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INDUCTION OF MUNGBEAN [*VIGNA RADIATA* (L.) WILCZEK] AS A GRAIN LEGUME IN THE ANNUAL RICE-WHEAT DOUBLE CROPPING SYSTEM

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Abstract

A traditional approach to deal with the declining yields of rice-wheat system has been introduction of pre-rice legumes as manuring crops. However, despite the long-term beneficial effects on soil fertility and productivity of the rice-wheat system, farmers are reluctant in practicing green manuring technology. Major constraints in the adoption of green manuring technology are the additional cost of green manure production and the lack of short-term benefits. An alternate approach i.e., induction of a short-duration grain legume in the rice-wheat system appears to be more attractive as it offers short-term additional benefits to farmers and is equally beneficial in sustaining the productivity of rice-wheat system over time. Present study was carried out to evaluate the induction of short-duration (maturity period, 55-70 days) mungbean [*Vigna radiata* (L.) Wilczek] as a grain legume in the pre-rice niche of the rice-wheat annual double cropping system. The mungbean crop (grown without mineral N fertilizer) produced 1166 kg ha^{-1} of grain in addition to 4461 kg ha^{-1} of the manure biomass (containing 52 kg N ha^{-1}) that was ploughed under before planting rice with urea-N applied in the range of 0–160 kg N ha^{-1}. Averaged across urea-N treatments, manuring significantly increased the number of tillers plant^{-1} (11% increase), rice grain yield (6% increase), grain N content (4% increase) and grain N uptake (9% increase). Significant residual effects of manuring were observed on the subsequent wheat crop showing higher grain yield (21% increase), grain N uptake (29% increase) and straw yield (15% increase). The results suggested the feasibility of including mungbean in the pre-rice niche to improve the productivity of the annual rice-wheat double cropping system.

Introduction

The annual rice-wheat double cropping system occupies 26 million ha in the South and East Asia and contributes to about one-fourth of the regional cereal production (Timsina & Connor, 2001; Prasad & Nagarajan, 2004; Gupta & Seth, 2007). The system has been showing signs of fatigue as indicated by yield decline, negative nitrogen balance and reduced response to the applied mineral N (Duxbury *et al*., 2000; Ladha *et al*., 2003). The major reasons for this yield decline are soil based and include inefficient use of fertilizer-N and a decline in the soil organic matter content (Grace *et al*., 2003; Kukal *et al*., 2009). Sustainability issue of the Asian rice farming systems has been historically addressed by increasing crop diversity, using crop rotations and by inserting pre-rice legumes (Garrity & Becker, 1994; Lauren *et al*., 2001). However, most of the research on legume green manuring pertains to the growth and N_2 fixation of legumes, and effects of green manures on the soil fertility and yields of the succeeding rice crop, whereas relatively less attention has been directed toward the cost effectiveness and adaptability of the green manuring technology for rice production

(Aulakh *et al*., 2000; Yadav *et al*., 2000; Lauren *et al*., 2001; Kolhe & Mittra. 2008). In the annual rice-wheat double cropping system, a major constraint in introducing the green manuring crop in the pre-rice niche is the relatively short time span for the growth of green manuring crop, while soil moisture regime is also not favourable for the cash crop growth (Garrity & Becker, 1994). Prototype legumes for the pre-rice niche include *Sesbania* spp., *Crotalaria juncea*, *Tephrosia purpurea* and more recently the stem-nodulating *S. rostrata* and *Aeschynomene afraspera* (Garrity & Becker, 1994). However, despite the beneficial effects on the soil fertility and sustainable crop production, there are certain constraints in the use of green manuring technology as compared to the mineral N fertilizers. A major constraint is the additional cost for the production of green manure crops. In the long run, however, green manuring may be economical if evaluated in absolute terms (Ali & Narciso, 1994).

Compared to the leguminous manure crops without grain production, inclusion of forage or grain legumes in the rice-wheat system appears to be more attractive as it offers short-term additional benefits to farmers and is equally beneficial in sustaining the resource productivity over time (Ali & Narciso, 1994; Lauren *et al*., 2001). Only limited information exists on sustainability of the rice-wheat-grain legume cropping system eg., rice-wheat-mungbean system in India (Sharma & Sharma, 2006). In Pakistan, where rice-wheat system occupies 2.52 m ha^{-1} and constitutes the major economic activity for the rural population (Baloch *et al*., 2006; Ahmad *et al*., 2009), induction of grain legumes in the rice-wheat system has not been evaluated. The present study was conducted to test the feasibility of introducing a short-duration grain legume *viz*., mungbean during the fallow period between wheat harvest and sowing rice with the following objectives: (1) to determine the additional benefit to the farmer in the form of mungbean pulse; (2) to explore the biomass and N accumulation potentials of mungbean; and (3) to elucidate the effects of incorporating mungbean residues on the soil fertility and yields of rice and the subsequent wheat crop. Mungbean was selected as it is a short duration crop (55–70 days) thus fitting conveniently in the pre-rice niche in the rice-wheat system. It produces a substantial amount of grain pulse in addition to manure biomass which is comparable to that of *Sesbania* in terms of dry matter and N yields (Sharma *et al*., 1995).

Materials and Methods

Study site: The study site at the Nuclear Institute for Agriculture and Biology, Faisalabad is located at 31.4°N, 73.2°E, and is 183 m above the sea level. The area has a subtropical arid climate with a mean annual rainfall of 340 mm, most of which is received during July and August in the form of heavy monsoon downpours. The soil (Hafizabad series; Typic Ustocrept) is a deep, well-drained sandy-clay loam developed in a mixed calcareous medium-textured alluvium derived from Himalayas (Anon., 1967). Some physicochemical properties of the arable (0−15 cm) soil layer are given in Table 1. The selected field had been (for the last 20 years) under flood-irrigated rice-wheat cropping system with about 2-month fallow period between wheat harvest and planting rice. Three field experiments were conducted to study (1) the grain yield and manure biomass potential of mungbean; (2) the response of Basmati rice to different levels of urea-N applied either alone or in combination with mungbean crop residues; and (3) the residual effects of mungbean residues (applied to rice) on the subsequent wheat crop.

Table 1. Some physicochemical properties of the arable (0−15 cm) soil layer of the experimental field.

Total organic carbon	0.6 %
Total nitrogen	0.05 %
pH (saturation paste)	7.9
EC (saturation extract)	0.04 S m^{-1}
Water-holding capacity	35.5 %
Bulk density	1.5 g cm^{-3}
Porosity	44.5 %
Sand	46 %
Silt	26 %
Clay	28 %

Cultivation of mungbean during the fallow period between wheat harvest and planting rice: After wheat harvest during the last week of April, the field (13 x 21 m) was irrigated and land prepared for sowing mungbean. The field was divided into six strips (3 x 19 m; 1 m apart); three alternate strips were left fallow, whereas the other three sown (29th April) to a short-duration mungbean cv. NM-92 (maturity period 55–70 day) with a plant-plant and row-row distances of 15 cm and 30 cm, respectively. Both the fallow and mungbean plots were unfertilized, and received two irrigations (27th May and 13th June; each 75 mm). At maturity (9th July), plants in a $1m^2$ were sampled randomly from each plot for the determination of manure biomass including roots, which were recovered by digging the soil down to 30 cm depth. After separating the grain, the plant material was oven dried (70°C) weighed and a sub-sample ground (<0.5 mm) for analysis of nitrogen. Shoots and roots were returned to the respective mungbean plots. For determination of the grain yield, aerial plant parts (nearly at half plant height; comprising mainly of mature pods along with young branches and leaves) of the whole plots were harvested. After separating and weighing the grains, rest of the material (dry young branches and leaves) was returned to the respective plots and ploughed under before sowing rice.

Response of rice crop to urea-N with and without legume manuring: Plots (manured or non-manured) were flood-irrigated, puddle and each divided into four subplots (3 x 3 m; 1 m apart). Seedlings of rice (*Oryza sativa* L. cv. Super-Basmati; 35-day old) were transplanted (19th July) with a plant-plant and row-row distance of 20 cm. The experiment was carried out in a randomized complete block design with respect to N treatments, each replicated 3 times. A basal dose of phosphorus (75 kg P_2O_5 ha^{-1} ; as single superphosphate) was applied to all plots, whereas urea was applied at 0, 40, 80, 120 and 160 kg N ha^{-1} in two equal splits (a week after transplanting, and at flowering stage). The crop was irrigated to maintain the water level up to 50 mm till 3 weeks before harvest. When required, weeds were removed manually. At maturity (17th November), samples of 5 hills from each plot were randomly collected to record agronomic data i.e., number of tillers $hill^{-1}$, plant height and panicle length; the rest of the crop was harvested to determine the grain and straw yields. Sub-samples of straw and grain were oven dried (70°C), weighed and ground (<0.5 mm) before analysis of total N. Soil samples of the plough layer (0−15 cm) were also collected from each plot for determination of the total and mineral N.

Residual effects on the wheat crop: Following rice harvest, plots were irrigated (100 mm) and manually prepared for sowing wheat (*Triticum aestivum* L. cv. Inqlab-91) on 29th November with a plant-plant and row-row distances of 10 cm and 20 cm, respectively. The crop was grown without any fertilizer and received 4 irrigations (each 75 mm). At maturity (26th April), all the above-ground biomass was harvested, grain separated and sub-samples of grain and straw taken. The sub-samples were oven dried (70°C), weighed and ground (<0.5 mm) before analysis of the total N. Following wheat harvest, soil samples (0–15 cm depth) were also collected for analyses of the total and mineral N.

Analyses: The total N of plant and soil samples was determined by a micro-Kjeldahl method (Bremner & Mulvaney, 1982), whereas the soil mineral-N was measured by a micro-Kjeldahl method after extracting 10 g soil with 50 ml of 2*N* KCl (Keeny & Nelson, 1982). The data were subjected to an analysis of variance followed by Duncan's multiple range test (Gomez & Gomez, 1982). Results are reported on the basis of oven-dry weight and are means of three replicates.

Results

Biomass and N yields of mungbean: The mungbean crop grew well and the root system was profusely nodulated with pink nodules indicating the contribution of biological N_2 fixation. The crop matured in 70 days producing a grain yield of 1166 kg ha^{-1} (1295 kg ha^{-1} air dry basis) in addition to non-harvestable (manure) biomass of 4461 kg dry weight ha^{-1} that contained 51.9 kg N ha^{-1} (Table 2). The manure was incorporated in soil before rice cultivation under different urea-N regimes.

Rice cultivation with and without green manure under different urea-N levels: Table 3 shows the effects of legume manuring on different agronomic parameters of rice grown under different urea-N levels. Legume manuring produced significantly higher tiller count as compared to the non-manured rice plants (average increase, 11%; $p<0.05$); the effect was more pronounced with urea-N applied at 120 and 160 kg ha^{-1} producing 18% and 24% increase, respectively. The plant height and the panicle length, however, were not affected by the urea application rate or manuring. Averaged across urea-N treatments, manuring though decreased the rice straw yield by 10%, the effect was only significant in treatment receiving urea-N at 160 kg ha^{-1} (29% decrease; $p<0.05$). Manuring caused a 36% increase in the straw N concentration in the unfertilized soil but decreased the straw N concentration (27% decrease) and uptake (47% decease) with urea-N applied at 120 kg ha^{-1} ($p<0.05$). Averaged across urea application rate, manuring caused a 6% increase in the rice grain yield; the increase was most pronounced in unfertilized plots (16% increase) and least (9% increase) with 120 kg urea-N ha^{-1}; manuring along with 160 kg urea-N ha^{-1} caused a 13% decrease ($p<0.05$). Manured plots receiving 120 kg urea-N ha^{-1} produced maximum paddy yield (4341 kg ha^{-1}) that was comparable with that produced by non-manured plots fertilized with urea-N at 160 kg ha^{-1}. Manuring also increased the grain N concentration and uptake though the effect was significant in treatments with lower urea-N rates (40–80 kg ha^{-1}). Irrespective of the urea-N applied, the harvest index was higher in the manured than in the non-manured treatments, whereas N partitioning in the grain component was also higher in the manured treatments receiving urea-N in the range of 40–120 kg ha^{-1} (data not shown).

Table 2. Dry matter yield and nitrogen content of mungbean planted during the fallow period between wheat harvest and sowing rice

Component	Dry matter yield	Nitrogen	
	kg ha^{-1}	%	kg ha^{-1}
Above ground non-harvestable biomass	3916	1.24	48.6
Root biomass	545	0.61	3.3
Total non-harvestable biomass	4461	-	51.9
Grain	1166	3.75	43.7
Total yield	5627	-	95.6

Residual effects on the wheat crop: Incorporating the mungbean crop residues to rice showed significant residual effects on the subsequent wheat crop grown without urea-N application (Table 4). Averaged across urea-N treatments, manuring of rice significantly increased the wheat straw yield (15% increase), the grain yield (21% increase) and the grain N uptake (29% increase), whereas the straw N uptake was not affected. The residual effect on the wheat straw yield was only observed when 160 kg ha^{-1} of urea-N was applied to the preceding rice crop. Manuring of rice along with urea-N applied at 80-160 kg ha^{-1} caused 20–33% higher grain yield of the subsequent wheat crop; the maximum effect was observed with 80 kg ha^{-1} of urea-N applied to rice ($p<0.05$). Wheat grain N yield was also significantly higher (24–52% increase) in the manured than the non-manured rice plots receiving urea-N; the maximum effect was observed in rice plots receiving urea-N at 160 kg ha^{-1} (Table 4).

Effects of legume manuring on the soil N after rice and wheat harvest: Averaged across urea-N treatments, the total soil N concentration after rice harvest was 10 % higher in the manured than in the non-manured plots ($p<0.05$; Table 5); the effect was significant (17% increase) only in treatment receiving urea-N at 120 kg ha^{-1}. Appreciable amounts of mineral N (23–30 kg ha^{-1}) had accumulated after rice harvest but without showing treatment effect. Residual effect of manuring on the soil total N diminished by the wheat harvest.

Discussion

The mungbean grain yield obtained in the present study is higher than that reported for a rice-wheat-mungbean system in India, whereas N yield in the form of mungbean residues was lower (Sharma *et al*., 1995; Sharma & Sharma, 2006). The variation in N accumulation in legumes is attributable to varietal differences; under local conditions, the biological N_2 fixation potential of different mungbean genotypes varies from 25 to 55 kg N ha^{-1} (Anon., 1996). In manured soils, the increased yields are attributed mainly to the increased N availability (Limon-Ortega *et al*., 2000). In a rice-wheat system, application of leguminous green manures like cowpea or *Sesbania* to rice could replace mineral N fertilizer without affecting the yield, whereas integrated use of leguminous green manure with low doses of mineral N fertilizer to rice produced higher yields both of rice and wheat as compared to yields obtained by recommended rates of mineral N fertilizer (Aulakh *et al*., 2000). Thus integrated use of leguminous green manure with ½ of the recommended dose of mineral N fertilizer not only saved fertilizer-N by 50% for rice and 25% in wheat but also reduced NO_3^- leaching (Aulakh *et al.*, 2000). Ali (2000) also found combined application of green-manure with modest dose of mineral N fertilizer to be more beneficial as compared to the mineral N fertilizer applied at recommended rate. In the present study, however, maximum rice dry matter and N yields were recorded in manured plots receiving relatively higher dose of urea-N (120 kg N ha^{-1}). Nevertheless, comparing study of Aulakh *et al.*, (2000) with rice-wheat system using *Sesbania* as green manuring crop, the extra dose of urea required in the present study could be compensated by the additional income in the form of mungbean pulse. The discrepancy in the response to manuring is attributable to the differences in N supplying potential of various legume residues (Mann & Garrity, 1994). Assuming that 60% of the legume residue-N was mineralized during the current crop (Matsushita *et al.*, 2000), the mungbean residues contributed about 31 kg N ha^{-1}, which is much less than the maximum N (104 kg N ha^{-1}) harvested in the manured plots receiving urea-N at 120 kg ha^{-1}. Comparing the unfertilized treatments, application of mungbean residues alone had no effect on the rice straw and N yields but produced an extra 406 kg ha^{-1} of grain containing 8.5 kg of N. In the present study, it was not possible to precisely differentiate between the contributions of various N pools toward the N uptake by rice. However, we may not rule out the indirect benefits of legume green manuring since legumes like *Sesbania* besides directly serving as N source may also increase mineralization of the native soil N pool and its uptake by rice (Ashraf *et al.*, 2004). Higher soil N concentration in the manured than the non-manured field observed after rice harvest and the residual effects on the subsequent wheat crop are well documented (Tiwari *et al.*, 1980; Tahir *et al.*, 1988; Mann & Gerrity, 1994; Yadav *et al.*, 2000; Kumar & Goh, 2002; Mandel *et al.*, 2003). While in the present study, wheat received no fertilizer-N, application of low doses of urea-N (40–80 kg N ha^{-1}) may further increase the yield of subsequent wheat crop (Tiwari *et al.*, 1980). Although it can be assumed that amount of residual N is limited, continued green manuring of rice would accumulate modest amounts of N in soil thus showing measurable effects either by raising yields or by reducing the fertilizer-N requirements of the subsequent crops (Mann & Gerrity, 1994).

Conclusions

The present study indicates that a short-duration grain legume like mungbean can be successfully inserted during the pre-rice fallow period in the rice-wheat double cropping system. At prevailing local market rates, the grain pulse produced (1295 kg ha^{-1}) worth about Rs. 142,000 ha^{-1}, whereas subtracting the expenditure on mungbean cultivation (ca. Rs. 42,000 ha^{-1}) resulted in a net extra income of Rs. 100,000 ha^{-1} (US $ 1165). This additional income is substantial as in terms of the prevailing local commodity price it is equivalent to about 4000 kg of wheat grain, or 5750 kg of urea. Therefore, reluctance of the farmers regarding extra efforts and time in producing green manures could be compensated. Results of the present study emphasize that induction of a short-duration grain legume like mungbean in the pre-rice niche in the annual rice-wheat double cropping system could be more attractive to farmers as compared to legume crops which only provide biomass for manuring.

Table 3. Effect of legume manuring on some agronomic parameters of rice grown with different urea-N application rates.

Parameter	Manure treatment	Urea applied (kg N ha^{-1})					Urea treatment mean
		0	40	80	120	160	
Number of tillers (plant^{-1})	–	7.27 e[1]	9.06 cd	10.48 b	9.74 bc	9.86 bc	9.28 B
	+	8.40 d	9.80 bc	9.86 bc	11.46 a	12.2 a	10.34 A
	Manure treatment mean[2]	7.83 D	9.43 C	10.17 B	10.6 AB	11.03 A	
Plant height (cm)	–	102.2a	103.3 a	107.4 a	109.5 a	107.1 a	105.9A
	+	100.2 a	101.1 a	105.5 a	110.5 a	110.3 a	105.5 A
	Manure treatment mean	100.2 A	102.2 A	106.5 A	110.0 A	108.7 A	
Panicle length (cm)	–	28.1 a	27.3 a	29.2 a	29.3 a	27.9 a	28.4 A
	+	28.4 a	29.9 a	29.1 a	28.7 a	29.5 a	29.1 A
	Manure treatment mean	28.3 A	28.6 A	29.2 A	29.0 A	28.7 A	
Straw yield (kg ha^{-1})	–	3005 f	3795 ef	4610 cde	5830 ab	6040 a	4656 A
	+	3110 f	3948 de	4386 cde	5080 bc	4681 cd	4241 B
	Manure treatment mean	3058 D	3872 C	4497 B	5455 A	5360 A	
Straw N (%)	–	0.42 d	0.51 bcd	0.51 bcd	0.61 a	0.57 abc	0.52 B
	+	0.53 abc	0.50 cd	0.53 abc	0.48 cd	0.61 ab	0.53 A
	Manure treatment mean	0.47 C	0.50 BC	0.52 BC	0.55 AB	0.59 A	
Straw N uptake (kg ha^{-1})	–	12.3 d	19.3 cd	23.1 bc	35.8 a	34.6 a	25.0 A
	+	16.7 cd	19.8 cd	23.4 bc	24.3 bc	28.6 ab	22.6 A
	Manure treatment mean	14.5 C	19.6 BC	23.3 B	30.1 A	31.6 A	
Grain yield (kg ha^{-1})	–	2476 g	2995 f	3521 de	3995 bc	4259 ab	3449 B
	+	2882 f	3375 e	3866 c	4341 a	3772 cd	3647 A
	Manure treatment mean	2678 D	3185 C	3694 B	4168 A	4015 A	
Grain N (%)	–	1.33 c	1.38 c	1.48 bc	1.72 a	1.67 a	1.52 B
	+	1.44 bc	1.56 ab	1.64 a	1.68 a	1.57 ab	1.58 A
	Manure treatment mean	1.38 D	1.47 CD	1.56 BC	1.70 A	1.62 AB	
Grain N uptake (kg ha^{-1})	–	33.0 f	41.4 e	52.0 d	68.6 ab	71.0 a	53.2 B
	+	41.5 e	52.8 d	63.5 bc	73.0 a	59.1 cd	58.0 A
	Manure treatment mean	37.0 E	47.2 D	57.7 C	70.8 A	65.1 B	

[1] For each parameter, values in a row or column followed by different letter (*lower case*) are significantly different by Duncan's multiple range test (p<0.05).

[2] For each parameter, values for treatment means (manure or urea) followed by different letter (*upper case*) are significantly different by Duncan's multiple range test (p<0.05).

Table 4. Residual effects of legume manuring of rice on the wheat biomass and N yields.

Parameter	Manure treatment	Urea applied to rice crop (kg N ha^{-1})					Urea treatment mean
		0	40	80	120	160	
Straw yield (kg ha^{-1})	–	2376 b[1]	2563 ab	2460 b	2459 b	2291 b	2430 B
	+	2700 ab	2709 ab	2796 ab	2645 ab	3113 a	2792 A
	Manure treatment mean[2]	2537 A	2636 A	2628 A	2552 A	2702 A	
Straw N uptake (kg ha^{-1})	–	5.2 de	8.3 ab	7.5 abcd	5.7 cde	6.1 bcde	6.6 A
	+	4.9 e	7.9 abc	9.4 a	6.2 bcde	6.7 bcde	7.4 A
	Manure treatment mean	5.0 B	8.1 A	8.5 A	6.0 B	6.4 B	
Grain yield (kg ha^{-1})	–	1154 cde	1145 cde	1129 de	1061 e	1021 e	1102 B
	+	1256 bcd	1292 bc	1501 a	1277 bcd	1338 b	1333 A
	Manure treatment mean	1205 B	1219 AB	1315 A	1169 B	1180 B	
Grain N uptake (kg ha^{-1})	–	15.9 c	15.8 c	15.3 c	15.1 c	14.5 c	15.3 B
	+	17.4 bc	19.6 ab	20.3 ab	19.3 ab	22.0 a	19.7 A
	Manure treatment mean	16.7 A	17.7 A	17.8 A	17.2 A	18.2 A	

[1] For each parameter, values in a row or column followed by different letter (*lower case*) are significantly different by Duncan's multiple range test ($p<0.05$).

[2] For each parameter, values for treatment means (manure or urea) followed by different letter (*upper case*) are significantly different by Duncan's multiple range test ($p<0.05$). (Duncan's multiple range test).

Table 5. Concentration of total nitrogen (mg kg^{-1}) in soil after rice and wheat harvest

Urea-N applied[1]	After rice harvest			After wheat harvest		
	Non-manured	Manured	Manure treatment mean	Non-manured	Manured	Manure treatment mean
Unfertilized	589 ab[2] (30)[3]	624 ab (23)	607 A	467 a	490 a	478 A
40	566 b (23)	624 ab (29)	595 A	432 a	478 a	455 A
80	607 ab (23)	630 ab (28)	619 A	455 a	490 a	473 A
120	566 b (25)	665 a (30)	616 A	478 a	385 a	432 A
160	589 ab (27)	659 a (29)	624 A	502 a	502 a	502 A
Urea treatment mean	583 B (26)	641 A (28)		467 A	469 A	

[1] Urea-N (kg ha^{-1}) applied to rice crop.

[2] For each crop, values in a row or column followed by different letter (*lower case*) are significantly different by Duncan's multiple range test ($p<0.05$).

[3] Figures in parentheses indicate mineral N.

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