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SUSTAINING RICE-WHEAT SYSTEM THROUGH MANAGEMENT OF LEGUMES II. EFFECT OF GREEN MANURE LEGUMES AND N FERTILIZER ON WHEAT YIELD

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Abstract

This study was undertaken to assess the effect of 6 green manure legumes viz., mungbean (*Vigna radiata*), cowpea (*Vigna unguiculata*), soybean (*Glycine max*), sesbania (*Sesbania rostrata*), pigeonpea (*Cajanus cajan*) and guar (*Cyamopsis tetragonoloba*) and N fertilizer on wheat yield in rice-wheat system for three years (2001/02-2003/04) at Agriculture Research Institute, Tarnab, Peshawar, Pakistan. The grain, straw and N yields of wheat were significantly greater in the green manure legumes than in the fallow-based rice-wheat rotation during all the three years. The average improvement gained from the green manure legumes relative to fallow-based cropping, was 18.1% for grain yield, 18.4% for straw yield and 59.7% for total N uptake in grain and straw of wheat crop. The greatest gain of 27.5% in grain yield, 24.5% in straw yield and 82.8% in N uptake of wheat occurred due to green manuring of sesbania. The effects of N fertilizer on grain, straw and N yields of wheat were also significant during all the three years. The average increase by N fertilizer was 18.2% in grain, 19.2% in straw and 46.8% in N yields of wheat crop compared with no N fertilizer treatment. Our results thus suggest that involvement of green manure legumes in rice-wheat system is highly beneficial for sustainable crop production and must be made an integral part of the cropping system.

Introduction

Rice and wheat are the leading staple food crops of the people of south East Asia. More than 90% of rice and 43% of wheat in the world is produced and consumed in Asia. The rice-wheat system, one of the major cropping systems of the South Asia and parts of East Asia, requires special management. It is highly nutrient exhaustive system and annually removes more than 650 kg ha^{-1} of nutrients from the soil. The wheat crop alone annually removes about 390 kg ha^{-1} of nutrients from the soil. The rice-wheat cropping system therefore causes a considerable depletion of soil nutrients and consequently requires heavy use of fertilizers each year to realize the potential yields. In some developed countries and energy rich Less Developed Countries (LDC's) chemical fertilizers are supplied in sufficient amount but in majority of developing countries, however, this is not possible because of high cost of fertilizers, low per capita income and limited credit facilities available to farmers. As a consequence, farmer either uses the available organic sources or the crops remain under-fertilized. The result is failure to obtain the potential yield of major crops despite the fact that large responses of wheat and rice to fertilizers are well documented (Shah *et al*., 2003; Suman, 2004; Shafi *et al*., 2007; Bakht *et al*., 2009; 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 ability of legumes to fix atmospheric N, their nodulated roots and plant biomass represent a valuable source of N and other nutrients (Shah *et al*., 2003).

Research has shown that the yields of cereals grown after legumes are generally increased often as much as by 80% compared with cereals grown after cereals. 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). Rotation with leguminous green manure can result in significant inputs of nitrogen into the soil-plant system and subsequent crops (Fillery, 2001; Ramos *et al*., 2001; Cobo *et al*., 2002b). Mann *et al*., (2000) reported that green manuring of *Sesbania rostrata* (a stem nodulated and high N_2 fixing legume) can significantly improve the yield of following rice crop and saves about 50-60% N. Its continuous use for 3 years can results 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.

This paper report the results of a three years long field experiment where the effect of six green manure legumes e.g., mungbean, cowpea, soybean, sesbania, pigeon pea and guar were evaluated on wheat yield in rice-wheat system. Legumes were grown for about 50 days after wheat harvest and incorporated well into the soil before rice plantation. The effect of same legumes on rice yield has been reported elsewhere (Shah *et al*., 2011).

Materials and Methods

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 such green manure legumes and fertilizer N on rice and wheat production. The soil and climatic conditions of the experimental site are described in Shah *et al*., (2011).

A split-plot field experiment involving legumes in sub-plots and N fertilizer in main plots was commenced in summer 2001. Soon after wheat harvest, the site was cultivated to six legumes viz. mungbean, cowpea, soybean, sesbania, pigeon pea, and guar and left one fallow plot. Triple super phosphate (TSP) at 90 kg P_2O_5 ha^{-1} was applied uniformly to each treatment plot before sowing. After about 50 days of growth, 1 m^2 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. The site was planted to rice 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 recorded. This paper report the results of wheat yield.

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

Results

Grain yield of wheat: The data obtained on grain yield of wheat during three years (2001/02, 2002/03 and 2003/04) as influenced by the green manure legumes and N fertilizer are presented in Table 1. The results showed that in each year the grain yield of wheat were significantly ($p<0.05$) greater in the legumes-based (LRW) than in the fallow-based rice-wheat (FRW) plot. Averaged across the N fertilizer treatment, legumes increased the grain yield of wheat by 13.8% in 2001/02, 23.5% in 2002/03 and 17.0% in 2003/04 relative to the FRW plot. The overall gained in grain yield of wheat from the legumes relative to FRW, during three years was 18.1%. The effect however varied with green manure legumes. In each year, sesbania plot produced the greatest and guar the lowest grain yield of wheat. Relative to FRW plot, sesbania increased the grain yield of wheat by 22.2% in 2001/02, 32.7% in 2002/03 and 26.5% in 2003/04. The corresponding increases by guar were 5.4, 13.3 and 8.9%, respectively.

The results further revealed that grain yield of wheat was significantly ($p<0.05$) greater in the N fertilized (+N) than in the no N fertilized (ON) treatment during all the three years. Averaged across the legumes plots, N fertilizer increased the grain yield of wheat by 19% in 2001/02, 17% in 2002/03 and 19% in 2003/04 compared with the 0N treatment.

The interactions between N fertilizer and legume treatments were however non-significant. These results suggested that green manure legumes contributed substantially in the improvement of grain yield of wheat.

Straw yield of wheat: The results obtained on straw yield of wheat followed similar pattern of response to the green manure legumes and N fertilizer as that of grain yield. In each year, the LRW plots produced significantly (<0.05) greatest straw yield of wheat relative to LRW (Table 2). Averaged across the N fertilizer treatment, legumes increased the straw yield of wheat by 13.9% in 2001/02, 21.4% in 2002/03 and 20.0% in 2003/04 relative to the FRW plot. The overall gained in straw yield of wheat from the legumes relative to FRW, during three years was 18.4%. Like for grain yield, the effect for straw yield varied with type of green manure legumes. In each year, sesbania plot produced the greatest and guar the lowest straw yield of wheat. Relative to FRW plot, sesbania increased the straw yield of wheat by 22.6% in 2001/02, 30.5% in 2002/03 and 19.0% in 2003/04. The corresponding increases by guar were 4.3, 12.5 and 16.9%, respectively.

The effect of N fertilizer on straw yield was also significant in each year. Averaged across the legumes plots, N fertilizer increased the straw yield of wheat by 19% in 2001/02, 17% in 2002/03 and 22% in 2003/04 with overall increase of 19% compared with the 0N treatment.

The interactions between N fertilizer and legume treatments were however non-significant. These results suggested that green manure legumes contributed substantially in the improvement of straw yield of wheat.

Table 1. Wheat 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	2678	3091	2885c	3199	3655	3427c	3121	3624	3373c	2999	3457	3228c
Mungbean	2883	3513	3198b	4252	4738	4495a	3931	4180	4056a	3689	4144	3916a
Cowpea	3075	3863	3469a	4118	4682	4400a	3779	4155	3967a	3657	4233	3945a
Soybean	3090	3511	3301a	4113	4651	4382a	3544	4225	3885a	3582	4129	3856ab
Sesbania	3305	3745	3525a	4261	4837	4549a	3550	4985	4268a	3705	4522	4114a
Pigeonpea	2903	3438	3171b	3401	3969	3685bc	3278	4385	3832ab	3194	3931	3562b
Guar	2703	3378	3041bc	3261	4503	3882b	3473	3876	3675bc	3146	3919	3532bc
Mean	**2948b**	**3506a**		**3801b**	**4434a**		**3525b**	**4204a**		**3425b**	**4048a**	

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

Table 2. Wheat 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	4750	5500	5125c	5868	6498	6183b	5313	6500	5907b	5310	6166	5738c
Mungbean	5168	6250	5709ab	7375	8588	7982a	6462	7688	7075a	6658	7524	6922a
Cowpea	5480	6875	6178a	7325	8164	7745a	6118	7650	6884a	6308	7563	6935a
Soybean	5615	6250	5933a	7282	8240	7761a	5705	7513	6609a	6201	7334	6768ab
Sesbania	5819	6750	6285a	7523	8610	8067a	7431	7733	7582a	6924	7698	7311a
Pigeonpea	5041	6125	5583b	5988	7054	6521b	6386	8125	7256a	5805	7101	6453b
Guar	4810	5875	5343bc	5875	8036	6956ab	6250	8000	7125a	5645	7304	6474b
Mean	**5240b**	**6232a**		**6748b**	**7884a**		**6238b**	**7601a**		**6122a**	**7241a**	

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

Nitrogen contents of wheat

Grain N: The N concentration in wheat grain was consistently greater in the legumes than in the fallow-based rice-wheat plots during all the three years (Table 3). Averaged across years, differences among the legumes plots for N concentration in wheat grain were not significant. It was also observed that N concentration in wheat grain was consistently greater in the +N than in the 0N treatment during all the three years. The average of three years data revealed that application of fertilizer N increased the N concentration in wheat grain by 26.3% over the 0N treatment.

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

Straw N: The N concentration in wheat straw was consistently greater in the legumes than in the fallow-based rice-wheat plot during all the three years (Table 4). However, differences in N concentration in wheat straw among the legume plots were not significant during any of the three years. The N concentration in wheat straw was also consistently greater in the +N than in the 0N treatment during all the three years. Averaged across years, the N fertilizer application increased N concentration in wheat straw by 17.8% over the 0N treatment. Statistical analysis of the data showed that the interactions between N fertilizer and legumes for N concentration in wheat straw were not significant in any year.

Total N uptake: The green manure legumes and N fertilizer significantly increased the total N uptake in wheat crop compared with that in the fallow-based rice-wheat plot (Table 5). The N uptake in wheat was significantly greater in the legumes than in the fallow-based rice-wheat plot during all the three years. Averaged across years, the greatest N uptake in wheat was produced in sesbania and lowest in guar plot. However, differences among the legumes treatments were not remarkable. The N uptake in wheat 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 wheat by about 46.8% over the 0N treatment. The interactions between N fertilizer and legumes for N uptake in wheat were not significant at any occasion during three years.

Table 3. Wheat 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	1.020	1.230	1.125b	1.100	1.640	1.370c	1.020	1.240	1.130b	1.047	1.370	1.208c
Mungbean	1.390	1.570	1.480a	1.440	1.930	1.685ab	1.330	1.570	1.450a	1.387	1.690	1.538a
Cowpea	1.230	1.440	1.335a	1.460	2.100	1.780a	1.330	1.510	1.420a	1.340	1.683	1.512ab
Soybean	1.070	1.460	1.265ab	1.420	2.210	1.815a	1.350	1.610	1.480a	1.280	1.760	1.520a
Sesbania	1.490	1.630	1.560a	1.600	2.550	2.075a	1.480	1.620	1.550a	1.523	1.933	1.728a
Pigeonpea	1.300	1.550	1.425a	1.240	1.830	1.535b	1.440	1.600	1.520a	1.327	1.660	1.493b
Guar	1.370	1.510	1.440a	1.310	1.540	1.425bc	1.390	1.760	1.575a	1.357	1.603	1.480bc
Mean	**1.267a**	**1.484a**		**1.367b**	**1.971a**		**1.334a**	**1.559a**		**1.323b**	**1.671a**	

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

Table 4. Wheat 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	0.313	0.385	0.349a	0.276	0.328	0.302a	0.317	0.368	0.343a	0.302	0.360	0.331a
Mungbean	0.477	0.521	0.499a	0.398	0.505	0.452a	0.502	0.588	0.545a	0.459	0.538	0.499a
Cowpea	0.477	0.481	0.479a	0.420	0.508	0.464a	0.490	0.564	0.527a	0.462	0.518	0.490a
Soybean	0.431	0.502	0.467a	0.418	0.545	0.482a	0.466	0.608	0.537a	0.438	0.552	0.495a
Sesbania	0.389	0.483	0.436a	0.416	0.477	0.447a	0.529	0.527	0.528a	0.445	0.496	0.470a
Pigeonpea	0.411	0.527	0.469a	0.361	0.521	0.441a	0.515	0.543	0.529a	0.429	0.530	0.480a
Guar	0.459	0.492	0.476a	0.394	0.510	0.452a	0.488	0.562	0.525a	0.447	0.521	0.484a
Mean	**0.422a**	**0.484a**		**0.383a**	**0.485a**		**0.472a**	**0.537a**		**0.426a**	**0.502a**	

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

Table 5. Total wheat 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	42.2	59.2	50.7c	51.4	81.3	66.3c	48.7	68.9	58.8b	47.4	69.8	58.6b
Mungbean	64.7	87.7	76.2a	90.6	134.8	112.7a	84.7	110.8	97.8a	80.0	111.1	95.6a
Cowpea	64.0	88.7	76.3a	90.9	139.8	115.3a	80.2	105.9	93.1a	78.4	111.5	94.9a
Soybean	57.3	82.6	69.9	88.8	147.7	118.3a	74.4	113.7	94.1a	73.5	114.7	94.1a
Sesbania	71.9	93.6	82.8a	99.5	164.4	131.9a	91.8	121.5	106.7a	87.7	126.5	107.1a
Pigeonpea	58.5	85.6	72.0ab	63.8	109.4	86.6b	80.1	114.3	97.2a	67.4	103.1	85.3a
Guar	59.1	79.9	69.5b	65.9	110.3	88.1b	78.8	113.2	96.0a	67.9	101.1	84.5a
Mean	**59.7b**	**82.5a**		**78.7b**	**126.8a**		**77.0b**	**106.9a**		**71.8b**	**105.4a**	

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

Discussion

Planting of a legume immediately after wheat harvest and green manuring of same legume in soil before rice plantation can improve yields of subsequent crops. The effect of green manure legumes was not only significant on the following rice (Shah *et al*., 2011) but was also observed on the subsequent wheat crop. We found that the green manure legumes significantly increased the grain, straw and N yields of wheat. Among legumes, sesbania and cowpea exerted remarkable influence while the effect of guar was minimal. The positive effects of green manure legumes on subsequent crops could be partly associated with the amounts of plant food nutrients in general and N in particular, returned to soil in legumes biomass. 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. Thus nutrients contribution from legumes could be partly responsible for improvement in yields of subsequent rice and wheat crops. The contribution of nutrients from legumes can be judged from the facts that both grain and straw yields of wheat were about 17% greater in the legumes than in the fallow-based cropping with no N fertilizer application. Such increase in the legumes plots was only 20 % when N fertilizer was applied. These results indicated that the contribution of green manure legumes in yield increase was more than the N fertilizer. It has been reported that rotation with leguminous green manure can results in significant inputs of nitrogen into the soil-plant system and subsequent crops (Fillery, 2001; Ramos *et al*., 2001; Cobo *et al*., 2002b), and N availability from leguminous residues can be very high under tropical conditions (Abbasi *et al*., 2009; Cobo *et al*., 2002a). Legume mass characteristics of low C/N ratio, the high concentration of soluble compounds and low lignin and ploychenol contents favours the rapid microbial degradation (Cobo *et al*., 2002a; Shah & Khan, 2003) and subsequent release of nutrients to plants.

The variable effects of legumes on crop yields could be associated with the amount of plant biomass produced by the legumes (Shah *et al*., 2011), 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 (Shah *et al*., 2003), 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 are similar to the results of many other workers where legumes improved yields of both companion and subsequent crops (Varvel, 2000; Muhammad *et al*., 2003; Shah *et al*., 2003; Iqbal *et al*., 2006; Shafi *et al*., 2007; Bakht *et al*., 2009; Muhammad *et al*., 2008) 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 wheat in rice-wheat system. Earlier the rice yields and soil fertility were also improved by same green manure legumes. Thus, it could be concluded that 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 and N fertilizer significantly increased the crop and N yields of wheat in rice-wheat cropping system. The average improvement gained from the green manure legumes relative to fallow-based cropping, was 18.1% for grain yield, 18.4% for straw yield and 59.7 % for total N uptake in grain and straw of wheat crop. The greatest gain of 27.5% in grain yield, 24.5% in straw yield and 82.8% in N uptake of wheat occurred due to green manuring of sesbania. The effects of N fertilizer on grain, straw and N yields of wheat were also significant during all the three years. The average increase by N fertilizer was 18.2% in grain, 19.2% in straw and 46.8% in N yields of wheat crop compared with no N fertilizer treatment. Our results thus 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 NWFP 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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