rice-Pea	7.26	1.42	0.35	199.8	22.00	207.3	6.8	0.6	-16.7
S_8- Rice-Lentil+ Mustard (3:1)-Cowpea (F)	7.06	1.35	0.38	216.4	22.30	207.6	24.4	0.9	-16.4
S_9- Rice-Maize (cob)+ veg. Pea (1:1)-Cowpea (F)	7.05	1.34	0.38	211.2	22.50	201.4	19.2	1.1	-22.6
S_{10} - Rice-Potato-Green gram	6.98	1.35	0.37	203.3	22.40	204.6	10.3	1.0	-19.4
SEm ±	0.11	0.03	0.01	5.41	1.20	9.08	-	-	-
CD (P = 0.05)	0.31	0.08	NS	15.70	NS	NS	NA	NA	NA
Initial value	7.30	1.44	0.34	192.0	21.4	224.0	-	-	-

NA- Not analysed

wheat-*Sesbania* (green manure) sequence and though it remained at par to the sequences involving summer green gram or cowpea fodder *viz.* S_3, S_5, S_6, S_8, S_9 and S_{10}, all registered significantly lower soil pH than rice-wheat cropping system (Table 5). This decline in soil reaction might be due to organic compound added to the soil during decomposition of green as well as root biomass, produced more humus and organic acids. The CO_2 and organic acids produced during decomposition help in mobilizing calcium by dissolving calcium compound and consequently lower down the pH

(Bajwa 2002).

The sequences involving summer grain/fodder legume or *Sesbania* for green manure, significantly reduced bulk density of soil than rice-wheat system (Table-5). The lowest bulk density of soil was recorded in rice-wheat-*Sesbania* (green manure) rotation. Green manuring is an age old practices, adds lot of carbonaceous material and relatively narrow C/N ratio resulting lower down the bulk density and improves the physical condition of soil (Chhonkar and Pareek 2002).

In respect to organic carbon content (%) and available N (kg ha^{-1}) in soil at the termination of experiment, both were highest in rice-wheat-*Sesbania* (green manure) rotation (Table-5). The other sequences *viz.* S_8, S_6, S_9, S_3, S_5, and S_{10}, though remained at par to rice-wheat-*Sesbania* (S_4), recorded significantly greater organic carbon and available soil N than traditional rice-wheat cropping system. This may be attributed to the biomass added in the soil through green manuring by *Sesbania,* incorporation of green gram stover and roots as well as root and stubbles of cowpea fodder. Besides this, the sequences having summer green gram, cowpea fodder or *Sesbania* for green manuring, improved plant growth and ultimately yield of component crops in respective sequences (Table 2). It was quite obvious that this might have added greater root biomass and stubble to the soil consequently improving soil organic carbon. Campbell et al. (1991) advocated that organic matter content increased with increasing frequency of cropping and inclusion of legume as green manure crop in the rotations. This improved organic carbon accelerated nitrogen fixation by free living organism. The sequences having winter legume (S_2 and S_7) also showed slightly more available N in the soil, because of its biological nitrogen fixation ability. These results support by earlier studies (Ahlawat et al. 1981, Deka and Singh 1984). Another reason for improved available soil N is rotations containing legume crop reduces losses of soil N in the form of NO_3 leaching (Campbell et al. 1997).

As compared to rice-wheat system, sequences involving summer grain/fodder legume or *Sesbania* for green manuring, recorded greater available P and K at the end of the field trial. However, differences were not significant. This might be due to during decomposition of organic matter various organic acid are produced, solublized the phosphate and potassium bearing minerals. The incorporation of green manure also reduces P sorption by soil (Tiwari 2002).

At completion of four years experiment, the positive balance of soil N in all the sequences was observed except in rice-wheat system, where negative balance of N (- 5.8 kg ha^{-1}) was noticed. This could be ascribed to the excessive removal of N by rice-wheat system (Table 4) accompanied with low efficiency of applied N in spite of recommended dose of N applied to both the crops. The positive balance of soil available P was observed in all the sequences as compared to initial value. This might be due to comparatively lower uptake of P by crops (Table 4) than it application. When each component crop of an intensive production system receives P at the recommended rate, the apparent P balance remained positive in most growing situation (Swarup and Wanjari 2000). The higher positive soil available P balance was recorded in rice-wheat-*Sesbania* (green manure) and sequences having two leguminous crops. Amending soil with green manures, help in increasing P concentration in soil solution through mineralization of organic P and solubilization of native soil P compound resulted greater available P balance in the soil (Tiwari 2002). Contrary as compared to initial value, the available K balance of soil found to be negative in all the rotations after four crop cycle. This was mainly due to heavy removal of K by all the crop sequences (Table 4). The summer legumes in the present study did not receive fertilizer K, and K application to other crops were not sufficient to meet demand (Singh et al. 2002). The maximum K deficit was recorded in rice-wheat system. This result was also supported by earlier work of Srivastava and Srivastava (1993).

CONCLUSIONS

Inclusion of summer crop beneficially augmented soil physical as well as chemical properties of soils and productivity of the systems as whole. Substitution of rice-wheat with triple cropping system particularly rice-potato-green gram or rice-maize (cob) + vegetable pea (1:1)-cowpea (fodder) sequences, not only produce relatively higher rice equivalent yield, but also increased protein production. Diversification/ intensification of rice-wheat with summer grain/fodder legumes or *Sesbania* as green manuring, decreased soil pH, bulk density and improved the soil organic carbon as well as available N and P status of the soil.

Based on the experimental findings, it is recommended that intensely and purely grown rice-wheat cropping system in Indo-Gangetic Plain Region of India should be replaced with cropping system like rice-potato-greengram or rice-maize (cob) + vegetable pea (1:1)-cowpea (fodder) as these cropping systems are environmentally safe and economically viable. Hence, it would be imperative to make concrete and intensive efforts for creating awareness among farmers of IGPR of India regarding significance of aforesaid cropping system. Consequently, intensification and diversification of rice-wheat cropping system may be served as a base to uplift the socio-economic conditions of the farmers belonging to IGPR of India in general and particularly the small and marginal farmers by augmenting the production per unit area and per unit time along with restoring soil fertility and improving quality of resource bases.

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