SOIL NUTRIENT DYNAMICS AS INFLUENCED BY TROPICAL LEGUMES AND P FERTILIZATION UNDER RAINFED CONDITIONS

M.I. Sultani*, I.A. Mahmood*, Abdul Razzaq* and Sartaj**
*Rangeland Research Program, INRES, **Fodder Research Program, IFHC,
National Agricultural Research Centre, Islamabad.

A two year study was conducted to investigate soil nutrient dynamics influenced by various legumes (Sesbania, Cluster bean, Rice bean) and different P levels (0, 30, 60, 90 kg P_2O_5 ha^{-1}). Effect of incorporating green manure crops and P levels on NPK content of soil differed among various treatments. Sesbania caused an increase of about 26, 18 and 37% N, P and K, respectively, followed by Cluster bean i.e., 21, 12 and 29% in soil, respectively, over control. The percent increase in soil NPK by Rice bean over control was the lowest i.e., 16, 11 and 23%, respectively. The influence of P levels on soil NPK was also considerable and was maximum with 90 kg P_2O_5 ha^{-1}. On an average, the overall effect of P application on NPK status of soil was an increase of 5, 6 and 3%, respectively, over control.

Key words: Legume crops, P application, NPK status of soil, rainfed conditions, Pakistan.

INTRODUCTION

The soils of the Pothowar Plateau are generally low in fertility especially in organic matter, N and P. Moreover, the recent trend for growing continuous cereals on all arable lands has further depleted the nutrients in the soils which are already low (Rashid and Qayyum, 1991). Consequently, use of inorganic fertilizers has become important for successful crop production in rainfed areas of Pothowar Plateau. However, with the use of expensive inorganic fertilizers, the cost of crop production has substantially increased. It is, therefore, important to promote economically viable and environment friendly interventions for sustainable agriculture in rainfed farming system of Pothowar Plateau. Forage legumes have the potential to integrate in the present farming system of Pothowar region. Legumes grown in low fertility soils could improve the soil health by fixing atmospheric N and may partially supplement the use of inorganic fertilizers. Legumes may also improve the production of cereal crops by adding much needed organic matter in the soils and by improving physical properties of soils. Beneficial residual effects of legumes have been largely responsible in sustaining soil fertility and saving inorganic fertilizers in subsequent non-legume crops. Mahler and Auld (1989) observed that incorporation of peas, green manure crop and their residues after harvesting grains significantly increased subsequent wheat grain yield equivalent to nitrogen fertilizer equivalents to 75 kg N ha^{-1}.

Green manuring improves soil fertility (Warman, 1981). The benefits of green manuring have been reported to be manifold. For instance, since dawn of civilization it increased soil organic matter and available N, P and K concentration of nutrients near the soil surface in available form, reduction of N losses through leaching and soil erosion. Incorporation of crop residues into the soil caused a rapid increase in the soil microbial biomass which acted both as a sink for nutrients and as a catalyst for decomposition (Kolar *et al.* 1993). Green manuring seems particularly attractive for farmers on marginally productive soils, at least as a strategy to improve yield and yield sustainability (Diekmann *et al.* 1996). Therefore, the present study was conducted to investigate the residual effect of various green manures with different P levels on soil fertility under rain-fed conditions of Pothowar Plateau.

MATERIALS AND METHODS

The research studies outlined below were conducted at the experimental area of Forage and Pasture Program of National Agricultural Research Centre, Islamabad. The centre lies in a sub-tropical, sub humid continental highland climatic zone characterized by hot long summers and cold winters. Soils of the area are Inceptisol and loess in nature, slightly alkaline with pH 8.2 but low in organic matter (0.5%), total N 0.09%, available P 6.3 µg g^{-1} and extractable K 78.5 µg g^{-1} of soil. The mean annual rainfall is 1000 mm, 70% of which occur during the summer monsoons (July, August and September) while rest of 30% is distributed during remaining part of the year.

The legumes viz. i) Sesbans, *Sesbania aculeata* (Linn), ii) Ricebean, *Vigna umbellate* (Thunb), and iii) Cluster bean, *Cyamopsis tetragonaloba* L. were used as green manure crops. The experiment was conducted in two factors Randomized Complete Block Design (RCBD) with four replications. A total of 16 treatments including control were used. There were 64 plots of 8 x 6 m^2

each. The factors used were green manure legumes and P fertilization. The treatments were as follows:

T1 = Fallow
T2 = Fallow + P_2O_5 @ 30 kg ha^{-1}
T3 = Fallow + P_2O_5 @ 60 kg ha^{-1}
T4 = Fallow + P_2O_5 @ 90 kg ha^{-1}
T5 = Cluster bean
T6 = Cluster bean + P_2O_5 @ 30 kg ha^{-1}
T7 = Cluster bean + P_2O_5 @ 60 kg ha^{-1}
T8 = Cluster bean + P_2O_5 @ 90 kg ha^{-1}
T9 = Rice bean
T10 = Rice bean + P_2O_5 @ 30 kg ha^{-1}
T11 = Rice bean + P_2O_5 @ 60 kg ha^{-1}
T12 = Rice bean + P_2O_5 @ 90 kg ha^{-1}
T13 = Sesbania
T14 = Sesbania + P_2O_5 @ 30 kg ha^{-1}
T15 = Sesbania + P_2O_5 @ 60 kg ha^{-1}
T16 = Sesbania + P_2O_5 @ 90 kg ha^{-1}

A basal dose of N was applied @ 60 kg N ha^{-1} as urea. Different forage legumes were incorporated at blooming stage i.e., 60 days after their establishment. The tender stems and plants were manually harvested and later chopped and incorporated into the soil by rotavator. Soil samples were taken before and after the harvest of plants from 0-30 cm depth, air dried, passed through 2mm sieve and stored in soil sampling bottles for the analysis of total N, available P and extractable K.

Total Soil Nitrogen

Total nitrogen was measured through sulphuric acid digestion. Distillation was made with Micro-Kjeldahl method (AOAC, 1994).

Soil Phosphorus

Soil phosphorus was determined by extracting the soils with sodium bicarbonate solution and measuring it colorimetrically by developing a blue colour (Shiou Ktio, 1996).

Soil Potassium

Potassium was extracted with ammonium acetate solution adjusted to pH 7.0 and its concentration was determined by flame emission spectroscopy (Rhoades, 1982).

The data thus obtained were subjected to statistical analysis. A software package MStat C was used to calculate ANOVA Tables. Significant differences in selected crop growth and yields, and soil physical properties attributed to the main and interactive effects of green manures and phosphorus levels at two different depths of soil were analyzed using an ANOVA procedure of the MStat-C software.

RESULTS AND DISCUSSION

Green Manure Legumes versus Soil N

Table 1 reveals that green manure crops in general were responsible for increase of 23% soil Nitrogen over control. Sesbania caused 27% increase whereas Cluster bean and Rice bean caused 23 and 18% increase, respectively. These increases are impressive and are a function of increased biomass production of green manure crops as well as their increased N concentration. Effect of incorporating green manure crop on soil N content differed among crops themselves. High soil N contents in case of Sesbania incorporation may largely be attributed to its relatively narrow C:N ratio that presumably increased mineralization of its N when compared with that for the other treatments. Greater N yield with Sesbania than with the other green manure crops might also be due to the higher N content of former which initially might have mineralized rapidly, resulting in faster mineralization of nitrogen. A positive effect of such green manures has also been reported by Jiao (1983), Rinaudo *et al.* (1983), Nayyar and Chhibba (2000).

The residual N transfer to soil could improve N economy. In general, the root zone immediately behind the root tip is considered to be the major site of exudation. In Sesbania, the major N release might have been from roots as well as from nodules that caused significantly higher N content in soil. The capacity of legumes for symbiotic fixation of Nitrogen is the major factor responsible for improving soil N fertility, and they must fix large amounts of atmospheric N to maintain or increase the soil N pool. Legumes grown solely for incorporation as green manures can increase the soil N pool provided they effectively fix N_2, and losses of legume N are minimized. In a pot experiment, Ladha *et al.* (1989) determined N balances for weedy fallow-rice-weedy fallow-rice and *Sesbania rostrata* – rice – *Sesbania rostrata* – rice rotations under continuously flooded soil conditions. Sesbania was incorporated at 45 days after emergence for the first crop and 55 days after emergence for the second crop. In the second rotation, there was a net gain (151 mg N pot^{-1}) in soil N. The gain in N from N_2 fixation and irrigation water exceeded the N removal by the two rice crops. Similarly, Rinaudo *et al.* (1983) measured more soil N following a Sesbania-rice sequence, than following a fallow-rice sequence.

P Fertilization versus Soil N

The influence of P application on soil N (Table 1) was found to be very small but consistent. Maximum increase was 4% over control with 90 kg P ha^{-1} whereas for 60 and 30 kg P ha^{-1} increase was 3 and

1%, respectively. Phosphorus is a common limiting nutrient in soils of Pakistan, and its management is important for legumes in terms of biological nitrogen fixation. Cassman *et al.* (1981) observed that field grown legume crop has a higher P requirement when it is dependent on biological nitrogen fixation for its N supply as compared to mineral N dependency. They further reported that soybean dependent on BNF but not supplied with P attained only 28% of the maximum yield obtained at optimum P levels. The below ground N contribution by legumes could perhaps be significant if green manure legumes are incorporated during their flowering or early reproductive stages when root nodulation could be abundant and nodules are active as well.

P levels and Green Manure Legumes Residuals versus Soil N

The data pertaining to Table 1 indicate an overall residual effect of 4% more N in the succeeding year as compared to previous year. Close examination further explained that average residual effect of green manure crops was also 4% whereas effect of various P doses was 3%. Incorporation of green manure legumes or above ground residues of dual purpose legumes after grain forage harvest generally adds biologically fixed N to soil, which in turn becomes available to the succeeding crop. Many earlier studies demonstrated a rapid release of N and an increase in soil mineral N, followed by a plateau or decline in mineral N levels after legume residues incorporation. (The mineral N release from cowpea green manure and cowpea residues released almost 28 kg ha^{-1} and 20 kg, respectively within 15 days of incorporation). The net release of cow pea N as soil mineral N was 37% in case of green manure and 28% in case of residue (Nagarajah, 1988). Ladha *et al.* (1996) studied mineral N release of forage legume residues incorporated in soil. The residues of crotolaria, clitoria and siratro contributed to soil about 9-29 kg mineral N ha^{-1} within two weeks of their incorporation. The clitoria residues released 25% of its N in the soil during this period.

Smith and Sharply (1990) used seven different crop residues of legumes and non-legumes on eight different soils and reported that initial depression period in net N mineralization was more for non-legumes and it was enhanced for those soils where green manure residues were incorporated than for where residues were left on surface. Mineralization was, however, enhanced with the addition of legume residues. Beneficial residual effect of Sesbania green manure with P fertilization management has been significantly attributed to sustaining soil fertility. It might have been due to the addition of substantial amount of nitrogen in the soil and therefore, has increased straw yield of the wheat crop. As the initial study indicated that Sesbania produced higher protein as compared to other treatmens and hence proved to be rich in nitrogen that ultimately accounted for an even larger percentage of the soil N content. Many research workers have documented beneficial residual effects of green manure legumes on soil fertility (Mann and Garrity, 1994; Ahlawat, *et al.* 1998).

Green Manure Legumes versus Soil P

Data of Table 2 clearly indicate significant effect of green manure crops on phosphorus status of soil. On average there was P content of soil which is equivalent to 14% increase over control. Among green manure crops Sesbania had maximum influence of 18% followed by Cluster bean (12%) and Rice bean (10%) increase over control treatment. Green manure crops redistribute nutrients in soil profile. The leaves of Sesbania, for example, contain more P, followed by roots (SFI, 1980, Palaniappan and Budhar, 1994). This attribute of Sesbania enhance P status in the soil (0-30 cm). Also legumes have the ability to tap subsoil P and utilize insoluble phosphates through their well developed root system and when used as green manures, make P accessible and available to the succeeding crop (Ahlawat and Saraf, 1982).

Sahu and Nayak (1971) studied the effect of inorganic fertilizer alone and in combination with farm-yard and green manures. Organic manures improved the level of organic carbon, total N and available P more than inorganic fertilizers treatments. The factor involved in enhancing the P status of soil might be the application of P and green manuring further contributed in this respect. Some legumes can efficiently utilize occluded soil P and can grow well under low soil P levels (Gardner *et al.* 1981) by solubilizing occluded P with exuding citric acid which, as a chelating substance, solubilizes iron bound P (Gardner, *et al.* 1983). Green manuring can increase availability of P through changes in pH (Swanrup, 1986; 1987). Keeping in view the results of the study, green manuring by Sesbania with P application @ 30 kg P_2O_5 ha^{-1} is suitable to enhance soil fertility status and could be beneficial for the following crop in terms of increased yields.

P Fertilization versus Soil P

According to data of Table 2 the influence of P application monitored after green manure incorporation was also significant; the overall effect was an increase of 14% over control. As expected maximum influence was 20% increase over control with 90 kg P_2O_5 ha^{-1} which was followed by 16% increase with 60 kg P ha^{-1} and 4% increase over control with 30 kg P_2O_5 ha^{-1} treatment. Higher rate of P application (90 kg P_2O_5 ha^{-1}) significantly increased P in soil closely followed by lower rates of 30 and 60 kg P_2O_5 ha^{-1}. Increase in P status of soil due to increased P levels was observed but the differences were non-significant among the crops used for green manure purposes. There are strong indications that application of P triggers growth of a number of microorganism as well as higher plants and crops, which in turns firstly unlock P fixed in soil and secondly make it accessible to plants. This can be supported by the findings of Zia, *et al.*, (1998) who reported that significant effect of P application with Azolla green manures was observed.

P Fertilization and Green Manure Legumes versus Soil P

Data (Table 2) indicate an overall combined residual effect of different green manure crops and various doses of P application on soil status of P in the succeeding year to be around 8% of first year status. The above residual effect did not vary significantly among different green manure crops as well as various doses of P fertilization. Patra *et al.* (1995) observed that addition of plant residues affected the microbial biomass, in top soil (0-15 cm) was 150 µg g^{-1} for Japanese mint (*Menther aruensis* L.) and 215 µg g^{-1} of soil for palmrosa (*Cymbopogan martini* L.) and aromatic grass, due to higher input of organic matter from plant residues.

Green Manure Legume versus Soil K

Data (Table 3) reveal that green manure legumes on an average caused a significant increase (29%) in K status of soil during both years. Detailed examination of data shows that among various green manure crops Sesbania was more effective (36% increase over control) followed by Cluster bean (28%) and Rice bean (23%). As green manuring is known to improve soil fertility through increase in soil organic matter and available nutrients and hence increased aggregation of soil particles can cause a sufficient amount of K in soil. Leguminous green manure plants reportedly also have the ability to absorb K efficiently in the soil (Gu and Wen, 1981) and recycle it to the succeeding crops (Nagarajah,. 1988).

Green manuring by Sesbania has been frequently observed to improve soil fertility status in terms of organic matter, N, P and K levels of soil. This could be due to the fact that Sesbania contains large amounts of N, P, K and micronutrients. Both biomass and efficient N_2 fixing potential of Sesbania caused positive effect on soil health and increased the availability of K in soil. These results were confirmed by the findings of Katyal, (1977), Khind *et al.* (1987), and Nagarajah *et al.* (1989). Green manures have been shown to increase the availability of K in soil. The results discussed by Hargrove (1986) indicated that the available K increase in the surface layer from green manuring was due to recycling of K from the surface layer. In an other study Zia *et al.* (1992) observed that incorporation of plant residues and farm yard manures increased the N, P, K, S and Zn contents by 25, 10, 27.5, 7.5 and 0.23 kg ha^{-1} respectively. The contribution of plant residues resulted in the maximum increase in K level (60 kg ha^{-1}). Similar conclusions have also been reported by Gill and Meelu (1982). On the other hand, the green manure legumes might have facilitated the release of potassium from K bearing minerals. The K bearing minerals in the Pothowar soils include mica, feldspar and illite. Biotite is present in heavy sand fractions while light sand fractions contain muscovite and K-feldspar. Bhangu and Sidhu (1996) reported that biotite and illite appear to be sources of K release in these soils.

P application versus Soil K

Data of Table 3 indicates slight increase in K status of soil that was observed due to increasing rate of P application but was statistically non-significant during both the years. Even with the high dose of P application (90 kg ha^{-1}), the results were not significantly different than control treatment. This might have happened because most of the soils are rich in K containing micacious clay which is main stream of K supply in our soils (Bajwa, 1987). The river and ground water which contain on an average about 7 mg L^{-1} K is another source of K for crops (Shakir, *et al.* 1994). Keeping in view the nature of soils and water supply it could easily be assessed that K supply from soils could be adequate at least in medium to heavy textures soils (Bhatti, 1987).

Incorporation of higher plant biomass, in this case, definitely improved soil fertility status in terms of soil N, P and K levels. Application of proper P nutrition to Sesbania showed good response compared to other green manure crops. This treatment also improved N_2 fixing ability of Sesbania and hence enhanced K status of soil. Such synergistic effects between N, P and K have also been reported by Ahmed *et al.* (1992) on the basis of consolidated crop response.

Table 1. Soil N Concentration (%) as influenced by Green Manure Legumes and different P Level

Green Manures Legume	P Level (kg ha^{-1})				Mean
	0	30	60	90	
Fallow	0.19 d*	0.19 d	0.19 d	0.19 d	0.19 C
Cluster bean	0.23 a-c	0.23 a-c	0.24 a-c	0.24 a-c	0.23 AB
Rice bean	0.22 c	0.22 bc	0.22 bc	0.23 a-c	0.22 B
Sesbania	0.24 a-c	0.24 a-c	0.25 ab	0.25 a	0.24 A
Green Manure Mean	0.22 A	0.23 A	0.24 A	0.24 A	0.23 A
Grand Mean	0.22 A	0.22 A	0.22 A	0.22 A	0.22 A

*Values followed by same letter(s) are statistically similar at P=0.05 level of significance

Table 2. Soil Phosphorus (mg kg^{-1}) as influenced by Green Manure Legumes and different P Levels

Green Manure Legume	P Level (kg ha^{-1})				Mean
	0	30	60	90	
Fallow	5.74 gh*	5.90 f-h	5.66 h	5.94 e-h	5.81 B
Cluster bean	6.19 c-h	6.39 b-g	6.60 a-e	6.87 a-c	6.51 A
Rice bean	6.04 d-h	6.32 b-h	6.58 b-f	6.81 a-c	6.44 A
Sesbania	6.41 b-g	6.76 a-d	6.99 ab	7.26 a	6.86 A
Green Manure Mean	6.21 B	6.49 AB	6.72 AB	6.99 A	6.60 A
Grand Mean	6.09 B	6.34 AB	6.46 AB	6.73 A	6.40 A

*Values followed by same letter(s) are statistically similar at P=0.05 level of significance

Table 3. Soil Potassium (mol m^{-3}) as influenced by Green Manure Legumes and different Levels of Phosphorus

Green Manures Legume	P Level (kg ha^{-1})				Mean
	0	30	60	90	
Fallow	1.78 d*	1.75 e	1.77 e	1.79 e	1.77 C
Cluster bean	2.22 cd	2.26 b-d	2.30 a-d	2.33 a-d	2.28 AB
Rice bean	2.12 d	2.16 cd	2.18 cd	2.26 b-d	2.18 B
Sesbania	2.33 a-d	2.37 a-c	2.47 ab	2.52 a	2.42 A
Green Manure Mean	2.22 A	2.31 A	2.36 A	2.38 A	2.29 A
Grand Mean	2.11 A	2.18 A	2.23 A	2.24 A	2.16 A

*Values followed by same letter(s) are statistically similar at P=0.05 level of significance

REFERENCES

Ahlawat, I.P.S. and C.S. Saraf. 1982. Rooting and nodulation pattern of pigeonpea under different plant densities and P fertilization. Indian J. Agron. 27: 149-55.

Ahlawat, I.P.S., M. Ali, R.L. Yadev, J.V.D.K. Rao, T.J. Rego and R.P. Singh. 1998. Biological Nitrogen Fixation and residual effects of summer and rainy season grain legumes in rice and wheat cropping systems of the Indo-Gangeti plain. Intl. Crop Reds Inst. For the Semi Arid Tropic (ICRISAT).

Ahmad, N., M.T. Saleem and Jan Twyford. 1992. Phosphorus research in Pakistan. Review paper, pp: 59-92. *In*: Proceedings of Symposium on the role of phosphorus in crop production, National Agric. Res. Centre, Islamabad.

AOAC. 1994. Association of Official Analytical Chemists (AOAC). Official Method of Analysis. 12th ed Washington, DC.

Bajwa, M.I. 1987. Potassium mineralogy of Pakistan soils and its effects on potassium response. *In*: Proc. Potassium and Fertilizer use efficiency. March 21-22, 1987. P: 203-16.

Bhangu, S.S. and P.S. Sidhu. 1996. Mineralogy of Potassium in Soil of Punjab. J. Pot. Res. 6:1-8.

Bhatti, H.M. 1987. Crop response to potash and its future prospects in Pakistan. Review paper on potash, micronutrients and rhizobium. Technical Bulletin PARC, Islamabad. P.26-30.

Cassman, K.G., A.S. Whitney and R.L. Fox. 1981. Phosphorus requirements of soybean and cowpea as affected by mode of N nutrition. Agron. J. 73: 17-22.

Diekmann K.H., J.C.G. Ottow and S.K. DeDatta. 1996. Yield and Nitrogen response of lowland rice to Sesbania rostrata and *Aeschynmene afraspera* green manure in different marginally productive soils in the Philippines. Biol. Fertil. Soils. 21 (1-2): 103-108.

Gardner, W.K., D.G. Parbery and D.A. Barber. 1981. Proteoid root morphology and function in *Lupinus albus*. Plant Soil. 60: 143-47.

Gardner, W.K., D.G. Parbery and D.A. Barber. 1983. The acquisition of phosphorus by *Lupinus albus* L. III. The probable mechanism by which phosphorus movement in the soil/root interface is enhanced. Plant Soil. 70: 107-24.

Gill, H.S. and O.P. Meelu. 1982. Studies on the substitution of inorganic fertilizers with organic manures and their effect on soil fertility in rice-wheat rotation. Fertile. Res. 3: 303-13.

Gu, Rong-Shen and Wen, Qi-Xiao. 1981. Cultivation and application of green manure in paddy field of China. p 207-219. *In*: Proc. Symposium on Paddy Soil, 19-24. October 1980, Nanjing, China. Sci. Press, Beijing and Springer-Verlag, Berlin Heidelberg, NY.

Hargrove, W.L. 1986. Winter legume as nitrogen source for no-till grain sorghum. Agron. J. 78:70-74.

Jiao, B. 1983. Utilization of green manure for raising soil fertility in China. Soil Sci. 135: 65-69.

Katyal, J.C. 1977. Influence of organic matter on the chemical and electrochemical properties of some flooded soils. Soil Biol. Biochem. 9: 259-66.

Khind, C.S. A. Jugsuinda, C.W. Lindau and W. H. Patrick Jr. 1987. Effect of Sesbania straw in a flooded soil on soil pH, redox potential and water soluble nutrients, IRRN 12(3):42-43.

Kolar, J. S., H. S. Grewal and B. Singh. 1993. Nitrogen substitution and higher productivity of a rice-wheat cropping system through green manuring. Tropical Agric. 70:301-4.

Ladha, J. K., D. K. Kundu, M. G.A. Coppenolle, M.B. Peoples, V.R. Carangal and P. J. Dart. 1996. Legume productivity and soil N dynamics in low land rice based cropping systems. Soil Sci. Soc. Am. J. 60: 183-92.

Ladha, J. K., S. Miyan and M. Garcia. 1989. *Sesbania rostrata* green manure for lowland rice: growth, N_2 fixation, Azorhizobium spp. Inoculation and effects on succeeding crop yields and N balance. Biology and Fertility of soils 7: 191-97.

Mahler, R. L. and D. L. Auld. 1989. Evaluation of the green manure potential of Australian winter peas in Northern Idaho. Agron. J. 81:258-264.

Mann. R. A. and D. P. Garrity. 1994. Green Manure in rice-wheat cropping system in Asia. pp: 78-80. Published by International Rice Research Institute, Los Banos, Laguna, Philippines.

Nagarajah, S. 1988. Transformation of green manure N in low land rice soils. Pages 193-208 in Sustainable Agriculture: Green manure in rice farming. Los Banos, Manila, Philippine, IRRI.

Nagarajah, S., H. U. Neue and M. C.R. Alerto. 1989. Effect of Sesbania, Azola and Rice straw incorporation on the Kinetics of NH_4, K, Fe, Mn, Zn and P in some flooded soils. Plant Soil.116: 37-48.

Nayyar, V.K. and I.M. Chhibba. 2000. Effect of green manuring on micro-nutrient availability in rice-wheat cropping system of Northwest India. *In*: Long-term Soil Fertility Experiments in Rice-wheat Cropping Systems (Abrol, I.P., Bronson, K.F., Duxbury, J.M. and Gupta, R.K. eds.). Rice-wheat Consortium Paper Series 6. New Dehli, India.

Palaniappan, S. P. and M. N. Budhar. 1994. Seed production, crop establishment, and incorporation practices as agronomic constraints in green manure production systems. P: 83-98. In: Green manure production system for Asian rice lands. International Rice Research Institute, Los Banos, Laguna, Philippines.

Patra, D.D., S.Chand and M. Anwar. 1995. Seasonal changes in microbial biomass in soil cropped with palmrosa (*Cymbopogan martini* L.) and Japanes mint (*Meha arvensis L.*) in subtropical India. Biol. Fertil. Soils. 19: 193-96.

Rashid, A. and F. Qayyum. 1991. Cooperative Research Program on micronutrient status of Pakistan soils and its role in crop production. Final Report 1983-90, NARC., Islamabad.

Rhoades, J.B. 1982. Cation exchange capacity. *In*: Method of Soil Analysis. Part 2. Chemical; and microbiological properties. (ed. Page, A.L.). pp. 149-158. American Society of Agronomy, Madison. Wisconsin.

Rinaudo, G., B. Dreyfus and Y. Dommergues. 1983. *Sesbania rostrata* green manure and the nitrogen content of rice crop and soil. Soil Biol. Biochen. 5: 111-113.

Sahu, B.N. and B.C. Nayak. 1971. Soil Fertility investigation in Bhaubaneswar long-term fertility trial. P. 873-87. In: Proceedings of the International Symposium on Soil Fertility Evaluation. Indian Soc. Soil. Sci., New Delhi.

SFI-Soil and Fertilizer Institute, Guangdong Acad. of Agricultural Sciences. 1980. Sesbania. Publishing House of Agric., Beijing. China.

Shakir, M. Y., M. Anwar and M. Rashid. 1994. Irrigation water as a source of potassium nutrient. J. Agric. Res. 32(2): 179-86.

Shiou Ktio. 1996. Phosphorus in "Method of Soil Analysis Part III, Chemical Methods" American Society of Agronomy, Madison, Wisconsin, USA.

Smith, S. J. and A. N. Sharpley. 1990. Soil nitrogen mineralization in the presence of surface and incorporated crop residues. Agron. J. 82: 112-116.

Swanrup, A. 1986. Effect of pre-transplanting sub-mergence and green manure on yield and sodic soil improvement. IRRN, 11, 5: 39.

Swanrup, A. 1987. Effect of submergence of green manuring (*Sesbania aculeate*) on nutrition and yield of wetland rice (*Oryza sativa* L.) on sodic soils. Biol. Fert. Soils. 5: 203-208.

Warman, P. 1981. Basic principles with useful Table of green manure crops with notes on appropriate soil type, climate methods of cultivation. F.A.P. Publication 51. Macdonald. J. 40(1): 3-6.

Zia, M. S., A. Ali, Rahmatullah and M. Salim. 1998. Productivity of rice-wheat system in relation to Azolla green manure fertilized with nitrogen and phosphorus. Pak. J. Sci. and Ind. Res. 41(1): 32-35.

Zia, M.S., M. Munsif, M. Aslam and M. A. Gill. 1992. Integrated use of organic manures and inorganic fertilizers for the cultivation of low land rice in Pakistan. Plant Nutr., 38(2): 331-38.