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Response of Rice to Nitrogenous Fertilizer and Irradiated Sewage Sludge

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A greenhouse pot experiment was conducted to study the effect of γ-irradiated sewage sludge, applied alone or along with ^{15}N-labelled ammonium sulphate (1.0 atom % ^{15}N excess), on rice yield and N uptake. Six-kg portions of a clay loam were amended with sewage sludge to obtain N addition rates of 30, 60, 90 and 120 mg kg^{-1} soil. In other treatments, nitrogen was applied at 120 mg kg^{-1} as ^{15}N-labelled ammonium sulphate or 120 mg kg^{-1} as $^{15}NH_4$-N + sludge-N in the ratios of 1:3, 1:1,or 3:1. All the treatments were given before transplanting rice. Three healthy seedlings (4-week old) of rice (*Oryza sativa* L., var. Bas-Pak) were transplanted pot^{-1} and the plants harvested at maturity. Application of sewage sludge caused a significant improvement in rice yield. Grain yield increased by 188% at sludge-N of 120 mg N kg^{-1}. The yield benefit at similar rate of fertilizer N was 304%, the increase being more at higher rates of application. The increase in rice yield was dependent on uptake of N and sewage sludge significantly improved the availability of N to the plants. The additional plant N in sludge treated soil was partially attributable to enhanced mineralization of soil N and N_2 fixation by free-living microorganisms. Application of inorganic N led to a significant increase in the availability of N to plants from soil organic matter and sewage sludge. Results of combined application suggested that substantial savings of fertilizer N can be made by using sewage sludge on rice fields.

Key words: Sewage sludge, Rice, N uptake, ^{15}N, Fertilizer N, γ-irradiation

Introduction

Organic manuring is a widely recognized method of improving soil fertility. In rice production system, animal wastes, crop residues, green manures, and urban wastes are some of the important manures (Hesse 1984). Of these, leguminous green manures have traditionally been used as a popular source of plant-available N and as a means of improving soil productivity (Azam 2002; Ventura and Watanabe 1993). Green manures are reported to provide a substantial portion of the N required by rice (Deikman 1993). However, some other reports show that N supplying potential of green manures is limited and the rice crop can make use of 10-50% of the N applied (Azam *et al* 1985; Deikman 1993). Indirectly, however, leguminous crop residues with high N content may lead to an increase in the availability of N from soil organic matter to the plants (Azam 1990; Azam *et al* 1985,1993; Fox *et al* 1990). The low and variable N supplying potential of leguminous residues could be attributed to the differences in N concentration and the resultant C/N ratios; the factors that play an important role in net N mineralization (Azam *et al* 1985, Palm and Sanchez 1991, Clement 1995).

Application of inorganic N along with plant residues having low N concentration may lead to enhanced availability of N from the later and improved crop yields. However, in spite of the reported benefits of leguminous plant residues in terms of nutrient (especially N) supply, increase in rice yields is attributed mainly to an overall improvement of soil conditions as a result of organic matter addition. It has been suggested that the role of organic matter as a source of N and other nutrients is less important than that leading to excellent physical, chemical, and biological properties to the soil (Wallace 1994).

Like plant residues, sewage sludge may serve as a good source of organic matter and nutrients for soil and crop plants, respectively. The information already available suggests a highly positive effect of sewage sludge on the ecosystem functioning. However, some reservations prevail on the possible negative effects due to the contamination of sewage sludge with pathogens, heavy metals and organic pollutants. The problem of pathogens in sewage sludges could fairly be overcome by digestion of sludge and/or radiation of the material before use may be more assuring. Aside from pathogens, heavy metal content of most sewage sludges, particularly in situations where industrial wastes get mixed with domestic wastes, may pose a serious problem following accumulation after repeated applications and their entry into plant and animal systems. However, once the metals are in the soil, there is little removal by cereal crops or movement

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down the soil especially in heavy soils high in organic matter. The positive effects of sewage sludge through supplemental nutrient supply and improvement in physico-chemical and biological properties of soil may more than balance the negative effects of heavy metals

The release of N from sewage sludge may be restricted because of a relatively wider C/N ratio. Supplementing sewage sludge with fertilizer N may help overcome this problem. Our objective was to study the growth and N uptake of flooded rice in soil treated with sewage sludge and inorganic N fertilizer, applied separately or in different combinations.

Materials and Methods

The soil used in this study was collected from the experimental field at the Nuclear Institute for Agriculture and Biology, Faisalabad, Pakistan. Air-dried and sieved (<2 mm) soil sampled to a depth of 20 cm had the following characteristics: organic C, 0.56%, total N, 0.06%, pH (saturation paste), 7.7, water holding capacity 28%, sand, 52%, silt, 28%, clay 20%. The sludge obtained from a treatment plant in Islamabad had the following characteristics: pH, 7.05, organic matter, 23.2%, total N, 1.5%, P, 0.55%, K, 0.2%, Zn, 63.5 ppm, Fe, 5596 ppm; Mn, 288 ppm, Co 18.7 ppm; Cu 113 ppm. A portion of the sludge was radiated at Pakistan Radiation Services (PARAS), Lahore at a dose of 5 kGy in cuboid packets. Density of coliform bacteria in irradiated and non-irradiated sludge samples was 12 and 900 (MPN index per 100 ml), respectively.

Six-kg portions of the soil placed in plastic pots were amended with: i) γ-irradiated sewage sludge to obtain N addition rates of 30, 60, 90 and 120 mg kg^{-1} soil, ii) ^{15}N-labelled ammonium sulphate at 120 mg N kg^{-1} soil, and iii) 120 mg N kg^{-1} soil as sewage sludge and ammonium sulphate in the ratios of 1:3, 1:1or 3:1 on the basis of N. All the treatments were given to triplicate pots before transplanting rice. Three healthy seedlings (4-week old) of rice (*Oryza sativa* L., var. Bas-Pak) were transplanted pot^{-1}. A second dose of fertilizer N (80 mg kg^{-1}) was given 6 weeks after transplanting as the plants started showing N deficiency symptoms. The harvested plants were separated into root, straw and grain portions, dried, weighed, and finely powdered. Portions of plant material were analyzed for total N (Bremner and Mulvaney 1982) and the resulting distillates processed for ^{15}N isotope ratio analysis on a mass spectrometer.

Results and Discussion

Table 1 shows the results of dry matter yield and harvest index. Root portion showed no effect of sewage sludge when applied alone. However, a significant improvement was recorded when fertilizer N was applied alone or along with sewage sludge. Apparently, the positive effect was due mainly to fertilizer N since it increased with the amount applied. Straw portion exhibited significant increase due to both sewage sludge and fertilizer N. The increase was much higher when both sewage sludge and fertilizer N were applied together. It appeared, however, that sewage sludge decreased the benefit of fertilizer N since straw yield decreased with the increase in the proportion of sewage sludge. Similar results were

Table 1

Dry matter yield, its distribution and harvest index as affected by application of sewage sludge and ammonium sulphate applied separately or in ratios of 1:3, 1:1 and 3:1.

Treatments*	Dry matter yield, g pot^{-1}				Harvest
	Roots	Straw	Grain	Total	index
Nil (Cont)	8.0c**	40.2e	9.5f	57.7g	0.19c
SS-N30	8.0c	41.3e	9.5f	58.9g	0.19c
SS-N60	7.2d	41.3e	16.8e	65.3ef	0.29ab
SS-N90	7.6cd	43.4e	19.9d	70.8e	0.31a
SS-N120	7.6cd	49.8d	24.6c	82.0d	0.33a
AS-N120	14.5a	80.1a	31.2b	125.7a	0.28b
SS+AS, 1:3	13.2a	72.9b	34.9a	121.0a	0.32a
SS+AS, 1:1	13.3a	66.5bc	29.6b	109.1b	0.31a
SS+AS, 3:1	12.3b	63.2c	25.1c	100.5c	0.28b

* 30, 60, 90 and 120 refer to the amount of N (mg kg^{-1}) applied; SS, sewage sludge; AS, ammonium sulphate

** a-e, yield quantity (g). Figures followed by a similar letter in a column are not significantly different at 5% level according to DMRT

Table 2

N yield, its distribution and harvest index as affected by application of sewage sludge (SS) and ammonium sulphate (AS) applied separately or in ratios of 1:3,1:1 and 3:1.

Treatments*	N yield, g pot^{-1}				N Harvest
	Roots	Straw	Grain	Total	index
Nil (Cont)	48.3c**	183.4ef	102.5f	334.2h	0.36d
SS-N30	49.6c	184.5ef	102.2f	336.2h	0.36d
SS-N60	45.5d	177.9f	187.5e	410.9g	0.51c
SS-N90	46.4cd	193.6de	210.7d	450.7fg	0.52c
SS-N120	45.9d	216.4d	294.4c	556.6e	0.58a
AS-N120	94.5a	376.5a	412.9ab	883.9a	0.58a
SS+AS, 1:3	83.2b	315.0b	428.4a	826.6bc	0.58a
SS+AS, 1:1	82.2b	296.3bc	385.7b	764.4c	0.57b
SS+AS, 3:1	77.7b	281.8c	303.0c	662.4d	0.52c

* and **,Please see Table 1 for details

Table 3

Percent increase or decrease (-) in dry matter and N content of different plant components in response to application of sewage sludge and N fertilizer

Treatments*	Dry matter yield			N yield		
	Root	Straw	Grain	Root	Straw	Grain
SS-N30	1.1f**	2.6g	0g	2.7e	0.6g	0f
SS-N60	-9.6d	2.8g	76.4f	-5.8d	-3.0f	83.6e
SS-N90	-5.0e	7.8f	108.9e	-3.9d	5.6e	106.2d
SS-N120	-4.2e	23.8e	157.8d	-5.0d	17.9d	188.2c
AS-N120	81.8a	99.0a	227.1bc	95.7a	105.3a	304.2a
SS+AS, 1:3	66.0b	81.2b	266.5a	72.3b	71.8b	319.3a
SS+AS, 1:1	67.3b	65.4c	210.6c	70.1b	61.7b	277.6b
SS+AS, 3:1	54.1c	57.1d	163.2d	60.8c	53.6c	196.6c

* and **, Please see Table 1 for details

Table 4

Percent N content of different plant components of rice in response to application of sewage sludge and N fertilizer

Treatments*	% N content		
	Root	Straw	Grain
Nil (Cont)	0.61a**	0.46ab	1.08c
SS-N30	0.62a	0.45ab	1.07c
SS-N60	0.63a	0.43b	1.12c
SS-N90	0.61a	0.45ab	1.06c
SS-N120	0.60a	0.43b	1.20b
AS-N120	0.65a	0.47a	1.32a
SS+AS, 1:3	0.63a	0.43b	1.23ab
SS+AS, 1:1	0.62a	0.45ab	1.30a
SS+AS, 3:1	0.63a	0.45ab	1.21ab

*and** , Please see Table 1 for details

observed for grain yield, but the benefit of sewage sludge was more pronounced. Combined application of sewage sludge and ammonium sulphate (3:1 on N basis) gave grain yield almost equivalent to that obtained with sewage sludge alone applied at 120 mg N kg^{-1} soil. However, total dry matter yield was better when 25% of the applied N was in the form of ammonium sulphate. Soil treatment caused a significant improvement in harvest index, an observation different than that recorded for wheat where no significant change in harvest index was observed.

Trends in N yield and N harvest index due to different soil treatments were similar to those recorded for dry matter yield Table 2 and a highly significant relationship was obtained between the two parameters (r = 0.91, when all values of Tables 1 and 2 were computed). However, compared to dry matter partitioning to grain, partitioning of N was more positively affected by different treatments, particularly by ones that had fertilizer N alone or with sewage sludge.

A comparison of the different treatments in terms of percent change in dry matter and N yield of different plant components is shown in Table 3. Both the dry matter and N content of roots showed a decrease of 4.2-9.6% and 3.9-5.8%, respectively. However, fertilizer N applied alone or with sewage sludge caused an increase of 54-82% in the root dry matter and 61-96% in the root N content; the lowest values being recorded for highest proportion of sludge-N in the treatment and highest values for the fertilizer N alone. The increase in straw dry matter was 23.8% at the highest level of sludge. Application of sludge along with fertilizer N in different ratios produced an increase of 57.1-99% in straw dry mater and 60.8-96% in N content. Much higher increase in grain yield and grain N content (76.4-266.5% and 83.6-319.3%, respectively) was obtained due to the combined effects of sewage sludge and fertilizer N.

Percent N content of root and straw portions was not affected significantly due to soil treatments (Table 4). However, an improvement in grain N concentration was observed at higher level of sewage sludge when applied alone and at all levels when applied with fertilizer N.

The contribution of ^{15}N-labelled fertilizer to the N content of whole plant and its components is shown in Table 5. As the amount of applied fertilizer N decreased, its contribution to the total plant N (and to its components) also decreased as could be expected. Similar observations were recorded for wheat. Among the three plant components, maximum fertilizer N was found in the grain portion. The efficiency of fertilizer N uptake remained fairly low and the plants contained only 22.4% of the fertilizer N when applied alone. Although percentage of fertilizer N determined in whole plant decreased to some extent with increasing proportion of sewage sludge, the decrease was more pronounced for grain portion. However, the role of sewage sludge in affecting the fate of fertilizer N could not be established in the present study where the main objective was to study the combined effect of two N sources on plant performance. It would thus be worthwhile to study the effect of different levels of sewage sludge on the fate of fertilizer N applied at a constant rate.

In this study, up to 70% of the applied fertilizer N (refers only to ^{15}N-labelled fertilizer applied at the start of experiment and excludes second dose of unlabelled fertilizer N applied during plant growth) was lost from the soil-plant system. Amount of sewage sludge did not seem to have a major effect on the percent fertilizer N lost. Another observation (data not presented) was that application of sewage sludge in the

Table 5
Contribution to plant N and total uptake of fertilizer N applied alone or with sewage sludge

Treatments*	Root	Straw	Grain	Whole plant
		% N derived from fertilizer (%)		
AS-N120	21.3a**	16.8a	18.8a	18.2a
SS+AS, 1:3	11.2b	13.5b	15.4b	14.3b
SS+AS, 1:1	11.3b	7.5c	6.6c	7.5c
SS+AS, 3:1	7.6c	4.5d	4.8d	5.0d
		% fertilizer N taken up		
AS-N120	2.8b	8.8a	10.8b	22.4a
SS+AS, 1:3	1.7c	7.9b	12.3a	21.8b
SS+AS, 1:1	2.6b	6.2d	7.1c	15.8d
SS+AS, 3:1	3.3a	7.0c	8.1c	18.3c

*and **, Please see Table 1 for details; statistics applied independently to each of the two data sets of 4 values each

Table 6
Effect of different treatments on the content of unlabelled N in whole plant and its components (this will be derived from native soil organic matter, sewage sludge and unlabelled fertilizer)

Treatments*	N derived from soil, mg pot^{-1}			
	Root	Straw	Grain	Whole plant
Nil (Cont)	48.3b	183.4de	102.5g	334.2d SS-
N30	49.6b	184.5de	102.2g	336.2d SS-
N60	45.5b	177.9e	187.5f	410.9c SS-
N90	46.4b	193.6d	210.7e	450.7c SS-
N120	45.9b	216.3c	294.4cd	556.6b AS-
N120	74.4a	313.2a	335.3b	722.8a
SS+AS, 1:3	73.9a	272.6b	362.3a	708.8a
SS+AS, 1:1	72.9a	274.4b	360.3a	707.5a
SS+AS, 3:1	71.8a	269.2b	288.5d	629.4b

* and **, Please see Table 1 for details

absence of ^{15}N-labelled fertilizer led to a dilution of plant ^{15}N that was more at higher rates of application. This dilution could be attributed either to sewage sludge N (which had lower ^{15}N-abundance as compared to native soil N taken up by plants) and/or to enhanced N_2 fixation. At the moment, however, we do not have ^{15}N analysis of sewage sludge to ascertain its role in ^{15}N dilution.

Table 6 presents the data on N uptake from sewage sludge and/or soil as affected by different treatments. Application of sewage sludge alone had negligible effect, while application of fertilizer N lead to a significant increase in unlabelled N of roots. Almost similar trends were observed for the straw components, where, fertilizer N alone had the maximum positive effect on unlabelled N content. The grain portion contained significantly higher amounts of unlabelled N at the two higher doses of sludge. Again the application of fertilizer N had a significantly positive effect on unlabelled N content of grain portion; the effect being greater in the presence of sludge. On the whole plant basis, the amount of unlabelled N almost doubled due to combined application of fertilizer N and sewage sludge. Application of sewage sludge alone also caused a significant increase in unlabelled N at the two higher rates. In all treatments, a significant proportion of the unlabelled N could, however, be derived from unlabelled fertilizer which was applied at a later stage of plant growth following appearance of N deficiency symptoms in plants.

Application of sewage sludge had a significantly positive effect on rice yield (3-8% and upto 158% increase in straw and grain yield, respectively) and harvest index; an observation in line with several other reports in which different manures have been used (Ahmad *et al* 1998; Witt *et al* 2000). Yield response of 22-133% has been reported in some studies. Sewage sludge was found to compensate for inorganic fertilizer to a significant extent for grain production. Combinations of green manure and inorganic fertilizer are reported to have a positive effect on rice yield (Azam 1990; Zoysa 1990). The results of this study show that a substantial saving in fertilizer N could be made simultaneous to sewage sludge disposal on rice fields.

Application of sewage sludge also caused a significant increase in plant N that was more at higher levels of application, an observation in line with studies reported by others (Munn *et al* 2000). The effect of different soil treatments was fairly dependent on N uptake as revealed by a close correlation (r = 0.91) between dry matter yield and N content of the plants; dependence of crop yields on net N uptake is quite well established. Nitrogen benefits of organic amendments result mainly from a net release of N from decomposing organic matter with high N concentration and narrow C/N ratio (Ladd *et al* 1983; Clement 1995). However, the increase in yield observed in the present study seems to be more than that expected from organic manures like sewage sludge with a wide C/N ratio. Sewage sludge had a positive rather than negative effect on N availability; plant N increased by 0.6%-67% at the lowest and highest rates of addition, respectively. Since N mineralized from wide C/N ratio residues (like sewage sludge in the present study) tends to be re-immobilized by the soil microflora, a significant proportion of additional plant N in sludge-treated soil could have resulted from N_2 fixation by the free-living microbes. Indeed a significant dilution of plant ^{15}N was observed (data not presented) as a result of soil amendment with sewage sludge in the absence of ^{15}N-labelled fertilizer. Stimulation of N_2-fixation by the addition of organic matter has been reported (Roper and Smith 1991). In addition, application of sewage sludge might have enhanced the mineralization of native soil N in a way similar to that reported for other organic materials (Azam 1990).

The influence of inorganic ^{15}N on the plant availability of unlabelled N was significantly higher than that observed for similar amount of N added as sewage sludge. Enhanced uptake of unlabelled N by plants and accumulation of unlabelled mineral N in soil following application of ^{15}N-labelled NH_4 and NO_3 has been reported (Jenkinson *et al* 1985; Hart *et al* 1986; Chalk *et al* 1990; Azam *et al* 1991). As a result, contribution of unlabelled N to the total plant would decrease as observed in the present study (Table 5). However, since different ratios of inorganic and organic N (sewage sludge) were used in this study, it was not possible to clearly demonstrate the effect of either N source on their respective plant availability.

In summary, the application of sewage sludge had a significant positive effect on rice yield and N uptake. A substantial saving in chemical fertilizers and disposal of sewage sludge on rice yields seems possible. More studies are, however, needed to determine i) the influence of inorganic fertilizer on the release of N from sewage sludge and ii) the effect of sewage sludge on plant availability and fate of inorganic N.

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