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Effect of crop diversification in rice (*Oryza sativa*)–wheat (*Triticum aestivum*) cropping system on system productivity, economics and soil health*

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Rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* emend Fiori. & Paol.) are the major cereals grown in the country and contribute nearly 80% towards food grain production. Now a days, there has been stagnation or decline in the yield of rice and wheat in rice–wheat cropping system even with balanced or integrated nutrient management practices and has resulted in over exploitation of natural resources by aggravating the decline in ground water reserves, increment in micronutrient deficiency, insect–pest and disease appearance, emergence of new weed flora, environmental pollution, human health hazards and loss of biodiversity. During the rice–wheat cropping cycle, soil undergoes drastic changes, i e aerobic to anaerobic environment leading to several chemical and electro- chemical transformations. Besides the contrasting needs of each crop, continuous rice–wheat cropping for longer periods with low system diversity and often with poor crop management practices, resulted in loss of soil fertility due to emergence of multiple nutrient deficiencies, deterioration of soil physical properties, decline in factor productivity and crop yields in high productivity areas. Balanced fertilizer use, complementary use of organic nutrient inputs with fertilizers and inclusion of legumes are the possible agro-techniques to sustain yield, increase fertilizer use efficiency and to restore soil fertility under intensive cropping (Dwivedi *et al*. 2003).

Introduction of legume crop in RWCS may have advantages well beyond the N addition through 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. Development of short-duration and uniformly maturing varieties of summer legumes (blackgram and green gram), and short to extra-short duration varieties of pigeon pea in recent years have enhance the feasibility of inclusion of grain legumes in RWCS, although such options have not been systematically evaluated. Considering the urgency of increasing food production and nutritive value, food crops like pulses, vegetables and oilseeds should be introduced in the rice–wheat cropping system by diversification and intensification. So far, in most parts of this region, the only option is to replace wheat by introduction of high value and nutritive crops. This approach is important for a largely vegetarian population of the country and is therefore, considered to be one of several important food system strategy to address the silent emergency of malnutrition in the region.

A field experiment on diversification in rice–wheat system was conducted at the Agricultural Research Farm, Institute of Agricultural Sciences, BHU, Varanasi, Uttar Pradesh during 2006–07, 2007–08 and 2008–09 in randomized block design, replicated thrice, with 14 crop sequences as treatments, viz rice–wheat (T_1), rice (early) – pea (grain) – blackgram (T_2), rice (early) – rapeseed – maize (cob) – *sesbania* (T_3), rice-wheat – greengram (T_4), rice – mustard – blackgram (T_5), maize (cob) – rapeseed-wheat (T_6), rice (basmati) – potato - black gram (T_7), rice – wheat + mustard (5:1) – blackgram (T_8) , early pigeonpea – wheat – maize (fodder) (T_9), rice (basmati) – maize (cob) + veg. Pea (1:2) – greengram (T_{10}), rice (basmati) – rapeseed – onion (T_{11}), rice (basmati) – vegetable pea – sunflower (hybrid) (T_{12}), rice (early) + blackgram - wheat + mustard (5:1) – greengram (T_{13}), rice(early) + sesamum (1:1) – wheat + lentil (3:2) – blackgram (T_{14}). The soil of experimental

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field was sandy clay loam having *p*H-7.4, EC – 0.35 dS/m, bulk density- 1.45g/cc, water-holding capacity- 33.83% and bacterial population- 61.44 × 10^6/g oven dry soil along with soil organic carbon-0.46%, available nitrogen 181kg N/ha, available P 16.91 kg P /ha and available potassium 179.56 kg K /ha. For the determination of *p*H, EC, organic carbon and available potassium standard procedure given by Jackson (1973) was followed, while the determination of bacterial population was done by method given by Cochran (1950). The crops were raised with recommended practices in accordance with IPNM, i e (75% through inorganic sources and 25% through organic sources). No fertilizer was added to green manure crops. For comparison of different crop sequences, the yield data for different seasons were pooled and converted into rice grain equivalent yield (RGEY). Economics of the inputs and output was worked out to arrive at the net return and benefit:cost ratio.

Amongst various rainy (*kharif*) crops rice variety 'Pusa Basmati 1' under treatment (T_{10}) recorded significantly higher rice grain equivalent yield (RGEY is 6.28 tonnes/ha) over other crops whereas early pigeon pea under treatment (T_9) had the lowest RGEY (2.16 tonnes/ha). Similar findings were reported by (Mishra *et al*, 2007). Among the different *rabi* crops, rapeseed - onion (T_{11}) had significantly higher Wheat Grain Equivalent Yield (WGEY is 11.69 tonnes/ha) than other crops followed by potato (T_7) and maize + vegetable pea (1:2) intercropping under treatment (T_{10}) and these treatments had significantly higher WGEY over others. Saroch *et al.* (2005) also obtained more productivity by replacing wheat with vegetables in rice-wheat cropping system. Greengram taken in sequential treatments T_{10} >T_4 >T_{13} produced lucidly higher green gram grain equivalent yield (GGEY) than other summer crops in various sequences.

Productivity of various cropping sequences in terms of system rice grain equivalent yield (SRGEY) shows that among different cropping sequences rice–potato–blackgram cropping sequence (T_7) noticed significantly highest system productivity (SRGEY) (28.88 tonnes/ha /year) over rest of

Table 1 Effect of different treatments on economic yield, rice frain equivalent yield (RGEY), system rice grain equivalent yield (SRGEY) and economics (pooled data of three years)

Treatment:	Economic yield (tonnes/ha)			RGEY (tonnes/ha)			SRGEY	Economics		
Cropping sequence	*Kharif*	*Rabi*	*Summer*	*Kharif*	*Rabi*	*Summer*	(tonnes/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	Benefit:cost ratio
T_1	5.64	4.14		5.64	4.14		12.09	89 215	51 354	1.35
T_2	3.90	1.91	1.11	3.90	3.84	1.05	15.59	102 014	57 747	1.30
T_3	3.84	1.12	8.71	3.84	2.28	1.162	13.73	93 980	44 135	0.88
T_4	4.85	4.03	1.25	6.06	4.03	1.248	19.19	133 448	84 621	1.73
T_5	4.68	4.14	1.07	5.85	4.02	1.016	17.68	119 803	74 141	1.62
T_6	8.80	1.16 (3.15)		5.81	5.52		14.34	93 650	49 211	1.08
T_7	4.98	22.77	1.18	6.21	10.63	1.118	28.88	180 905	119 610	1.96
T_8	5.59	3.50 (0.59)	1.07	5.29	4.72	1.019	18.53	129 560	80 924	1.66
T_9	0.56	3.82		2.16	5.82	0.444	11.14	88 002	50 194	1.32
T_{10}	5.03	9.63 (5.8)	1.27	6.28	7.92	1.268	25.67	168 927	118 082	2.33
T_{11}	4.99	1.10 (20.2)		6.23	11.69		24.44	154 387	99 809	1.83
T_{12}	4.83	9.07	1.94	6.02	5.14	1.075	19.87	130 777	78 132	1.49
T_{13}	2.10 (0.44)	3.53 (0.70)	1.23	4.51	4.96	1.228	19.00	131 965	85 378	1.84
T_{14}	2.02 (0.46)	2.72 (0.37)*	1.06	4.56	3.76	1.002	15.90	103 860	58 140	1.28
S Em ±	NA	NA	NA	0.20	0.19	NA	0.81	5 210	2 966	0.05
CD (P = 0.05)	NA	NA	NA	0.48	0.46	NA	1.95	12 556	7 148	0.13

*Figure in parentheses indicate intercrop yield; NA: Not analysed.

Selling price (₹/tonne): Rice: 7 000; rice (basmati): 8 500; wheat: 7 000; maize (cob): 4 000; blackgram: 7 000; rapeseed: 14 000; potato: 3 500; veg. pea: 3 000; pigeonpea: 27 000; veg. pea: 4 000; onion: 3 250; sunflower: 4 000; greengram: 7 000; sesame: 35 000; lentil: 25 000.

the cropping sequences, followed by rice-maize (cob) + vegetable pea (1:2) – greengram (T_{10}) cropping sequence. Inclusion of pulses in crop sequence increased the grain yield of both the crop sequence. This can be attributed to the legume effect of black gram and greengram on succeeding rice crop (Yadav *et al.* 2005).

The perusal of data revealed that maximum gross return was (₹ 180 905/ha) recorded in rice–potato–blackgram cropping sequence, which was significantly higher than other cropping sequence. This was mainly due to higher production potential of potato accompanied with good monetary returns from blackgram. The deep hoeing of the field because of ridge planting and hilling up as well as digging of potato tubers caused better soil aeration and weed free condition for the blackgram and it also utilized the residual fraction of fertilizer applied to potato (Singh *et al.* 2010), whereas the lowest gross returns (₹ 88 002/ha) was recorded in early pigeon pea–wheat–maize (fodder) (T_9). The net returns was also highest in rice–potato–blackgram cropping sequence (₹ 119 610/ha) which was significantly superior to rest of the cropping sequences except rice–maize (Cob) + vegetable pea (1:2) – greengram cropping sequences (₹ 118 082/ha) which was statistically *at par* with this treatment. This clearly shows that besides having more input, this sequence also produces higher energy equivalent resulting into maximum net return. The lowest net return was recorded in rice (early) – rapeseed – maize (cob) – *sesbania* (T_3) cropping sequence. Similarly, benifit: cost ratio was also maximum in rice – maize (cob) + vegetable pea (1: 2) – greengram cropping sequence (2.33) followed by rice-potato-black gram (1.96) and the lowest value was in rice (early) – rapeseed – maize (cob) – *sesbania* cropping sequence (0.88).

Inclusion of legumes either as green manure crop or grain/fodder legume caused marked reduction of *p*H, EC and bulk density. The lowest *p*H (7.30) was recorded in black gram (1:1) – wheat + mustard (5:1) – greengram cropping sequence (T_{13}) and though the reduction was not significant. All the sequences registered lower soil *p*H than rice – wheat (T_1) cropping sequence (7.38). It was observed that maximum EC (0.360 dS/m) was recorded in rice–wheat (T_1) cropping sequence. While, the minimum EC (0.327 dS/m) was recorded in blackgram (1:1) – wheat + mustard (5:1) – greengram cropping sequence (T_{13}). Highest organic carbon content (0.50%) was recorded in rice – rapeseed – maize (cob) – *sesbania* (GM) cropping sequence (T_3) which was significantly superior over rice - wheat (T_1) cropping sequence. Whereas, the other treatments were at par with treatment T_3. This was probably due to the accumulation of root residues (Porpavai *et al*. 2011) as green manure and leguminous crops are high in protein, therefore they are rich in nitrogen. Because most pulse crop's residues contain much more carbon than nitrogen, and bacteria in the soil need both, the nitrogen supplied by legumes facilitated the decomposition of crop residues in the soil and their conversion to soil building organic matter. Lowest soil available nitrogen (166.00 kg/ha) was recorded with rice–wheat cropping sequence. While, highest amount of soil available nitrogen (232.00 kg/ha) was recorded in treatment (T_3) with rice - rapeseed – maize (cob) – *sesbania* (GM) cropping sequence which was significantly superior to all other treatments. This was due to nitrogen fixing character of *sesbania* (GM) which resulted in highest amount of soil available nitrogen. Inclusion

Table 2 Effect of different treatments on soil parameters after three years of experimentation

Treatment: Cropping sequence	*p*H	EC (dS/m)	OC (%)	BD (g/cc)	WHC (%)	Available nitrogen (kg/ha)	Available phosphorus (kg/ha)	Available potassium (kg/ha)	Bacterial population (10^6/g soil)
T_1	7.38	0.360	0.44	1.48	40.23	166	18.65	174.22	62.25
T_2	7.35	0.343	0.48	1.41	41.96	180	19.31	192.05	65.10
T_3	7.32	0.334	0.50	1.40	41.99	232	21.00	198.60	66.00
T_4	7.36	0.348	0.47	1.42	41.26	177	18.79	178.10	64.55
T_5	7.32	0.336	0.47	1.43	40.92	179	19.18	181.85	64.15
T_6	7.31	0.333	0.46	1.49	40.00	176	18.76	196.09	63.75
T_7	7.37	0.353	0.47	1.42	41.34	183	19.08	185.89	63.90
T_8	7.33	0.347	0.46	1.47	40.19	171	19.45	174.36	64.00
T_9	7.31	0.330	0.46	1.46	40.17	188	19.29	192.33	64.35
T_{10}	7.36	0.348	0.47	1.44	41.23	180	19.82	181.03	65.30
T_{11}	7.34	0.350	0.45	1.47	40.01	187	18.68	187.72	63.60
T_{12}	7.36	0.348	0.46	1.46	40.54	175	19.70	189.58	63.95
T_{13}	7.30	0.327	0.47	1.44	41.13	181	19.66	188.61	64.75
T_{14}	7.32	0.337	0.47	1.43	40.99	185	19.67	194.31	64.95
S Em ±	0.24	0.014	0.02	0.05	1.43	7.29	0.64	7.12	1.26
CD (P = 0.05)	NS	NS	0.05	NS	NS	22	1.89	21.04	3.72

of legume in the sequence enhanced the soil N (Porpavai *et al*. 2011). Rice – rapeseed – maize (cob) – *Sesbania* (GM) (T_3) cropping sequence resulted in higher amount of available phosphorus content (21.00 kg/ha). The lowest soil available phosphorus (18.65 kg/ha) was recorded with rice–wheat (T_1) cropping sequence. Rice – rapeseed – maize (cob) – *Sesbania* (GM) (T_3) cropping sequence resulted in higher amount of available potassium content (198.60 kg/ha) which was significantly superior to treatments (T_1) and (T_8), which may be due to inclusion of legume (Kumar *et al*. 2008). The maximum bulk density (1.49 g/cc) was associated with maize (cob) – rapeseed – wheat cropping sequence (T_6) cropping sequence, which was closely followed by rice - wheat (T_1) cropping sequence. The magnitude of reduction in bulk density due to green manuring over fallow was also reported by Mandal *et al*. 2003. This may be due to increased organic carbon content in the upper soil layer which increased soil porosity and reduced soil compaction resulting in the lowering of soil bulk density. The maximum water-holding capacity (41.99%) was associated with rice – rapeseed – maize (cob) – *Sesbania* (GM) (T_3) cropping sequence. This particular cropping sequence reported maximum water holding capacity in the soil due to addition of organic matter with green manuring, which ultimately improved bulk density and water holding capacity. The lowest water-holding capacity (40.00%) was associated with maize (cob) – rapeseed – wheat (T_6) cropping sequence. This was due to association of relatively lesser amount of organic matter with this particular cropping sequence. Bacterial population in soil was recorded significantly higher (66.00×10^6) in rice – rapeseed – maize (cob) – *Sesbania* (GM) (T_3) cropping sequence which was statistically at par with all other treatments except rice – wheat (T_1) cropping sequences which registered some decline in it's population over initial soil value. Thus, the result of the experiment showed that crop sequences involving pulses and green manure improved the microbial environment in the soil. It contributed to an increased diversity of soil flora and fauna leading to a greater stability to the total soil life. Significantly higher available N, P and K were also recorded in rice – rapeseed – maize (cob) – *Sesbania* (GM) (T_3) cropping sequence.

SUMMARY

A field experiment comprised of treatments comprising 14 crop sequences were conducted to study the effect of crop diversification in rice (*Oryza sativa*)–wheat (*Triticum aestivum*) cropping system on system productivity, economics and soil health. The results revealed that overall productivity of the system in terms of system rice grain equivalent yield was noticed significantly highest in rice-potato-blackgram (28.88 tonnes/ha/yr) compared to rest of the cropping sequences, followed by rice–maize (cob) + veg. pea (1:2) – greengram cropping sequence (25.67 tonnes/ha/yr). In addition to that inclusion of legumes either as green manure crop or grain/fodder legume proved crucial in maintenance of soil bio-physico-chemical properties of the soil. Therefore, diversification of rice–wheat system under irrigated condition by inclusion of moong crop after potato or wheat could enhance the overall productivity and profitability of the farm, besides improving the soil sustainability on long term basis.

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