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Sustainability of rice (*Oryza sativa*)–wheat (*Triticum aestivum*) sequential cropping through introduction of legume crops and green-manure crop in the system

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ABSTRACT

A study was undertaken by replacing one of the cereal crops rice (*Oryza sativa* L.) or wheat (*Triticum aestivum* L. emend. Fiori & Paol.) by a grain legume crop or to introduce summer green-manure crop (*Sesbania*) in the sequence. Over 5 years period wheat yield was higher by 0.71 tonne/ha after pigeonpea [*Cajanus cajan* (L.) Millsp.] compared with that after rice. The fertilizer dose to rice after lentil (*Lens culinaris* Medikus) or wheat after pigeonpea should remain the same as in rice–wheat sequence. The overall productivity of the system in terms of wheat equivalent was highest in pigeonpea–wheat sequence compared with rice–lentil or rice–wheat sequence. Introducing *Sesbania* green-manure in rice–wheat sequence increased its productivity by 1.08 tonnes/ha. Any reduction in fertilizer even with green-manuring brought reduction in system productivity. Introduction of legume in the system increased soil organic carbon and available soil phosphorus. Thus replacement of rice with pigeonpea for some time or introduction of *Sesbania* green-manuring may inhance the sustainability of rice–wheat system.

The problem of sustainability of prominant rice (*Oryza sativa* L.)–wheat (*Triticum aestivum* L. emend. Fiori & Paol.) crop sequence in Indo-Gangetic plains needs to be explored by introducing legume crops in the system in different ways, viz. replacing rice or wheat crop by a legume crop, i.e. rice by pigeonpea [*Cajanus cajan* (L.) Millsp.] in summer or wheat by lentil (*Lens culinaris* Medikus) in winter, or introducing a summer green-manure crop of *Sesbania* after the harvest of wheat and before planting of rice. The production potential of these cereal–cereal, cereal–legume, and cereal–legume–cereal sequences has been worked out in terms of grain yield and economic returns to compare it with that of rice–wheat system. Further, the impact of introducing legumes on nitrogen economy of the system has been worked out so as to see whether any economy in nitrogen fertilizer use is possible by the introduction of legume in the system.

MATERIALS AND METHODS

A field experiment was conducted at Pantnagar for 5 years (1986–87 to 1990–91) comparing rice–wheat sequence with rice–lentil, pigeonpea–wheat, and rice–wheat–*Sesbania* sequences at recommended and less than recommended fertilizer rate where legume was introduced in the system. Eight experimental treatments were laid out in randomized block design

with 4 replications. All crops were raised with recommended practices except that the fertilizer was given as per treatments. No fertilizer was added to green-manure crop. Crop yields were recorded and these were converted to equivalent values of wheat yield, total calories, protein and carbohydrate content. Economics of the inputs and output was worked out to arrive at the net return and benefit : cost ratio. The produce was analysed for its N, P and K content to work out the uptake of these nutrients. After the completion of the experiment, the soil organic carbon, total nitrogen and available phosphorus contents were analysed to study the change in soil fertility under different crop sequences and to work out the balance of nutrients in soil under different crop sequences for 5 years.

RESULTS AND DISCUSSION

Crop yield

The yield of rice and wheat crops at recommended fertilizer level was higher when the preceding crop was grain legume, i.e. rice yield was slightly higher after lentil compared to that after wheat (Table 1). The difference was more clear in wheat as wheat yield after pigeonpea was 0.71 tonne/ha more compared to that after rice. The yield of rice as well as wheat in sequence with grain legume (lentil/pigeonpea) was higher at recommended fertilizer level compared with that at 25% less than recommended level. This shows that for rice as well as wheat, the fertilize dose should not be reduced after grain legume. In this experiment grain legume crops, viz. pigeonpea and lentil, were grown repeatedly in the same plots for 5 years and so due to pathogen build-up these crops suffered heavily in last 2 years. Thus, it may be difficult to raise grain legumes every year in the same field and a break in the cycle may be necessary after a certain period of time.

Introducing green-manure crop of *Sesbania* during summer in rice–wheat sequence with recommended fertilizer increased rice and wheat yields by 12% each. But this increase in yield was achieved

Table 1. Yield and economic returns from different crop sequences (based on means of 5 years)

Crop sequence	Crop yield (tonnes/ha)		Wheat-grain equivalent (tonne/ha)	Benefit : cost	Net return (Rs/ha)
	Rainy season	Winter season			
Rice (100)–wheat (100)	4.42	4.51	8.65	1.40	15,391
Rice (100)–lentil (100)	4.55	1.40	8.27	1.54	14,546
Rice (75)–lentil (100)	4.34	1.37	7.98	1.51	13,995
Pigeonpea (100)–wheat (100)	1.33	5.22	9.02	2.24	18,394
Pigeonpea (100)–wheat (75)	1.34	4.73	8.46	2.12	17,179
Rice (100)–wheat (100)–GM	4.95	5.06	9.73	1.40	17,511
Rice (75)–wheat (75)–GM	4.65	4.67	9.06	1.36	15,602
Rice (50)–wheat (50)–GM	4.21	4.23	8.19	1.27	13,203
CD (P = 0.05)			0.42	0.20	1,099

Figures in parenthesis shows percentage of recommended N and P dose
GM, Green-manuring with *Sesbania aculeata*
Net return has been worked out at current prices

when recommended level of fertilizer was maintained along with green-manure. When the fertilizer applied to rice and wheat was decreased by 25 or 50%, there was decline in yield. However at 25% less fertilizer and with summer green-manuring rice and wheat yields were still higher over rice–wheat with recommended fertilizer but without green-manuring. A 50% reduction in fertilizer along with green-manuring gave less yield than rice–wheat alone but with recommended fertilizer. Sharma (1984) and Sharma and Mitra (1988) reported beneficial effect of green-manuring. According to Boulding (1988) green-manure contains 2 fractions–one decomposes during the first rice crops and the other decomposes slowly over several years. With most green-manure crops, the first fraction is 50–80% of the total N. Residual effects (N supply to a second crop) are relatively small when green-manure is applied only once, but the cumulative effects of several applications are expected to be appreciable.

Wheat-grain equivalent

Among the cereal–cereal (rice–wheat) and cereal–legume (pigeonpea–wheat/rice–lentil) sequences at optimum fertilizer level, highest wheat-equivalent yield was recorded in pigeonpea–wheat sequence, as wheat yield was highest in this sequence. Lowest wheat-equivalent yield was observed in rice–lentil sequence which was 0.75 tonne/ha lower than that in pigeonpea –wheat sequence. Reduction in recommended fertilizer rate by 25% for cereals (rice, wheat) after grain legumes resulted in reduced wheat equivalent in both sequences (pigeonpea–wheat and rice–lentil). Thus, as mentioned earlier the recommended dose of fertilizers to rice and wheat should not be reduced even when the preceding crop is grain legume or in other words short duration cv. 'UPAS 120' and lentil cv. 'Pant L 639' did not leave any positive after-effect for the succeeding crop. There are reports that early-duration pigeonpea cultivars fix little nitrogen and for the best fixing cultivar, N_2-fixations represented only 52% of the total nitrogen uptake. Rao *et al.* (1980) reported that pigeonpea yield had increased up to 22% by the application of 200 kg N/ha, suggesting that nitrogen fixed by this crop was not enough even to meet its own requirement and hence no beneficial after-effect can be expected. The soil analysis at the end of 5 years showed that total soil nitrogen was little different under different sequences. Legumes in sequence did increase soil-available phosphorus, but as the soil was already rich in available phosphorus, further increase in available phosphorus did not bring any beneficial effect on the crops in sequence.

Highest wheat-equivalent yield was obtained when summer green-manuring was introduced in rice–wheat sequence and the 2 crops received recommended fertilizer rate. In this treatment wheat-equivalent yield was 1.08 tonnes/ha more than similar rice–wheat sequence without green-manuring. Reduction in fertilizer dose to rice and wheat by 25 or 50% reduced wheat-equivalent yield indicating that to get maximum productivity from rice–wheat–green-manure sequence, the fertilizer dose to rice and wheat should be maintained at recommended level.

Net return and production efficiency

Rice–wheat sequence at recommended fertilizer gave net return of Rs 1,539/ha. Introducing pigeonpea in place of rice in the

Table 2. Production efficiency (per day productivity/return) of different crop sequences

Crop sequence	Net returns (Rs/ha)	Grain production (kg/ha)	Protein (kg/ha)	Carbohydrate (kg/ha)	Calories (K Cal) × 10^4/ha
Rice (100)–wheat (100)	42.2	23.7	1.9	15.9	7.6
Rice (100)–lentil (100)	39.9	22.7	1.5	9.2	4.5
Rice (75)–lentil (100)	38.3	21.9	1.5	8.9	4.3
Pigeonpea (100)–wheat (100)	50.4	25.0	2.4	13.8	6.9
Pigeonpea (100)–wheat (75)	47.1	23.1	2.3	12.9	6.4
Rice (100)–wheat (100)–GM	48.3	26.7	2.2	17.9	8.6
Rice (75)–wheat (75)–GM	42.7	24.8	2.0	16.7	8.0
Rice (50)–wheat (50)–GM	36.2	22.5	1.8	15.1	7.3

Figures in parentheses show percentage of recommended N and P dose
GM, Green-manuring of *Sesbania aculeata*

sequence raised the net return by Rs 3,000/ha. Thus, on a sandy-loam soil, where rice yield was 4.4 tonnes/ha and pigeonpea 1.37 tonnes/ha, pigeonpea–wheat was found more paying compared to rice–wheat. Rice–lentil gave the lowest return. In pigeonpea–wheat and rice–lentil sequences, the net return decreased with reduction in fertilizer dose to wheat and rice crops. The benefit : cost ratio was also highest (2.24) in pigeonpea–wheat sequence, where both crops were raised with recommended fertilizer level.

Green-manuring with *Sesbania* before rice planting increased the net profit of rice–wheat sequence by Rs 2,210/ha. Even with 25% less fertilizer to rice and wheat in rice–wheat–*Sesbania* sequence, the same net return was obtained as with rice–wheat with recommended fertilizer but without green-manuring.

The production efficiency, i.e. productivity per day in terms of net return and protein production, was the highest in pigeonpea–wheat sequence, followed by rice–wheat–*Sesbania*, whereas in terms of grain and carbohydrate production and total calories, rice–wheat–*Sesbania* was most efficient, followed by pigeonpea–wheat sequence (Table 2). Pillai *et al.* (1987) reported higher energy and carbohydrate yield under pure cereal cropping sequence, but protein yield was maximum under legume–cereal sequence.

Nutrient uptake and changes in soil fertility

The total nutrient uptake (NPK) varied from 294 to 465 kg/ha and it was highest in rice–wheat–*Sesbania* sequence (Table 3). Nutrient uptake was higher in cereal–cereal rotation than to cereal–legume rotations. Soil analysis after 5 years showed minor variations in organic carbon and total nitrogen content. In pure cereal rotation (rice–wheat) the net change in soil organic carbon and total nitrogen content was negative, whereas in all sequences having legume component (grain legume or green-manure) this change was on positive side. Soil-available phosphorus content was affected substantially by legume component in the sequence and the level of fertilize applied. Available phosphorus in soil was the highest under rice–wheat–*Sesbania*

Table 3. Nutrient uptake and fertility status of soil (differences between initial and final soil test values) under different crop sequences over a period of 5 years

Crop sequence	Nutrient uptake (means of 5 years) (kg/ha)				Change in fertility status in 5 years		
	N	P	K	Total	Organic carbon (%)	Total N (kg/ha)	Available P (kg/ha)
Rice (100)–wheat (100)	186	30	178	394	—0.004	—8.0	1.4
Rice (100)–lentil (100)	170	24	132	326	0.006	10.0	4.8
Rice (75)–lentil (100)	162	23	125	310	0.004	6.0	2.9
Pigeonpea (100)–wheat (100)	166	24	129	319	0.006	9.0	8.8
Pigeonpea (100)–wheat (75)	154	22	118	294	0.003	5.0	7.1
Rice (100)–wheat (100)–GM	215	36	213	464	0.010	15.0	13.8
Rice (75)–wheat (75)–GM	201	33	199	433	0.007	10.0	6.8
Rice (50)–wheat (50)–GM	178	29	177	384	0.001	3.0	1.9

Figures in parentheses shows percentage of recommended N and P dose
GM, Green-manuring of *Sesbania aculeata*

sequence receiving recommended fertilizer level and it was lowest in rice–wheat sequence. Next to *Sesbania* green-manuring was the sequence having pigeonpea which also increased the available phosphorus content over rice–wheat sequence. The green-manure shows important effects on soil properties other than ability to supply nitrogen Bouldin (1988). In the long run these effects may be more important than the value of green-manure as nitrogen source only. Thus, regular incorporation of green-manure in rice–wheat system may improve soil conditions and enhance the sustainability of the system.

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