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# 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 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.

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$^o$04$'$N, 71$^o$40$'$E) with the objectives to involve green manure legumes in the rice-wheat system for sustainable production and study the effects of six green manure legumes (such as mungbean, cowpea, soybean, sesbania, guar and pigeonpea) and fertilizer N on rice production. The climate is classified as semi-arid tropical. Annual precipitation average 375 mm with summer dominance. The soil of the experimental site was alkaline (pH 7.80), non-saline (EC 2.00 dSm$^{-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 $P_2O_5$ ha$^{-1}$ was applied uniformly to each treatment plot. 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.

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 0N 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 0N 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 0N 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 0N 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 0N treatment during all the three years. Averaged across years, the N fertilizer application increased N concentration in rice straw by 24% over the 0N 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, $NH_4$-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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