

SUSTAINING RICE-WHEAT SYSTEM THROUGH MANAGEMENT OF LEGUMES I: EFFECT OF GREEN MANURE LEGUMES ON RICE YIELD AND SOIL QUALITY

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Abstract

This study was aimed to attempt if we can fit a green manure legume in the gap between wheat harvest and rice plantation for sustainable rice (*Oryza sativa*) -wheat (*Triticum aestivum*) system. The effect of six green manure legumes viz. mungbean (*Vigna radiata*), cowpea (*Vigna unguiculata*), soybean (*Glycine max*), sesbania (*Sesbania rostrata*), pigeonpea (*Cajanus cajan*) and guar (*Cyamopsis tetragonoloba*) was assessed on rice yields and soil organic fertility in rice-wheat system for three consecutive years (2001/02-2003/04) at Agriculture Research Institute, Tarnab, Peshawar (Pakistan). The paddy and straw yields of rice were significantly increased by all green manure legumes during all the three years. However, on average, the greatest paddy and straw yields were recorded for cowpea and sesbania. The N uptake in rice was also significantly increased by legumes. However, the greatest N uptake occurred in the sesbania plot. Significantly positive effects of green manure legumes were also observed on soil organic matter, total N and mineral N relative to the fallow-based rice-wheat system. Our results suggest that the gap between wheat harvest and rice plantation can be effectively used to grow any green manure legume in general and sesbania or cowpea in particular in Khyber Pakhtunkhwa for sustainable rice-wheat system. Although this technology was tested in Peshawar valley, it has equal applications any where in the rice-wheat system.

Introduction

The rice-wheat cropping system is highly nutrient exhaustive and annually remove more than 650 kg ha⁻¹ of N, P, and K, and 0.5-1.0 kg ha⁻¹ Zn, 2-3 kg ha⁻¹ Fe and 3.0-3.5 kg ha⁻¹ Mn. The rice-wheat cropping systems therefore cause a considerable depletion of soil nutrients and their effect on long-term productivity is threatening. Consequently farmers have to use increased fertilizer doses each year to realize the same yield levels which were obtained with relatively lower amounts of fertilizers in the past. Unfortunately, chemical fertilizers are highly expensive and their adequate application by farmers in developing countries is not possible in the current scenario despite the fact that quite positive responses of wheat and rice to fertilizers are obtained (Suman, 2004; Akhtar *et al.*, 2009). It is in such system that legumes can play an increasingly important role in improving crop productivity and maintaining soil fertility.

The cereal-cereal based cropping systems usually result in negative N balances in the soil even when all the component crops of the system are provided with recommended levels of fertilizers (Shah *et al.*, 2003). Inclusion of a legume component in such rotations helps in maintaining the status of soil N (Muhammad *et al.*, 2003, 2009). It also improves organic C and mineralizable N content of soil (Shah *et al.*, 2003; Shafi *et al.*, 2007; Abbasi *et al.*, 2009; Bakht *et al.*, 2009). Mann *et al.*, (2000) reported that green manuring of *Sesbania rostrata* (a stem nodule and high N₂ fixing legume) can significantly improve the yield of following rice crop and saves about 50-60% N. Its continuous use for 3 years can result into significant residual effect on the second wheat crop and improve physico-chemical properties of the soil. Ibrahim *et al.*, (2000) found that integrated use of green manuring of guar and sesbania with NP in rice-wheat system significantly increased the yield of both crops.

There is a short fallow period of 40-70 days between harvest of wheat and planting of rice. Wheat is harvested in the first week of May and rice is planted in the second or third week of July. This fallow period of about 2 months between wheat harvest and rice planting can be used effectively for raising a suitable summer fodder or grain legume crop. Various summer legumes have been attempted to raise in the

intervening period between wheat and rice. This practice not only provides pulse grains but also benefits the succeeding cereal crops through improvement in N status of the soil.

The involvement of summer legumes (sesbania, mungbean) in rice-wheat system has shown positive impacts in Pakistan (e.g Mann, 2000). But such information are limited, therefore comprehensive studies were needed to test wide spectrum of potential green manure legumes for sustainable rice-wheat system. This paper report the results of a three years long field experiment where six legumes (e.g. mungbean, cowpea, soybean, sesbania, pigeon pea, and guar) were tested for their impacts on rice yield and soil fertility in rice-wheat system.

Materials and Methods

Trial description: The experiment was conducted at the Research Farm of Agricultural Research Institute, Tarnab, Peshawar, Khyber Pakhtunkhwa Pakistan (34°04'N, 71°40'E) with the objectives to involve green manure legumes in the rice-wheat system for sustainable production and study the effects of six green manure legumes (such as mungbean, cowpea, soybean, sesbania, guar and pigeonpea) and fertilizer N on rice production. The climate is classified as semi-arid tropical. Annual precipitation average 375 mm with summer dominance. The soil of the experimental site was alkaline (pH 7.80), non-saline (EC 2.00 dSm⁻¹), and low in soil fertility (organic matter 0.93%, total N 0.046%, mineral N 25.00 mg kg⁻¹).

The experiment was commenced with legumes in summer 2001. Soon after wheat harvest, the site was cultivated to legumes viz. mungbean, cowpea, soybean, sesbania, pigeon pea, and guar. The experiment was arranged in a split-plot design by assigning main plots to fertilizer N and sub-plots to legumes with four replications. One plot was left fallow. Triple super phosphate (TSP) at 90 kg P₂O₅ ha⁻¹ was applied uniformly to each treatment plot. After about 50 days of growth, 1 m² area was harvested in each treatment plot of legumes and biomass weight recorded. The remaining crop was incorporated into the soil (by rotovator) of respective treatment plots.

Rice was planted immediately after green manuring. Nitrogen, phosphorus and potash were applied at recommended levels. Nitrogen was applied only to +N plots.

The rice crop was harvested at maturity and data on grain, straw and N yields recorded. The site was planted to wheat immediately after rice receiving all recommended cultural practices throughout the growing season. Like in rice, N was applied only to +N plots.

After wheat harvest, the site was planted to same legumes in same layout receiving same cultural practices. The experiment was continued for three years. Data on crop yields and soil fertility was recorded.

Soil and plant analysis: Soil organic matter (SOM) was determined by the Walkley-Black procedure using $K_2Cr_2O_7$ as an oxidizing agent (Nelson & Sommers, 1996). Total N (TN) in soil and plant samples was determined by the Kjeldhal method as described in Bremner (1996). The soil mineral N ($NH_4-N + NO_3-N$) was determined by the steam distillation method as described in Mulvaney (1996).

Statistical analysis: The data was analyzed statistically using Statistix PC DOS Version 2.0, NH Analytical Software and means were compared using the least significance difference (LSD) test (Steel and Torrie, 1980).

Results

Shoot Biomass and N Yields of legumes: The shoot biomass of legumes varied significantly from one another in each year. In 2001, the greatest DM shoot biomass was obtained for mungbean followed by cowpea, and sesbania (Table 1). The lowest biomass was recorded for pigeonpea and guar. In the following year 2002, the maximum shoot biomass was obtained for sesbania which was at par with cowpea, soybean and pigeonpea whereas the lowest biomass was recorded for guar. In 2003, the greatest shoot biomass was recorded for sesbania which was at par with cowpea whereas the lowest biomass was recorded for pigeonpea and guar. Averaged across years, the greatest DM shoot biomass was obtained for sesbania and the lowest for guar. Nitrogen concentration in shoot biomass of legumes did not vary significantly among legumes. The shoot biomass N in legumes however varied with the year. Averaged across years, the greatest N was produced in cowpea and sesbania and the lowest in pigeonpea and guar. Thus, greatest N was returned to soil in the green manuring of cowpea and sesbania.

Paddy yield of rice: The data obtained on paddy yield of rice for three consecutive years (2001/02, 2002/03 and 2003/04) as influenced by green manuring of summer legumes and fertilizer N is presented in Table 2. The results showed that in each year the paddy yields of rice were significantly ($p < 0.05$) greater in legumes than in the fallow-based rice-wheat plot. The differences among legume plots were, however, mostly at par with each other. The average effect of three years showed that the greatest paddy yield was obtained in cowpea plot which was followed closely by sesbania and mungbean plot. The lowest paddy yield was recorded in the fallow plot. Averaged across years, the greatest increase of 22-23% in paddy yield occurred in cowpea or sesbania plot and the lowest of 12.5% in guar plot.

The results further revealed that paddy yield was significantly ($p < 0.05$) greater in the N fertilized (+N) than in the no N fertilized (ON) treatment during all the three years. However, the increases due to N fertilization were only 15 to 17%.

The interaction between fertilizer N and legume treatments were non-significant. These results suggested that legumes contributed substantially in the improvement of paddy yield. This could be due to contribution of N by legumes as fertilizer N application increased paddy yield only by 17% which under normal situation could be up to 80% in this part of the world.

Straw yield of rice: The results obtained on straw yield of rice followed similar pattern of response to green manuring of legumes and fertilizer N as that of grain yield. The straw yield was significantly (< 0.05) greater in the legumes than in the fallow-based rice-wheat plot during all the three years (Table 3). The differences among legume plots were, however, not remarkable. The average of three years data showed that the greatest straw yield of rice was obtained for sesbania which was followed closely by mungbean and cowpea plots. The straw yields of rice in the other three legume plots were close to each. These results suggested that incorporating legumes in the gap between wheat harvest and rice plantation enhanced the straw yield of rice significantly. The improvement in straw yield ranged from 12 % by guar to 23 % by sesbania compared with the fallow treatment.

Like grain yield, the straw yield of rice was also significantly greater in the +N than in the ON treatments during all the three years. The N fertilizer treatment increased the straw yield of rice from 14% in 2001/02 to 17% in 2003/04 over the ON treatment. Like for grain yield, the interactions between legume and N fertilizer for straw yield were also not significant in any year indicating that the role of each factor was independent of each other.

Nitrogen contents of rice

Grain N: The legumes as well as N fertilizer treatments significantly influenced the N concentration in rice grain. The N concentration in rice grain was significantly greater in the legumes than in the fallow-based rice-wheat plots during all the three years (Table 4). Averaged across years, differences among the legumes plots for N concentration in rice grain were not significant. It was also observed that N concentration in rice grain was significantly and consistently greater in the +N than in the ON treatment during all the three years. The average of three years data revealed that application of fertilizer N increased the N concentration in rice grain by 14% over the ON treatment.

Statistical analysis of the data showed that the interactions between fertilizer N and legumes for N concentration in rice grain were not significant in any of the three years.

Straw N: The N concentration in rice straw was influenced significantly both by the legumes and the N fertilizer treatments. The N concentration in rice straw was consistently greater in the legumes than in the fallow-based rice-wheat plot during all the three years (Table 5). The average of three years data revealed that maximum N concentration of 0.313% in rice straw was found in the sesbania plot. However, differences in straw N among the legumes were not significant. The N concentration in rice straw was also consistently and significantly greater in the +N than in the ON treatment during all the three years. Averaged across years, the N fertilizer application increased N concentration in rice straw by 24% over the ON treatment. Statistical analysis of the data showed that the interactions between N fertilizer and legumes for N concentration in rice straw were not significant in any year.

Table 1. Shoot biomass and nitrogen yields of legumes used as green manure in rice-wheat system.

Legumes	2001	2002	2003	mean
DM Shoot biomass (kg ha⁻¹)				
Mungbean	1450a*	637bc	2625b	1571b
Cowpea	1262a	1562a	4238a	2354a
Soybean	1137a	1375a	1350c	1287b
Sesbania	1137a	1612a	4350a	2367a
Pigeonpea	362b	1350a	1463c	1058bc
Guar	525b	800b	1650c	992c
N concentration in shoot biomass (%)				
Mungbean	0.853b	0.678c	0.906a	0.812a
Cowpea	1.446a	1.011a	0.973a	1.143a
Soybean	1.262a	0.768b	0.692b	0.907a
Sesbania	1.241a	0.831b	0.816a	0.963a
Pigeonpea	1.267a	0.864b	0.890a	1.007a
Guar	1.317a	1.118a	0.985a	1.14a
Total N in shoot biomass of legumes (kg N ha⁻¹)				
Mungbean	12.37b	4.32b	23.78b	13.49b
Cowpea	18.25a	15.79a	41.23a	25.09a
Soybean	14.35b	10.56a	9.34c	11.42b
Sesbania	14.11b	13.40b	35.50a	21.00a
Pigeonpea	4.59c	11.66a	13.02c	9.76b
Guar	6.91c	8.94ab	16.25c	10.70b

*Means followed by different letter(s) within column for a particular parameter differ significantly (p<0.05)

Table 2. Rice grain yield (kg ha⁻¹) as influenced by green manure legumes and fertilizer N in rice-wheat system.

Treatment	2001/02			2002/03			2003/04			Average (2001/02-2003/04)		
	0N	+N	Mean	0N	+N	Mean	0N	+N	Mean	0N	+N	Mean
Fallow	3642	4107	3875c	3808	4368	4088c	3273	3819	3546b	3574	4098	3836b
Mungbean	4556	5154	4855a	4245	5401	4823ab	3776	4692	4234a	4192	5082	4637a
Cowpea	4559	5008	4784a	4520	5398	4959a	3909	4809	4359a	4329	5072	4701a
Soybean	3784	4496	4140b	4411	4953	4682b	4277	4460	4369a	4157	4636	4397a
Sesbania	4222	5207	4715a	4952	5621	5287a	3803	4349	4076a	4326	5059	4692a
Pigeonpea	4443	5029	4736a	4130	4642	4386bc	3426	4128	3777b	4000	4600	4300a
Guar	4360	4951	4656a	4025	4704	4365bc	3563	4278	3921ab	3983	4644	4314a
Mean	4224B	4850A		4299B	5012A		3718B	4362A		4080B	4742A	

*Means followed by different letter(s) within columns for legumes or within row for fertilizer treatments differ significantly (p<0.05)

Table 3. Rice straw yield (kg ha⁻¹) as influenced by green manure legumes and fertilizer N in rice-wheat system.

Treatment	2001/02			2002/03			2003/04			Average (2001/02-2003/04)		
	0N	+N	Mean	0N	+N	Mean	0N	+N	Mean	0N	+N	Mean
Fallow	7000	7875	7438c	7313	8375	7844c	6263	7313	6788d	6859	7854	7357c
Mungbean	8750	9750	9250a	8834	10271	9553b	7250	9063	8157ab	8278	9695	8986a
Cowpea	8750	9750	9250a	8167	10167	9167bc	7500	9125	8313a	8139	9681	8910a
Soybean	7250	8500	7875c	7792	8833	8313de	8213	8688	8451a	7752	8674	8213b
Sesbania	8125	10188	9157a	9542	10625	10084a	7313	8438	7876b	8327	9750	9039a
Pigeonpea	8500	9500	9000a	8396	9438	8917cd	6563	7750	7157c	7820	8896	8358b
Guar	8375	9375	8875b	7750	9188	8469d	6875	8063	7469bc	7667	8875	8271b
Mean	8107B	9277A		8256B	9557A		7140B	8349A		7834B	9061A	

*Means followed by different letter(s) within columns for legumes or within row for fertilizer treatments differ significantly (p<0.05)

Table 4. Rice grain N (%) as influenced by green manure legumes and fertilizer N in rice-wheat system.

Treatment	2001/02			2002/03			2003/04			Average (2001/02-2003/04)		
	0N	+N	Mean	0N	+N	Mean	0N	+N	Mean	0N	+N	Mean
Fallow	1.194	1.425	1.310b	1.338	1.629	1.484b	1.392	1.809	1.601a	1.308	1.621	1.465b
Mungbean	1.740	1.944	1.842a	1.509	1.857	1.683ab	1.797	1.923	1.860a	1.682	1.908	1.795a
Cowpea	1.692	1.863	1.778a	1.635	1.812	1.724a	1.647	2.034	1.841a	1.658	1.903	1.781a
Soybean	1.740	1.884	1.812a	1.680	2.094	1.887a	1.713	2.025	1.869a	1.711	2.001	1.856a
Sesbania	1.725	2.022	1.874a	1.581	1.764	1.673ab	1.824	1.779	1.802a	1.710	1.855	1.783a
Pigeonpea	1.773	1.962	1.868a	1.608	2.127	1.868a	1.677	1.806	1.742a	1.686	1.965	1.826a
Guar	1.740	1.869	1.805a	1.641	1.830	1.736a	1.692	1.773	1.733a	1.691	1.824	1.758a
Mean	1.658A	1.853A		1.570B	1.873A		1.677A	1.878A		1.635A	1.868A	

*Means followed by different letter(s) within columns for legumes or within row for fertilizer treatments differ significantly (p<0.05)

Table 5. Rice straw N (%) as influenced by green manure legumes and fertilizer N in rice-wheat system.

Treatment	2001/02			2002/03			2003/04			Average (2001/02-2003/04)		
	0N	+N	Mean	0N	+N	Mean	0N	+N	Mean	0N	+N	Mean
Fallow	0.270	0.280	0.275a	0.082	0.119	0.101a	0.209	0.233	0.221a	0.187	0.211	0.199a
Mungbean	0.299	0.424	0.361a	0.134	0.158	0.146a	0.291	0.325	0.308a	0.241	0.302	0.272a
Cowpea	0.289	0.311	0.300a	0.116	0.152	0.134a	0.233	0.255	0.244a	0.213	0.239	0.226a
Soybean	0.281	0.358	0.319a	0.130	0.221	0.176a	0.218	0.323	0.270a	0.210	0.300	0.255a
Sesbania	0.363	0.549	0.456a	0.156	0.173	0.164a	0.309	0.328	0.318a	0.276	0.350	0.313a
Pigeonpea	0.256	0.363	0.310a	0.146	0.161	0.153a	0.237	0.263	0.250a	0.213	0.262	0.237a
Guar	0.290	0.343	0.316a	0.137	0.215	0.176a	0.255	0.259	0.257a	0.227	0.272	0.250a
Mean	0.292A	0.375A		0.128A	0.171A		0.250A	0.284A		0.224A	0.277A	

*Means followed by different letter(s) within columns for legumes or within row for fertilizer treatments differ significantly ($p < 0.05$)

Table 6. Total rice N (kg ha⁻¹) as influenced by green manure legumes and fertilizer N in rice-wheat system.

Treatment	2001/02			2002/03			2003/04			Average (2001/02-2003/04)		
	0N	+N	Mean	0N	+N	Mean	0N	+N	Mean	0N	+N	Mean
Fallow	62	81	71b	57	81	69b	59	86	72b	59	83	71b
Mungbean	105	141	123a	76	116	96a	89	120	104a	90	126	108a
Cowpea	102	124	113a	83	113	98a	82	121	101a	89	119	104a
Soybean	86	115	101a	84	123	104a	91	118	105a	87	119	103a
Sesbania	102	161	132a	93	118	105a	92	105	98a	96	128	112a
Pigeonpea	101	133	117a	79	114	96a	73	95	84ab	84	114	99a
Guar	100	125	112a	77	106	91a	78	97	87ab	85	109	97a
Mean	94B	126A		78B	110A		80B	106A		84B	114A	

*Means followed by different letter(s) within columns for legumes or within row for fertilizer treatments differ significantly ($p < 0.05$)

Total N uptake: The green manure legumes and N fertilizer significantly increased the total N uptake in rice crop compared with that in the fallow-based rice-wheat plot (Table 6). The N uptake in rice was significantly greater in the legumes than in the fallow-based rice-wheat plot during all the three years. Averaged across years, differences among the legumes treatments were not remarkable. The N uptake in rice was also significantly greater for the +N than for the 0N treatment during all the three years. Nitrogen fertilizer application (+N), on average, increased the N uptake in rice by about 33% over the 0N treatment. The interactions between N fertilizer and legumes for N uptake in rice were not significant at any occasion during three years.

Soil organic fertility: The results showed that legumes incorporation in soil in 2001 did not affect the level of SOM. The average contents of SOM were 0.99% in the legumes and 0.95% in the fallow-based rice-wheat plot (Table 7). The same trend was observed for total N and mineral N. On average, the total N content of soil was 0.063% in the legumes and 0.070% in the fallow plot. Similarly, the mineral N content of soil was 6.41 mg kg⁻¹ in the legumes and 7.89 mg in the fallow plot.

The results obtained on soil organic fertility after green manuring of summer legumes in summer 2002 showed that the SOM was consistently greater in the legumes than in the fallow plot. On average, it was 1.17% in legumes and 1.05% in the fallow plot (Table 7). The level of SOM, however, varied with the type of green manure legume. The greatest SOM of 1.24% was found in the sesbania and lowest of 1.09% in the guar plot. The same trend was observed for total N in the legumes and fallow plots. Like SOM, the total N was greater in the legumes than in the fallow treatment. The average total N was 0.114% in legumes and 0.090% in the fallow plot. Among the legume treatments, differences for total N were not substantial. The trend for mineral N content of soil in the legumes and fallow plot was similar to that for SOM and total N. Like SOM and total N, the mineral N was greater in the legumes than in the fallow plot. On average, the mineral N was 21.05 mg kg⁻¹ soil in the legumes and 8.30 mg kg⁻¹ soil in the fallow treatment. The maximum mineral N of

39.0 mg kg⁻¹ soil was found in sesbania and lowest of 11.8 mg in the cowpea plot.

Like in 2001 and 2002, the SOM in 2003 was also consistently greater in the legumes than in the fallow plot (Table 7). On average, it was 1.12% in the legumes and 1.02% in the fallow plot. The level of SOM, however, varied with the type of green manure legume. The greatest SOM (1.31%) was found in the sesbania and lowest (1.06%) in the guar plot. The same trend was observed for total N. The average total N was greater in the legumes (0.064%) than in the fallow (0.040%) plot. The trend for mineral N content of soil was similar to that for SOC and total N. Like SOM and total N, the mineral N was greatest in the legumes (25.79 mg kg⁻¹) and lowest in the fallow (7.44 mg kg⁻¹) plot. Among the legume plots, the maximum mineral N of soil was found in sesbania (45.41 mg kg⁻¹) and lowest (13.45 mg kg⁻¹) in the cowpea plot.

These results suggested that all fertility parameters (SOM, total N, mineral N) were considerably greater in the legumes-based than in the fallow-based rice-wheat plot.

Discussion

Planting of a legume immediately after wheat harvest and green manuring of same legume in soil before rice plantation can improve the yields of rice and the soil organic fertility. We observed that the green manure legumes increased the grain and straw yield of rice. Among legumes, sesbania and cowpea exerted remarkable influence on grain and straw yield of rice while the effect of guar was minimal. Both paddy and straw yields of rice had strong correlation with the biomass of green manure legumes produced during all the three years. The positive effect of green manure legumes was not limited to rice but was also observed considerably on the subsequent wheat during all the three years (Shah, personal communication). Using the average data of three years, regression models were developed to predict paddy ($y = 0.98b + 4325$) and straw ($y = 2.31b + 8597$) yields (y) of rice from the amount of legumes biomass produced (b) and used as green manure in the rice-wheat system. Thus knowing the biomass of green manure legumes, one would predict the expected yields of subsequent rice crop.

Table 7. Soil organic fertility as influenced by green manure summer legumes in rice-wheat system.

Year	Treatment	Soil organic matter (%)	Soil total N (%)	Soil mineral N (mg kg ⁻¹)
2001	Fallow	0.95	0.070	7.89
	Mungbean	1.01	0.065	6.94
	Cowpea	1.02	0.070	8.01
	Soybean	1.02	0.070	6.92
	Sesbania	1.04	0.060	5.58
	Pigeonpea	0.96	0.055	4.94
	Guar	0.97	0.060	6.07
	Mean (legumes)	1.00	0.063	6.41
2002	Fallow	1.05	0.045	8.3
	Mungbean	1.17	0.054	10.80
	Cowpea	1.19	0.055	11.8
	Soybean	1.22	0.060	18.5
	Sesbania	1.24	0.056	39.0
	Pigeonpea	1.09	0.053	26.4
	Guar	1.13	0.063	19.8
	Mean (legumes)	1.17	0.057	21.05
2003	Fallow	1.06	0.040	7.44
	Mungbean	1.22	0.080	17.82
	Cowpea	1.25	0.062	13.45
	Soybean	1.22	0.064	20.22
	Sesbania	1.31	0.065	45.41
	Pigeonpea	1.15	0.057	32.26
	Guar	1.02	0.055	25.56
	Mean (legumes)	1.20	0.064	25.79
Average 2001-03	Fallow	1.02	0.052	7.88
	Mungbean	1.13	0.066	11.85
	Cowpea	1.15	0.062	11.09
	Soybean	1.15	0.065	15.21
	Sesbania	1.20	0.060	30.00
	Pigeonpea	1.07	0.055	21.20
	Guar	1.04	0.059	17.14
	Mean (legumes)	1.12	0.061	17.75

The positive effects of green manure legumes on subsequent rice could be partly associated with the amounts of plant food nutrients returned to soil in legumes biomass and their subsequent utilization by rice crop. As we are aware that the rice-wheat cropping system is highly nutrient exhaustive and annually remove more than 650 kg ha⁻¹ of N, P, and K, and 0.5-1.0 kg ha⁻¹ Zn, 2-3 kg ha⁻¹ Fe and 3.0-3.5 kg ha⁻¹ Mn. Our data revealed that cowpea in 2003 contributed more than 41 kg N ha⁻¹ along with other nutrients. The nutrients contributed from legumes could be partly responsible for improvement in the yield of subsequent crop.

The variable effects of legumes on crop yields could be associated with the amount of plant biomass produced by the legumes, larger the biomass greater were the effects. This is someone would expect as large plant biomass return large amounts of nutrients to soil compared with the small plant biomass as the case in our study. The addition of more plant biomass not only add plant food nutrients to soil but also improve other soil conditions such as better aeration, porosity, temperature, microbial activities, water holding capacity and many others. The cultivation of legumes such as soybean, mungbean, cowpea, and pigeonpea has been shown to have had positive N balances in soil, and soil properties such as organic C, total and mineral N were also improved despite the fact legumes were not incorporated in soil (Shah *et al.*, 2004).

Our results also showed that green manure legumes not only increased the yields of subsequent rice crop but also improved the soil organic fertility. The soil analysis immediately after incorporation of legumes in soil in the first

season showed that legumes incorporation in soil had not exerted any discernable effect on any of the soil organic fertility parameter rather nutrient contents in the legumes treatments showed a declining trend compared with those in the fallow treatment. These results are perhaps not surprising as soil samples were taken immediately after the return of legumes biomass to soil. The benefits of legumes incorporation, if any, could be observed when legumes biomass is decomposed. The decomposition of legume biomass would require a month or so. The considerable increases in yields of the following crop by the legumes treatments add further weight to the assumption that legumes improve the soil organic fertility and in turn yield of the following crop. It was, however, observed that comparing with the initial nutrient levels in the composite sample, the legumes treatments did enhance some of the soil organic fertility parameters such as organic C, extractable P, and total N while some such as mineral N, NH₄-N, extractable K remained unchanged. These increase and decrease in the nutrient levels of soil after legumes incorporation are expected. When organic C is added to soil, it promotes microbial activities in soil and their requirements for different nutrients are increased (Shah *et al.*, 2002). Thus, the addition of carbonaceous material to soil will encourage immobilization of available nutrients particularly available N and P as their requirements by microbes are relatively high. This results in temporary decline in the available pool of N and P in soil. However, this decline is temporary and once the C/N ratio of the organic matter is stabilized (narrowed down), the organically bound nutrients

begin to mineralize and hence the available pools of nutrients begin increases. These results are supported by the findings of Shah and Khan (2003) where wheat straw with wide C/N ratio always exhibited N immobilization, the mungbean and pea crop residues showed immobilization during the first four weeks of incubation, and the lentil and soybean crop residues promoted N mineralization from the very beginning.

However, soil analysis afterwards during the course of the experiment and at the end of the experiment clearly shown that all of the fertility parameters (evaluated in this study) were consistently greater in the legumes green manured than in the un-manured fallow treatment. The beneficial effect of green manuring of legumes on rice yields and on soil organic fertility is perhaps not surprising. As evident from our data that legumes biomass contain large amounts of nitrogen (N) and reasonable amounts of other major and micronutrients while soil of the experimental site was low in N and other parameters of organic fertility. The return of such organic materials would expect to improve the crop yields through improvement in soil organic fertility and other physical, chemical and microbiological properties of soil. It has been widely documented that the inclusion of legumes in cropping system improved yields of both companion and subsequent crops (Varvel, 2000; Shah *et al.*, 2003; Iqbal *et al.*, 2006; Shafi *et al.*, 2007; Bakht *et al.*, 2009) and soil organic fertility (Shah *et al.*, 2003; Shafi *et al.*, 2007; Bakht *et al.*, 2009). Similarly, the return of organic materials/crop residues to low fertile soils increased crop yields (Shah *et al.*, 2003; Shafi *et al.*, 2007).

Our data suggest that the green manure legumes significantly increased the grain, straw and N yields of rice and improved the soil organic fertility in rice-wheat system. Therefore, a suitable green manure legume is beneficial to grow in the gap between wheat harvest and rice plantation for sustainable rice-wheat system.

Conclusions

This experiment has shown that the green manure legumes increased the grain, straw and N yields of rice and improved the soil organic fertility by more than 20% in rice-wheat system. Our results thus suggest that gap between wheat harvest and rice plantation can be effectively used to grow any green manure legume in general and sesbania or cowpea in particular in Khyber Pakhtunkhwa for sustainable rice-wheat system. Although this technology was tested in Peshawar valley, it has equal applications any where in the rice-wheat system.

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