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Comparative effects of organic and inorganic nitrogen sources applied to a flooded soil on rice yield and availability of N

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Abstract

A pot experiment was conducted to study the effect of organic and inorganic nitrogen (N) sources on the yield and N uptake of rice from applied and native soil-N. The residual effect of these N sources on a succeeding wheat crop was also studied. Organic N was applied in the form of ^{15}N-labelled *Sesbania aculeata* L., a legume, and inorganic N in the form of ^{15}N-labelled ammonium sulphate. The two sources were applied to the soil separately or together at the time of transplanting rice.

Recovery of N by rice from both the applied sources was quite low but both sources caused significant increases in biomass and N yield of rice. Maximum increase was recorded in soil treated with organic N. The residual value of the two materials as source of N for wheat was not significant; the wheat took up only a small fraction of the N initially applied. Loss of N occurred from both applied N sources, the losses being more from inorganic N.

Both applied N sources caused a substantial increase in the availability of soil-N to rice and wheat; most of this increase was due to organic N and was attributed to the so-called 'priming' effect or ANI (added nitrogen interaction) of the applied material.

Introduction

Leguminous green manures have traditionally been used as a source of plant-available nitrogen and as a means of improving soil productivity. Most of the work reported on green manuring in Asian countries has involved rice as a test crop because the time available between harvesting wheat and transplanting rice can be utilized to grow a green manure legume. These studies show significant increases in rice yields following incorporation in soil of green manures (Beri and Meelu, 1981; Bhatti *et al.*, 1985; Morris *et al.*, 1986a, 1986b).

In most of these studies, emphasis has been given to the N value of the green manures and only few studies have involved the use of ^{15}N-labelled leguminous material so as to identify the source of N in the rice crop (Huang *et al.*, 1981; Ito and Watanabe, 1985; Mian and Stewart, 1985a,b; Mo and Qian, 1983). Still few attempts have been made to compare green manures and mineral N fertilizers as sources of N for rice (Mian and Stewart, 1985a,b; Morris *et al.*, 1986a,b; Westcott and Mikkelsen, 1985). Such studies are desirable because N might not be the only factor causing enhanced rice yields. The organic matter reaching the soil in the form of green manure is highly labile and will affect the soil reaction, microbial processes, oxidation-reduction reactions and the mineralization/availability of nutrients including N. The effect of green manuring will thus be more on the overall soil fertility than merely on the increased availability of N. The studies reported by Azam *et al.* (1985, 1986) show that the value of green manures may lie more in long-term improvement of soil productivity than in enhancing the availability of N. Ladd *et al.* (1983) reached a similar conclusion.

An added effect of organic and inorganic N on crop productivity under upland conditions is through enhanced mineralization/availability of soil-N (Broadbent and Mikkelsen, 1968; Westcott and Mikkelsen, 1985). The improved availability of soil N is generally attributed to the so-called 'priming' effect (Hauck and Bremner, 1976). Jenkinson *et al.*, (1985) have termed this effect 'added nitrogen interaction' (ANI). However, the occurrence of a priming effect has not been clearly established for flooded soils (Westcott and Mikkelsen, 1985).

Objectives of the present investigation were to study: i) the performance of flooded rice (*Oryza sativa* L. var. IR-6) in potted soil treated with ^{15}N-labelled organic (leguminous plant material) and/or inorganic (ammonium sulphate) N; ii) the contributions of applied and native soil-N to the total N taken up by rice; iii) the balance of applied N; and iv) the ANI following treatment of flooded rice soil with organic or inorganic N.

Materials and methods

A clay-loam soil was collected from the surface (0–15 cm) of an experimental field at the Nuclear Institute for Agriculture and Biology, Faisalabad, Pakistan. Before use, the soil was air-dried and crushed to pass a 2-mm screen. The soil contained 0.6% C and 0.06% N and had a pH of 7.3.

Four-kg portions of the soil were put in plastic pots and treated as follows before transplanting rice: T1, control; T2, 100 μg N g^{-1} soil as ^{15}N-organic N (leguminous material of *Sesbania aculeata* L.); T3, 50 μg N g^{-1} soil as ^{15}N-inorganic N (ammonium sulphate); T4, 50 μg N as ^{15}N-organic N + 25 μg inorganic N g^{-1} soil; T5, 50 μg organic N + 25 μg ^{15}N-inorganic N. The rate of application of organic N was based on the assumption that ca. 50% of the legume N will be mineralized before the plants are harvested. This assumption is based on some previous studies which indicated a 50–56% mineralization of legume N in 3 different soils after 20 weeks of incubation at 60% WHC (Azam *et al.*, 1989a). In another study, about 49% of the N applied as *S. aculeata* plant material was mineralized in soil incubated for 8 weeks at 35°C and 180% WHC (Azam and Malik, 1986). In T2-T5 therefore the potentially mineralizable/available N in the applied sources will essentially be 50 μg g^{-1} soil.

^{15}N-labelled ammonium sulphate (2.0123 at. % ^{15}N) was obtained from IAEA. ^{15}N-labelled leguminous plant material was obtained by growing *Sesbania aculeata* L. plants in soil receiving ^{15}N-ammonium sulphate. The plants were harvested after 4 weeks. Dried and ground (< 0.5 mm) plant material contained 4% N and 1.1012 at. % ^{15}N ex.

Triplicate pots were used for each treatment and 6 rice seedlings were planted per pot. The plants were grown to maturity (18 weeks after sowing) under flooded conditions in the usual rice-growing season in Pakistan (July–October). During this period temperatures vary from 30–40°C. The agronomic parameters measured included plant height, no. of tillers, spike length, no. of grains and 100-grain weight. Dry matter yields of root, straw and spikes were determined separately, and ground material of the three components was analyzed for total N (Bremner and Mulvaney, 1982). The distillates were acidified, concentrated and subjected to isotope-ratio analysis on a mass spectrometer (Varian MAT GD 150) provided with a double inlet system with a detection limit of 0.0002 atom % ^{15}N.

After the rice harvest, the soil was air-dried, sampled for determining total N and ^{15}N, put back in triplicate pots (3.9 kg pot^{-1}) and sown to wheat (*Triticum aestivum* L. var. Pak-81) in late November, 1987 (the normal sowing time for wheat in Pakistan). Six seeds were sown per pot. Irrigation was given as required and the plants were harvested at maturity (22 weeks after sowing). Dry weight of root, straw and grain was recorded separately and ground material as well as soil samples were analyzed for total N and ^{15}N. All analyses were performed on triplicate samples.

Results

Application of organic and/or inorganic N had a significantly positive effect on all agronomic parameters studied (plant height, no. of tillers, spike weight, and no. of grains) except the 100-grain weight (data not presented). Among the different treatments, organic N alone generally produced the most positive effect on the various agronomic parameters; spike weight and no. of grains was about doubled compared to the control. A combination of the two N sources yielded a significantly better effect than inorganic N applied alone.

Table 1 shows data on total biomass, total N in plants and the distribution of the two over different plant components. Biomass and N yield were significantly improved in treated soil with the highest beneficial effect observed for organic N. When organic and inorganic sources were applied together, biomass and N yield were lower than with organic N alone treatment but higher than with inorganic N alone. In all treatments, relatively higher (45–53% av. 47.5%) proportions of total biomass were attributable to straw, while spikes contained 34–38% (av. 35.3%) of total biomass. The percent distribution of biomass among the 3 plant components was essentially similar in T2-T5, but significantly different from that in control; the latter had a higher proportion of total biomass in roots and straw, and the former in spikes. A major portion of N (56–59% of total) was located in spikes in all treatments. The partitioning of N over root, straw and spikes was essentially similar in T2-T5, but significantly different from control.

When applied alone, the contribution of organic N to total N in rice was 15.8% and that of inorganic N 6.8% (Table 2). When both nitrogen sources were applied together, the contributions of organic and inorganic N were 9.1 and 4.0%, respectively. Both N sources applied alone or together had significantly positive effects on uptake of native soil-N by rice. Maximum increase in the availability of soil-N was observed when organic N was applied alone and minimum increase when inorganic N was applied.

Rice absorbed only a small portion of the ^{15}N applied in organic or inorganic form (Table 3).

Table 2. N taken up by rice and its origin

Treatment	Plant N (mg pot^{-1})			
	Total	dfs[a]	dfo	dfi
T1	256.7	256.7 (100.0)	–	–
T2	487.7	410.6 (84.2)	77.1 (15.8)	–
T3	366.8	341.8 (93.2)	–	25.0 (6.8)
T4 and T5[b]	420.7	365.9 (87.0)	38.1 (9.0)	16.7 (4.0)
LSD ($P = 0.05$)	23.9	27.8	2.7	2.3

[a] dfs, dfo and dfi refer to N derived from soil, from the applied organic and the inorganic source, respectively. Figures in parentheses indicate percentages of total plant N derived from the respective sources.

[b] T4 and T5 have been combined because the two treatments were similar, except that in T4 organic N and in T5 inorganic N was labelled.

Table 1. Biomass and N yields of rice and their distribution over different plant components

Treatments	Biomass yield (g pot^{-1})				N yield (mg pot^{-1})			
	Root	Straw	Grain	Total	Root	Straw	Grain	Total
T1	13.5	21.6	16.8	51.9	46.8	59.71	150.2	256.7
	26.0	41.6	32.4		18.2	23.3	58.5	
T2	17.5	41.9	31.9	91.3	78.9	134.3	274.5	487.7
	19.2	45.9	35.0		16.2	27.5	56.3	
T3	14.2	32.9	24.7	71.8	59.7	97.3	209.8	366.8
	19.8	45.8	34.4		16.3	26.5	57.2	
T4	17.1	37.3	28.1	82.5	75.7	103.6	232.0	411.3
	20.7	45.2	34.1		18.4	25.2	56.4	
T5	17.0	40.2	28.5	85.7	81.9	108.0	240.2	430.1
	19.8	46.9	33.3		19.0	25.1	55.9	
LSD	1.9	2.5	2.2	3.1	4.6	5.8	14.2	14.6
($P = 0.05$)	2.2	2.7	2.1		1.9	1.3	3.1	

Underlined figures indicate percent of total biomass or N in the respective plant components.

Only 19.3% of the organic ^{15}N and 12.5% of the inorganic ^{15}N were taken up by the plants when the two sources were applied separately; when applied together, the respective values for organic and inorganic ^{15}N recovery were 19.1 and 16.7%. Significant losses of ^{15}N occurred for both the organic and inorganic N source losses being higher for the latter (14.4 *vs* 48.9%). Loss of applied organic ^{15}N increased in the presence of inorganic N, whereas the latter was relatively well conserved in the presence of the former N source.

Table 4 shows the biomass and N yields of wheat and the distribution of the two over root, straw and grain. The residual effects of the various soil treatments were similar to those observed for rice (Table 1). All treatments had significantly positive effects on biomass and N yield. The beneficial effect was highest when organic N was applied alone and lowest in the case of inorganic N. The three plant components showed positive responses to the previous soil treatments. The plants derived 11.1% of their N from the residual organic ^{15}N when applied alone; the contribution of inorganic ^{15}N was 5.1% (Table 5). Both applied N sources caused significant increases in the uptake of soil N.

In T4 and T5, 6.8 and 6.3% of the plant N was derived from the organic and inorganic sources, respectively. However, only a small fraction

Table 3. Percentage distribution of applied ^{15}N over plant, soil and unaccounted forms after rice had been harvested

Treatment	Plant	Soil	Plant + Soil	Unaccounted
T2	19.3	66.4	85.6	14.4
T3	12.5	38.7	51.2	48.9
T4	19.1	61.2	80.3	19.7
T5	16.7	40.8	57.4	42.6
LSD ($P = 0.05$)	1.96	2.65	2.93	3.52

Table 5. N taken up by wheat and its origin

Treatment	Plant N (mg pot^{-1})			
	Total	dfs[a]	dfo	dfi
T1	38.4	38.4 (100.0)	–	–
T2	74.6	66.4 (88.9)	8.3 (11.1)	–
T3	64.1	60.9 (94.9)	–	3.3 (5.1)
T4 and T5[b]	72.9	65.1 (86.9)	5.1 (6.8)	2.8 (6.3)
LSD ($P = 0.05$)	8.1	6.1	0.4	0.3

[a] dfs, dfo and dfi refer to N derived from soil, from the applied organic and the inorganic source, respectively. Figures in parentheses indicate percentages of total plant N derived from the respective sources.

[b] T4 and T5 have been combined because the two treatments were similar, except that in T4 organic N and in T5 inorganic N was labelled.

Table 4. Biomass and N yields of wheat and their distribution over different plant components

Treatments	Biomass yield (g pot^{-1})				N yield (mg pot^{-1})			
	Root	Straw	Grain	Total	Root	Straw	Grain	Total
T1	0.7	3.9	1.6	6.2	1.9	13.0	23.6	38.4
	10.7	63.0	26.4		4.8	33.2	61.4	
T2	0.9	6.4	3.8	11.1	3.8	18.3	52.6	74.6
	8.3	57.6	34.1		5.1	24.5	70.4	
T3	0.8	5.5	3.5	9.8	2.5	13.2	48.5	64.1
	8.1	56.1	35.8		3.9	20.5	75.6	
T4	0.8	5.4	4.0	10.1	3.1	13.4	54.7	71.2
	7.6	53.4	39.1		4.3	18.9	76.8	
T5	0.9	5.5	3.9	10.3	3.7	14.1	56.8	74.7
	8.9	53.3	37.8		5.0	18.9	76.1	
LSD	0.2	0.5	0.3	0.8	0.3	0.8	4.3	5.6
($P = 0.05$)	0.2	3.3	2.9		0.2	1.1	4.0	

Underlined figures indicate percent of total biomass or N in the respective plant components.

Table 6. Percentage recoveries of applied ^{15}N in plant, soil and unaccounted forms after wheat had been harvested

Treatments	Plant	Soil	Total	Unaccounted*
T2	2.1	56.3	58.3	22.4
T3	1.6	33.9	35.5	52.0
T4	2.6	50.2	52.7	28.2
T5	2.8	36.7	39.5	43.8
LSD ($P = 0.05$)	0.2	3.9	3.2	5.0

*100 − (% of applied ^{15}N in rice + wheat + residual soil).

(1.6–2.8%) of the N applied to rice was recovered by the wheat crop (Table 6), thus making an only small contribution to total N in the crop (Table 5).

Significant losses of applied ^{15}N were observed (Table 6, last column). The two crops used only 21.4% of the organic N (19.3 and 2.1% for rice and wheat, respectively) while the losses amounted to 22.4%. Similarly, 14.1% of the inorganic N was taken up by the two crops (12.5 and 1.6 for rice and wheat, respectively) and 52.0% was unaccounted for. When both the organic and inorganic N sources were applied together, the two crops utilized 21.6% of the organic N and 19.4% of the inorganic N, the losses for the two sources being 28.2 and 43.8%, respectively.

Discussion

Green manures can make significant contributions to the N nutrition of rice. Substantial increases in rice yields have therefore been reported following green manuring (Beri and Meelu, 1981; Bhatti *et al.*, 1985; Mian and Stewart, 1985a, b). The present study also shows significant increases in biomass and N yield of rice grown on soil treated with leguminous material. The increase was significantly higher than the one obtained with inorganic N. An increase in crop yield following green manuring is generally attributed to an increased N supply. The data presented here, however, show that the rice crop could use only 19.3% of the organic N applied. Although studies reported by other workers show a higher uptake efficiency of green manure N, it seems likely that the beneficial effect of the leguminous material must be attributed more to an improved overall fertility of the soil than to an improved availability of N. Azam *et al.* (1985, 1986) and Ladd *et al.* (1983) reached a similar conclusion in their studies on the uptake of legume N by wheat. This conclusion is also supported by the finding that a wheat crop following rice could make use of only a very small portion of the residual N from organic or inorganic N applied to soil, but yielded significantly higher in treated soil than in the control soil, thus showing a residual benefit of the soil treatments. Furthermore, it was assumed that roughly 50% of the organic N will be mineralized during the cropping period, thus making approx. 50 $\mu g\,N\,g^{-1}$ soil available to the plants in all four treatments. The treatments, however, differed in the amount of organic matter applied to the soil. Therefore, the observed differences in crop yield were probably more due to differences in quantity of organic matter applied to the soil than to differences in N availability.

A significant portion of the N applied in either form was lost from the soil-plant system, the losses being much higher when inorganic N was applied. Mian and Stewart (1985b) also found higher losses from ammonium sulphate than from Azolla. These losses may be due to NH_3 volatilization and/or denitrification.

Both organic and inorganic N sources applied to rice caused significant increases in uptake of native soil-N. This observation leads to the assumption that, in addition to their role as direct sources of plant-available N, the soil amendments improved crop productivity through an enhanced availability of soil N. Stimulation of soil-N uptake by rice following N fertilization has been reported by other workers as well (Broadbent and Mikkelsen, 1968; Broadbent and Reyes, 1971; Mian and Stewart, 1985b; Patrick *et al.*, 1974). This stimulation may be due to a greater exploitation of the soil profile by the fertilized than by the unfertilized plants (Broadbent, 1981) or due to the so-called 'priming' effect of the material on apparent soil-N mineralization (Hauck and Bremner, 1976). Jansson (1971) attributed the enhanced soil-N mineralization to the biological interchange of applied N with native soil-N.

The occurrence and extent of a priming effect has long been a subject of controversy. However, there is reason to believe that a small priming effect can occur in soils because soil microorganisms will react to the addition of energy-rich materials. (Jansson and Persson, 1982) and the increased microbial activity will involve mineralization of the native soil organic matter. Recently, Jenkinson *et al.* (1985) have introduced the term 'added nitrogen interaction' (ANI) for both positive and negative priming effects. According to them, ANI may be real or apparent. It will be real if *e.g.* fertilizer N increases the volume of soil explored by roots and apparent if it is caused by pool substitution or isotope displacement reactions. Apparent and real ANI can occur simultaneously in the same system and the former may complement the latter. Pool substitution is considered to be the main reason for apparent ANI. If the quantity of soil N taken up by the plants exceeds that of fertilizer N incorporated in soil organic matter, this could be considered as a case of real ANI caused by increased root growth and proliferation in the presence of added fertilizer and resulting in increased soil volume explored by the roots. Results of this study (Tables 1 and 4) show a substantial increase in root biomass in both crops following application of organic or inorganic N. The larger root system will not only explore a larger soil volume but will also support a higher microbial activity including N_2 fixation leading to an increased plant uptake of non-labelled N. An increase in rhizodeposition may also be expected which will result in a greater mineralization-immobilization turnover. In a recent study, an increase in the supply of glucose C to the soil was found to cause a consistent increase in the incorporation of soil N in microbial biomass (Azam *et al.*, 1989b) which was easily extractable.

Data reported in this study show that, after wheat had been harvested, the soil contained 33.9% (67.8 mg pot^{-1}) of the applied inorganic N (ammonium sulphate applied alone). In this treatment, rice and wheat removed 341.8 and 60.9 mg pot^{-1} (total 402.7 mg), respectively, of soil N which may also include biologically fixed N (Tables 2 and 5). In untreated soil, the two crops removed 295.1 mg soil N pot^{-1} (256.7 and 38.4 mg). The extra N taken up by the two crops was thus 107.6 mg pot^{-1} (402.7 minus 295.1) as compared to 67.8 mg pot^{-1} of applied inorganic N retained in soil organic matter after the two crops. It is obvious from these results that the applied inorganic N did cause a real ANI as defined by Jenkinson *et al.* (1985). At the same time, however, the ANI can be considered as apparent if we take into account the enhanced immobilization-mineralization turnover of applied N due to better root development and conceivably a higher rhizodeposition in soil treated with organic or inorganic N. Therefore, in the present study, root-derived immobilization is expected to occur and cause both a real and an apparent ANI as suggested by Jenkinson *et al.* (1985). The results obtained by Westcott and Mikkelsen (1985), however, support the concept that the priming effect of labelled fertilizer-N on soil-N mineralization is an apparent effect due to the interchange of N from the two sources. They further observed that addition of vetch (green manure) material had no effect on soil-N mineralization. Studies by Mian and Stewart (1985b), on the other hand, clearly demonstrate an enhanced soil-N availability to rice due to addition of organic or inorganic N, the amount of extra N released from soil showing an increase with increasing quantity of the amendment. Their data show a higher soil-N availability in soil treated with Azolla material as compared to ammonium sulphate. Results of the present study also show an increased soil-N availability due to the application of organic material alone or together with ammonium sulphate, the effect being more pronounced when the organic material was applied alone. To explain this finding it must be realized that the leguminous material was applied at a rate equivalent to 100 μg N g^{-1} soil when used alone and to 50 μg N when applied with inorganic N. This observation suggests that the effect of the applied material on soil-N mineralization increases with increasing quantity applied. Studies reported by Azam *et al.* (1988b) and Mian and Stewart (1985b) show that the extent of the priming effect of amendments on the mineralization/availability of soil-N is related to the amount of applied material.

In the present study, rice utilized 19.3% and 12.5% of the N applied in organic and inorganic forms, respectively. Data reported by other workers show plant recovery of organic N ranging between 17 and 52% of the quantity applied. Similarly, recovery of N from ammonium sulphate is generally reported to be around 50% (Huang *et al.*, 1981; Mian and Stewart, 1985a, b; Ito and Watanabe, 1985; Mo and Qian, 1983). The low recovery of added N by rice in the present study may be partially attributed to loss of N as well as to its non-availability through pool substitution (Jenkinson *et al.*, 1985) via microbial immobilization. There is evidence that considerable quantities of labelled N may be immobilized even if there is net mineralization of native N by the soil. Pool substitution will cause a greater incorporation of applied N into the soil organic N pool. Apparent ANI resulting from pool substitution will, in turn, contribute to real ANI and cause substantial increases in the amount of soil N taken up by the plants (Tables 2 and 5). Westcott and Mikkelsen (1985) noticed a close relationship between the mineralization of soil organic N and the immobilization of applied N. The interaction between these phenomena lends credence to the biological interchange concept of Jansson (1971) and the pool substitution concept advanced by Jenkinson *et al.* (1985).

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