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Utilization of Sewage Sludge for Enhancing Agricultural Productivity

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Abstract

A microplot field experiment was conducted to study the effect of irradiated and unirradiated sewage sludge on dry matter yield and N uptake of wheat. Sewage sludge was applied at rates equivalent to 120, 180, and 240 kg N ha^{-1}, either with or without ^{15}N-labelled $(NH_4)_2SO_4$-N at 20 kg ha^{-1}. In addition, one control (no treatment) and a treatment receiving 120 kg N ha^{-1} as ^{15}N-labelled $(NH_4)_2SO_4$ was also included in the experiment. Wheat was grown to maturity and the plots were then sown to *Sesbania aculeata* (a green manuring legume). A highly positive effect of sewage sludge, whether irradiated or unirradiated on dry matter yield and N uptake. Sewage sludge not only served as an additional source of plant available N but it helped conserve fertilizer N leading to its increased uptake by plants. The beneficial effect of sludge was more pronounced in the presence of fertilizer N and the effect increased with the rate of application. The effects seemed to persist after harvesting wheat as suggested by higher dry matter yield and N yield of *Sesbania*. However, the analyses of physico-chemical and biological properties of the soil after harvesting wheat indicated that probably the applied sewage sludge decomposed quite rapidly and thus did not add much to the soil organic matter content and other properties. Nevertheless, N content of the soil showed some improvement although not very consistent with the rate of application.

Introduction

Soils in Pakistan are fairly low in organic matter content (generally less than 1%) because of the prevailing climatic conditions that are quite conducive for a rapid loss of C (Malik *et al.*, 1980). Long term field experiments using farmyard manure suggest a meagre build up of organic matter over years of repeated applications. Further, the organic matter returns to the soil are low and a greater proportion of the farm produce is removed from the field. Nevertheless, organic manuring does lead to a temporary improvement in soil fertility and crop production especially when plant residues rich in nutrient elements e.g., leguminous green manures are applied.

Municipal wastes and sewage sludges are important sources of organic matter and are produced in bulk quantities. Traditionally, application of sewage sludge to farm lands is not very common in Pakistan and there is no systematic collection of sewage sludge for use in agriculture. However, with increasing environmental concerns of unorganized dumping of sewage sludge and the realization that sewage sludges could help increase agricultural productivity, the situation may change in the near future. The information already available suggests a highly positive effect of sewage sludge on the ecosystem functioning (Clapp *et al.*, 1984, Benckiser and Simarmata 1994, McGrath *et al.*, 1995) but with some reservations on the possible negative effects via pathogens, heavy metals and organic pollutants (Unken, 1987, Benckiser and Simarmata, 1994).

The problem of pathogens in sewage sludges could fairly be overcome by digestion of sludge and/or; raditation of the material before use may be more assuring (Anonymous, 1994) although not so practicable particularly in countries that lack the facilities for mass scale radiation. Nevertheless, this approach is worth consideration. 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 (McGrath *et al.*, 1994). However, once the metals are in the soil there is little removal by plants or movement down the soil especially in heavy soils high in organic matter (Koskela, 1985). Persistence of elevated concentrations of heavy metals in the plough layer following repeated applications of sludge have been reported (Chang *et al.*, 1984). It would appear that soils in Pakistan which are generally very low in organic matter may retain relatively higher content of mobile heavy metals following sludge application. However, 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. However, the positive effect of sludge may be fairly short lived because of expected rapid decomposition.

The objectives of the experiment reported here was to study: i) the effect of sewage sludge on growth and nutrient uptake of wheat with particular reference to N uptake, and ii) the effect of sludge on some physico-chemical and biological properties of the soil, and iii) the residual effect of soil treatments on subsequent crops.

Materials and Methods

The experiment was conducted at the experimental farm of the Nuclear Institute for Agriculture and Biology, Faisalabad, Pakistan. Forty-eight plots (1.4 x 2.0 m) 1 m apart were established and treated in quadruplicate as under:

T1. Control (no treatment)
T2. 120 kg N ha^{-1} as $(NH_4)_2SO_4$, 1.0 atom % ^{15}N excess
T3. 20 kg N ha^{-1} as $(NH_4)_2SO_4$, 10.0 atom % ^{15}N excess
T4. 20 kg N ha^{-1} + 120 kg N as RSS

T5. 20 kg N ha^{-1} + 180 kg N as RSS
T6. 20 kg N ha^{-1} + 240 kg N as RSS
T7. 20 kg N ha^{-1} + 120 kg N as SS
T8. 20 kg N ha^{-1} + 180 kg N as SS
T9. 20 kg N ha^{-1} + 240 kg N as SS
10. 120 kg N as SS
11. 180 kg N as SS
12. 240 kg N as SS

where RSS is irradiated sewage sludge and SS is unirradiated sludge. The sludge obtained from a treatment glant in Islamabad had the following characteristics: pH, 7.05; organic matter, 23.2%; total N, 1.5%; P, 0.55%; K, 0.2%; 2n, 63.5 ppm; Fe, 5596 ppm; Mn, 288 ppm; Co, 18.7 ppm; Cu, 113 ppm. A portion of the sludge was irradiated at Pakistan Radiation Services (PARAS) Lahore at a dose of 5 kGy in cuboid packets. Both irradiated and unirradiated sludge samples were analyzed for density of coliform bacteria and Ascaris ova.

Treatments were arranged in a completely randomized block design. Recommended dose of N for wheat in Pakistan is 120 kg ha^{-1} and accordingly the doses of sewage sludge were adjusted to obtain N equivalent of 120, 180 and 240 kg N ha^{-1} . Nitrogen added alongwith sludge had 10 atom % ^{15}N. Sewage sludge was uniformly spread on the soil surface and N was applied in solution as a spray on the surface. Superphosphate and mureate of potash were applied to obtain P and K addition rates of 50 kg ha^{-1}. The sludge was then worked well into the top 15 cm soil layer and seeds of wheat (*Triticum aestivum* var. Ingilab) were sawn in rows (6 x 7) such that ultimate experimental ^{15}N area was 1 x 1.5 m with 20 plants; 22 plants on the boundary were considered non-experimental.

Plants were harvested at maturity and grain and straw portions were prepared separately for the analysis of total N and ^{15}N. Total N was determined by micro-Kjeldahl method (Bremner and Mulvaney 1982) and ^{15}N analysis was performed on an IRGA mass spectrometer modified to suit Rittenberg method.

Triplicate soil samples (0-15 cm) were collected from each experimental plot, pooled, wet sieved and stored at 4°C before analysis. Total N, mineral N, organic C, WHC, pH and microbial biomass N (fumigation-incubation method of Jenkinson and Powlson (1976) of the moist samples was determined.

After collecting soil samples, the plots were sown to *Sesbania* (a green manuring crop commonly cultivated between wheat and rice to serve as additional source of organic C and N). After 8 weeks of growth, the plants were harvested, weighed fresh, sub-sampled for N analysis, and incorporated into the plots about two weeks prior to transplanting rice. In this paper only some data on *Sesbania* is being presented with more details to be reported after harvesting rice.

Results and Discussions

Irradiation of sewage sludge at the dose of 5 kGy significantly reduced the population of coliform bacteria and Ascaris ova (Table 1). Results of the presumptive phase showed MPN of 2 and 240 in irradiated and unirradiated sludge, respectively after 24 hrs of incubation, while after 48 hrs, MPN was 300 and 1600. In general, both acid and gas production was noticed for unirradiated sample, while production of acid was the predominant feature for irradiated sample. Confirmation test on brilliant green lactose broth showed MPN of 12 and 900 in irradiated and unirradiated samples, respectively.

Table 1: Coliform density (MPN index/100 ml)

	Presumptive phase		Confirmed phase
	24 hrs	48 hrs	
SS	240	1600	900
RSS	2	300	12

Maximum dry matter yield was obtained with N addition rate of 120 kg ha^{-1} which was significantly higher than the control and other soil treatments (Fig. 1). The differences in grain yield were relatively less as compared to total dry matter yield. Application of sewage sludge whether irradiated or unirradiated caused a substantial increase in total dry matter yield and the effect increased with the rate of application. No significant differences were observed between irradiated and unirradiated sewage sludge so far as the dry matter production is concerned. Grain yield also increased, the increase being more when sewage sludge was applied along with 20 kg N ha^{-1}.

Trends in N content (or N yield) were fairly similar to those observed for dry matter yield (Fig. 2). Application of sewage sludge without N, however, appeared to have somewhat depressing effect on N content as compared to control.

Fig. 3 compares the averages of 3 rates of different sludge treatments for their effect on dry matter and N yield. This figure clearly demonstrates similarity of irradiated and unirradiated sludge for their influence on the two growth parameters. The results also suggest a beneficial effect of supplementing sewage sludge with small quantities of inorganic N. It will be interesting to study different combinations of sewage sludge and inorganic N for their yield enhancing properties.

Table 2 describes more clearly the results of percent changes (increase or decrease) in dry matter yield and N yield due to different soil treatments. Grain yield and total dry matter yield increased by 143 and 69 percent, respectively in response to fertilizer N applied at 120 kg ha^{-1}; respective increase in N yield was 63 and 83 percent. A small but significant increase was also noticed at 20 kg N ha^{-1}. With irradiated and unirradiated sewage sludge applied together with 20 kg N ha^{-1} of fertilizer N, there was a significant improvement in dry matter and N yield that increased with the rate of addition. When applied alone, however, sewage sludge caused a significant increase in dry matter but a reduction in N content of the harvested parts. It seems that when applied alone, the sludge used in the present studies did not serve as an additional source of N and any positive effects on dry matter yield could be attributed to factors like soil improvement as a whole and

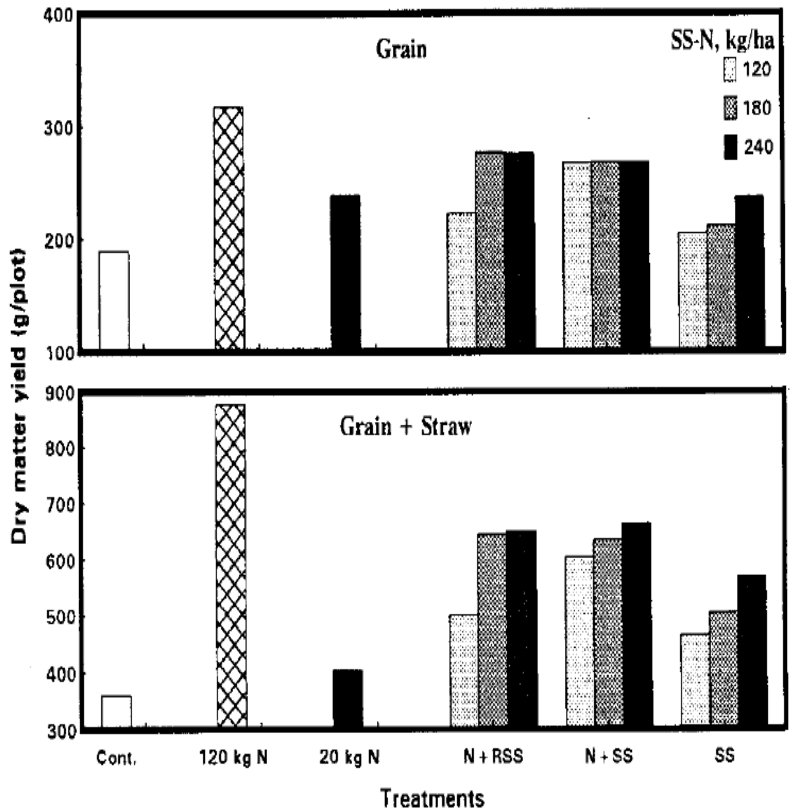

Fig. 1: Dry matter yield of wheat as affected by different soil treatments

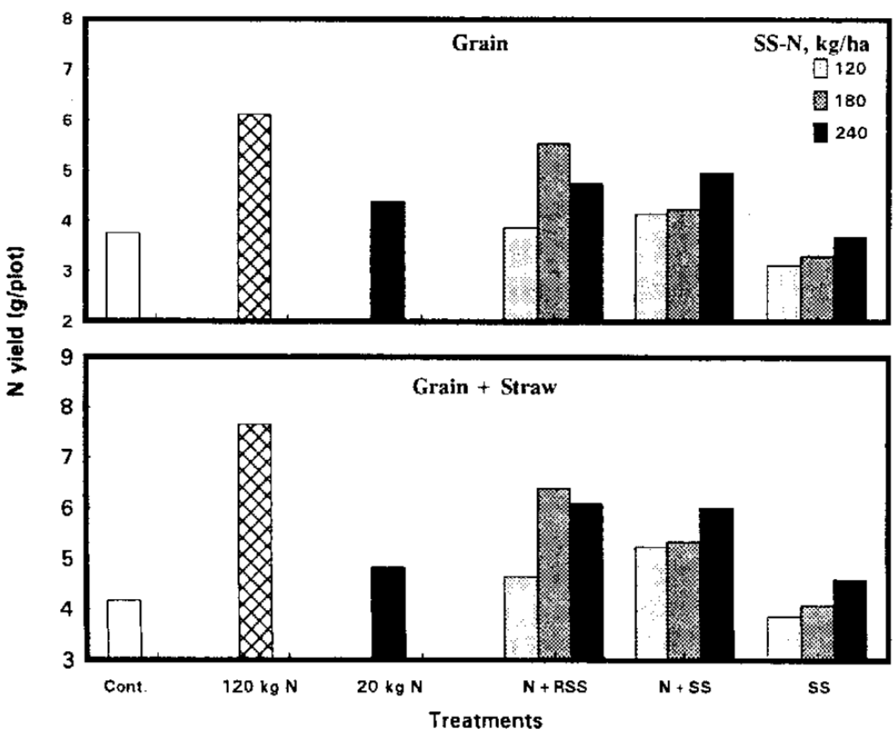

Fig. 2: N yield of wheat as affected by different soil treatments

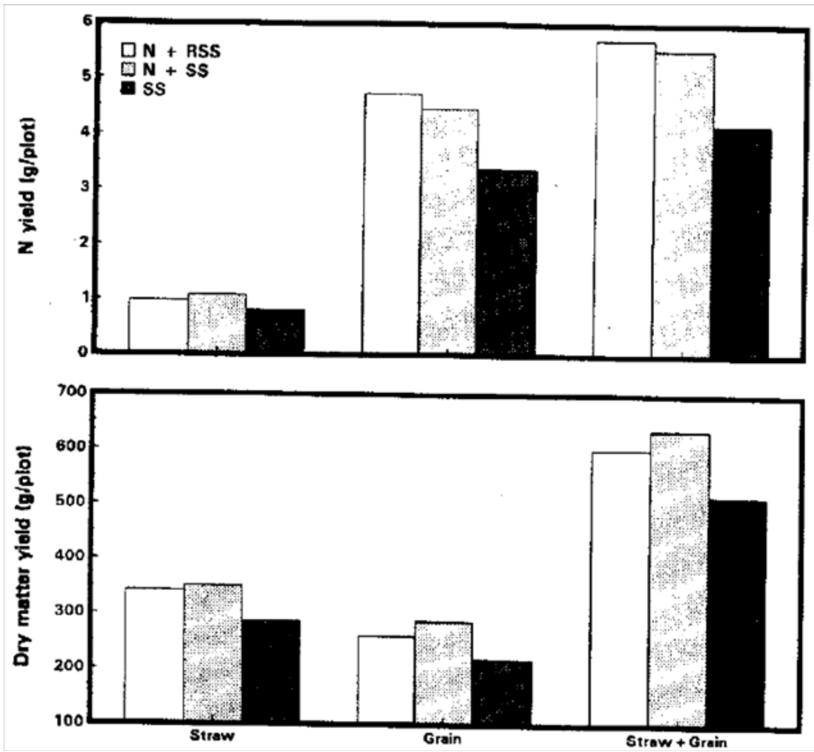

Fig. 3: Effect of irradiated and unirradiated sewage sludge on dry matter and N yield (average of 3 sludge rates)

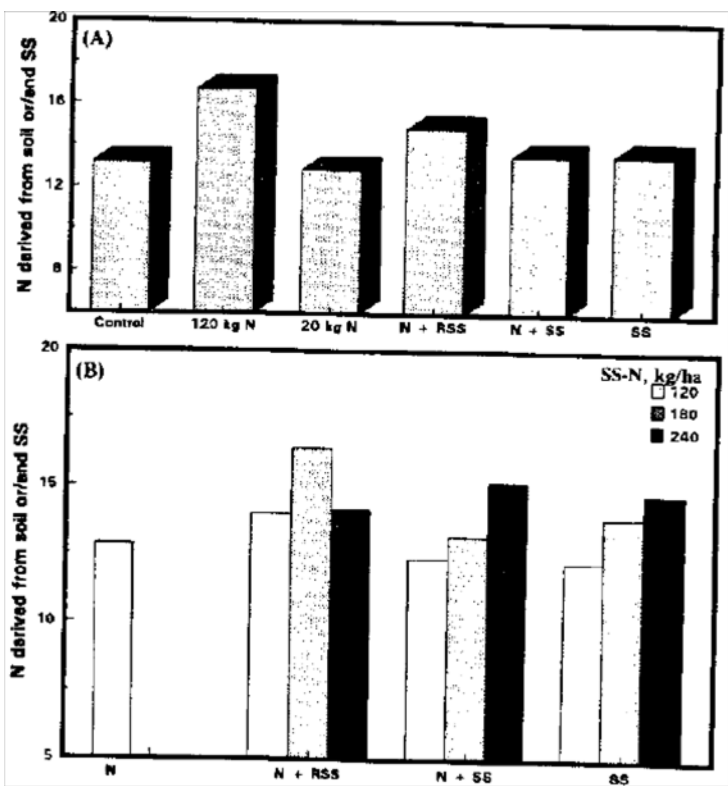

Fig. 4: Effect of different soil treatments on plant N derived from soil and/or sewage sludge (A) comparison of sewage sludge (average of 3 levels) with other treatments (B) effect of N and sewage sludge alone, or in combination

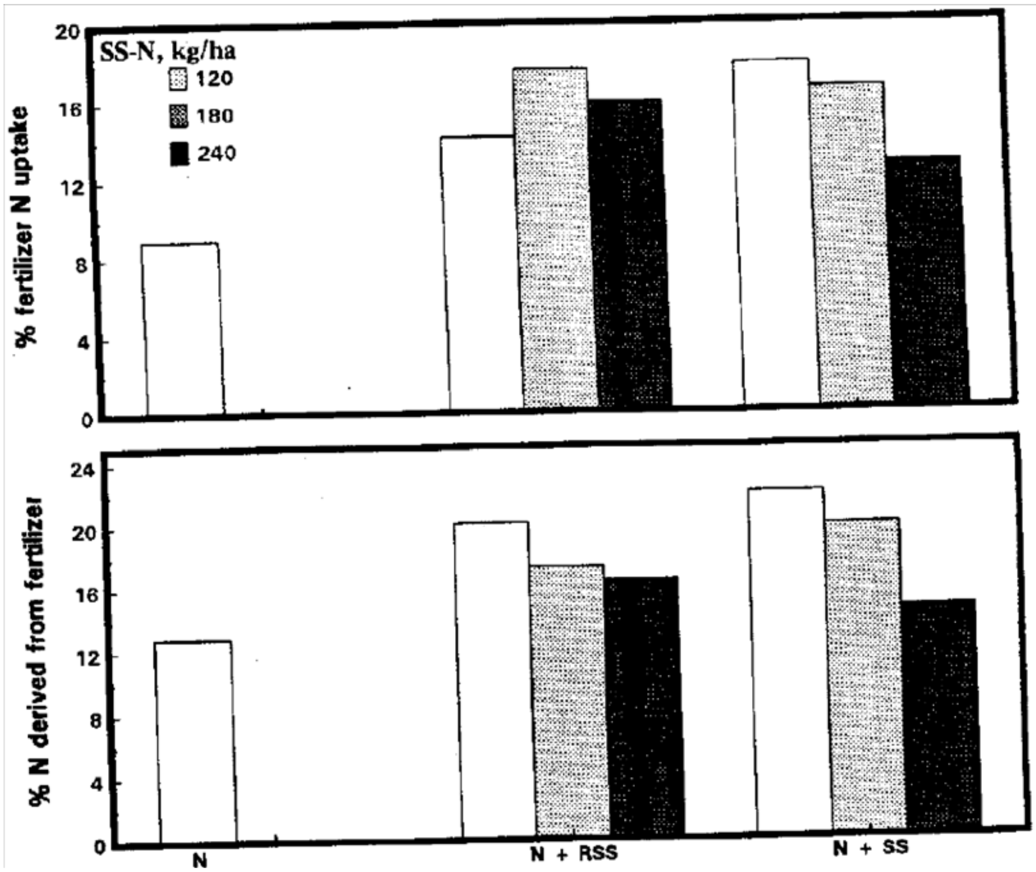

Fig. 5: Percent plant N derived from fertilizer and percent of fertilizer N in plants in response to different soil treatment

availability of nutrients other than N. Detailed elemental analysis of the harvested material may help understand the basis. However, addition of small quantities of fertilizer N might have helped the release of sludge N as well as soil N leading to increased N content of plants. Favourable effects of inorganic N on the mineralization of organic N from sources like green manures has been reported (Azam *et al*., 1985, 1995).

Table 2: Response (% of control) of dry matter and N content of wheat to different soil treatments

Treatments	Dry matter yield		N yield	
	Grain	Total	Grain	Total
120 kg N	142.7	69.1	62.9	83.2
20 kg N	12.7	25.7	16.8	15.9
20 kg N+ RSS1	39.2	17.4	3.4	11.4
20 kg N+RSS2	79.1	45.8	47.8	53.1
20 kg N + RSS3	80.6	45.1	26.6	45.9
20 kg N i RSS1	67.8	41.1	10.4	25.4
20 kg N +RSS2	76.6	41.8	13.0	28,1
20 kg N + RSS3	84.3	68.9	32.3	43.1
551	29.4	8.2	-16.6	-7.5
552	40.5	11.8	-11.9	-2.1
583	57.8	24.7	-1.8	10.2

Table 3: Dry matter, N content and ^{15}N of *Sesbania*

Treatments	Dry matter Yield (g/plot)	N yield (g/plot)	N (%)	N-15a
Control	1.167	20.68	1.74	0.36
120 kg N	1.073	22.00	2.06	0.37
20 kg N	1.011	22.70	1.78	0.37
20 kg N + RSS1	1.009	25.16	2.50	0.37
20 kg N + RSS2	1.054	24.40	1.78	0.37
20 kg N + RSS3	1.318	30.20	2.29	0.37
Mean	1.127	26.59	2.19	0.37
20 kg N + RSS1	1.855	40.72	2.19	0.37
20 kg N + RSS2	1.587	33.88	2.13	0.37
20 kg N + RSS3	1.733	41.94	2.40	0.37
Mean	1.725	38.84	2.24	0.37
SS1	1.385	28.72	2.07	0.37
SS2	1.589	40.18	2.52.	0.36
SS3	1.714	37.26	2.17	0.36
Mean	1.563	35.38	2.25	0.36

Fig. 4 provides additional information on the effect different soil treatments on the availability to plants of (unlabelled) from sources other than fertilizer N. Application of fertilizer N at 120 kg ha^{-1} significantly enhanced uptake of unlabelled N from soil (Fig. 4a), an observation in line with many other reports that attribute such effects to an added nitrogen interaction or a "priming" effect (Azam 1992, Hart *et al.*, 1986; Jenkinson *et al.*, 1985; Westerman and Kurtz 1973). At 20 kg N ha^{-1}, however, there was no significant effect on the plant availability of unlabelled N. When 3 rates of sewage sludge were averaged, only irradiated sludge was found to cause a significant increase in the plant uptake of unlabelled N, while the other two sludge treated sets did not show any major changes. Effect of organic amendments high in N content are reported to increase the availability of soil N to plants (Azam, 1990).

In general, the uptake of unlabelled N increased with the rate of sludge application (Fig. 4b), however source of this extra N (sludge or native soil organic matter) could be determined only if ^{15}N-labelled sludge was used. While deciding the treatments, however, it was assumed that sewage sludge would lead to a dilution of plant ^{15}N in comparison to a treatment where 20 kg ha^{-1} of ^{15}N labelled fertilizer (10 atom % ^{15}N excess) was used. This dilution could be used to calculate the amount of N derived from sludge by using the equation:

ndfss (%) = (1-(at % ^{15}N excess with sludge/that without)x 100

However, the atom % ^{15}N excess of plant samples grown in sludge treated soils always remained less than that of plants grown without sludge. This would mean that in fact sewage sludge enhanced the availability of added ^{15}N labelled N. This contention is supported conclusively from the data presented in Fig. 5. Not only the plants treated with sewage sludge derived a higher percentage of their N from applied ^{15}N-labelled fertilizer but the absolute amounts of fertilizer N taken up by plants was also substantially higher compared to non-sludge treatment. This may mean that sludge conserved fertilizer N for a prolonged period and the plants were able to make use of it over an extended period of time; the extra amount of unlabelled N (Fig. 4). It was not enough to offset this effect so as to lead to a substantial dilution of plant N. These observations demand further studies, particularly on the rate of N uptake from fertilizer and other sources at different stages of plant growth.

Beneficial effects of inorganic fertilization and sewage sludge were also exhibited on the second crop i.e., *Sesbania* (a leguminous green manuring crop, Table 3). In this case, however, unirradiated sewage sludge proved better as was also the sludge without N. Apparently, in these treatments the first crop had a relatively higher exhaustive effect on the soil resources leading to lesser residual effects. Total N yield and percent N content of the plants was also more in treated soils. *Sesbania* growth lead to a significant dilution of ^{15}N due to biological N2 fixation, the dilution being almost similar for irradiated and unirradiated sludge treatments. The trends in atom % ^{15}N excess of different treatments were fairly similar in wheat (data not shown) and *Sesbania* samples. Again a lesser dilution of plant ^{15}N in case of sludge treated soils in comparison to the treatment receiving only 20 kg N ha^{-1} of labelled N suggested a conservational effect of sludge on fertilizer N.

Analysis of fumigated and unfumigated soil samples after harvesting wheat did not show major effects of different soil treatments on microbial biomass (Table 4). On an average, irradiated or unirradiated sludge and sludge without fertilizer N did not show clear differences in the amount of biomass N. The content of NH_4-N increased significantly due to fumigation and the flush of NH_4-N (difference of fumigated and untreated soils) was used to calculate biomass N employing a kn factor of 0.3. Biomass N ranged between 41 and 69 ug g^{-1} soil, an observation in conformity with previous findings (Azam *et al.*, 1985). The amount of NO_3-N decreased during incubation of soils following fumigation suggesting its immobilization.

Soil samples obtained after harvesting wheat were analyzed for organic C, total N, mineral N, pH and WHC (Table 5). Samples analyzed before wheat showed a significant

Table 4: Determination of mineral N in chloroform fumigated and unfumigated soils as a measure of microbial biomass N

Treatments	Fumigated			Unfumigated			Biomass N
	NH_4	NO_3	NH_4+NO_3	NH_4	NO_3	NH_4+NO_3	
				ug N g^{-1} soil			
Control	25.18	12.09	37.37	5.96	15.32	21.28	64.1
120 kg N	24.76	12.03	36.79	4.21	15.19	19.41	68.7
20 kg N	20.84	9.20	30.03	3.11	12.16	15.28	59.0
20 kg N+RSS1	24.02	14.70	38.71	3.25	14.70	17.94	59.3
20 kg N+RSS2	20.28	10.31	30.58	3.29	13.14	16.43	56.7
20 kg N+RSS3	20.51	11.49	32.00	1.62	12.67	14.29	57.3
20kg N+RSS1	19.10	9.16	28.26	2.55	12.17	14.72	55.3
20 kg N+RSS2	18.05	9.24	27.29	1.41	9.71	11.12	55.3
20 kg N+RSS3	19.58	10.22	29.80	0.32	10.71	11.03	64.3
551	19.81	9.94	29.74	0.32	10.58	10.90	65.0
552	15.15	9.89	25.04	1.65	13.52	15.17	45.7
553	13.52	9.57	23.09	1.12	10.76	13.88	41.3

Table 5: Soil analyses before and after wheat

Treatments	Org. C (%)	Total N (ug g^{-1})	Min. N (ug g^{-1})	pH	WHC
			Before wheat		
Control	0.25	547	17.6	7.22	27.08
SS1	0.33	591	35.6	7.05	35.00
SS2	0.37	616	33.7	7.06	38.96
SS3	0.39	633	42.9	6.80	42.56
			After wheat		
Control	0.28	542	2.3	7.12	25.12
120 kg N	0.29	573	3.1	6.98	24.48
20 kg N	0.22	575	5.6	6.95	25.44
20 kg N+RSS1	0.25	546	9.9	6.75	26.28
20 kg N+RSS2	0.21	573	9.1	6.66	26.44
20 kg N+RSS3	0.23	603	5.8	6.87	25.24
20 kg N+RSS1	0.23	543	3.5	6.81	26.00
20 kg N+RSS2	0.21	645	4.1	6.96	28.84
20 kg N+RSS3	0.23	579	5.2	7.12	26.80
SS1	0.23	653	3.3	7.11	25.60
SS2	0.21	608	4.5	7.16	27.08
SS3	0.23	667	4.3	6.71	26.98

increase in characteristics other than pH due to sewage sludge addition, the later showed a decrease. At wheat harvest, comparison of different treatments indicated a substantial increase in total N content, while pH decreased to some extent. Total organic C was almost unaffected suggesting a rapid decomposition of the applied sludge. However, there was some improvement in WHC, while mineral N content was fairly low. The results of this study do suggest a positive effect of sewage sludge on physico-chemical and biological properties of the soil as well as substantial beneficial effect on crop yield and nutrient (N) uptake. However, the material used in this study seemed to be fairly easily decomposable resulting in negligible addition to the total organic matter content of the soil. Results of coliform enumeration indicated an almost complete kill at an irradaition dose of 5 kGy.

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