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Recycling gamma irradiated sewage sludge as fertilizer: A case study using onion (*Alium cepa*)

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ABSTRACT

Recycling sewage sludge into fertilizer for agricultural purposes may improve soil fertility by influencing the physical, chemical, and biological properties of the land. However, there is concern regarding elevated levels of heavy metals and pathogenic microorganisms, which may result from the use of untreated sewage sludge. Gamma radiation is found to be an efficient tool in the hygienization of municipal sewage sludge. In order to evaluate the agricultural potential of gamma irradiated sewage sludge and to assess the safety of this fertilizer, field experiments were performed in a root crop, onion (*Alium cepa*), during the 2003–2004 and 2004–2005 winter months. The influence over major nutrients, metallic micronutrients, and heavy metals in soil and crop plant were key factors to be analyzed. Treatments consisted of three source of fertilizers {S_1: farmyard manure (FYM); S_2: gamma irradiated sewage sludge (GISS); and S_3: non-irradiated sewage sludge (NISS)}, each at three separate levels (L_1: 5 t ha^{-1}; L_2: 10 t ha^{-1}; and L_3: 15 t ha^{-1}), which were evaluated and compared. The growth parameters and onion yield were not significantly influenced by the different sources of fertilizer, or the different application levels. Values of pH, organic carbon, organic N, available P and K, metallic micronutrients (Zn, Mn, Fe, Cu) and heavy metals (Ni, Cd, Pb, Co) indicate no negative effects on either soil or plant properties. Concentrations of heavy metals in soil and plant were slightly higher in NISS treatment in compare to GISS; however, the concentrations did remain within the prescribed limit, and no significant increase was consistently noted. The results prove that the gamma irradiated sludge material was of equal quality compared to the conventional FYM.

1. Introduction

The unprecedented growth of urban population has resulted in a vast buildup of sewage sludge throughout the world, and the improper handling and disposal of this sewage sludge has resulted in a major source of environmental pollution (Mor et al., 2006a). Presently, the majority of sewage sludge generated in developing countries is disposed of via open dumps; however, this method of inadequate disposal is a public health risk (Gautam et al., 2005). Due to increased population and urbanization, sewage sludge treatment has become an important component in the disposal and management of environmental pollution (Benton and Wester, 1998; Rathod et al., 2008).

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The use of sewage sludge as a land fertilizer or soil conditioner is a method of resource conservation that is practiced worldwide. In fact, municipal sewage sludge has been spread over soil as a form of organic fertilizer for about two decades now (Krogman et al., 1997). Though there are obvious benefits to this practice, it is imperative for sewage sludge to be treated before it is discharged, although this is not always the case. For example, presently only 30% of the sewage sludge in India is being treated before discharge (GOI, 2002). Since municipal sewage sludge contains a substantial load of pathogenic bacteria and viruses, it can cause a public health risk when it is released untreated (Pike, 1986; Ahmed and Sorensen, 1997). Another potential health hazard is that the sludge could elevate the level of heavy metals in the soil and plant (Jung et al., 2002). Due to these possible health threats, several techniques have been designed in order to ensure that the sludge is biologically and chemically safe before it is distributed over soil. Such techniques include anaerobic digestion, composting and thermal disinfection (APHA-AWWA-WPCF, 1989).

Ionizing radiation has been introduced as an effective and rapid method of sewage sludge treatment (Bauer, 1994; Getoff, 1996). Several studies have confirmed the efficacy of ionizing radiation in treating sewage sludge (Lowe et al., 1956; Pikav and Shubin, 1984; Hashimoto et al., 1986; Lessel, 1988; Swinwood and Fraser, 1993). Although gamma radiation is by far the most commonly used form of radiation in the treatment of sewage sludge, other types of radiation including alpha, beta, and X-ray have also been used (Getoff, 1992; Waite et al., 1992). Effective hygienization of sewage sludge treated by gamma radiation is well documented (Kapila et al., 1981; Pandya et al., 1987; Rawat et al., 1998). Radiation doses (specifically gamma radiation, not electron beam radiation) varied from 2 to 25 kGy (kiloGray, 10^3 Gy: measures the deposited energy of radiation), with the majority between 3 and 6 kGy.

The rationale for implementing radiation in the treatment of sewage sludge rests on a number of documented facts. The practical advantages of gamma irradiated sewage sludge include: (i) the destruction of microbial life, which can result in the inactivation of pathogenic micro flora. Gamma rays can also remove a wide variety of organic contaminants, as well remove harmful microorganisms from the sludge (Borrely et al., 1998), (ii) an increase in the mobility of micronutrients in the soil, including Cu, Pb and Zn; this could possibly be due to an increase of the more easily adsorbed free forms of metals derived from the degradation of soluble organic complexes (for more details, see Campanella et al., 1989). As long as the concentrations of Cu, Pb and Zn are below the prescribed limit, these micronutrients are beneficial to the plant, especially in soils which restrict them. However, research into the behavior of trace metals in soils is needed in order to understand the long-term effect of sludge disposal on agricultural land. It is well known that an excess amount of heavy metals in sewage sludge may create a potential threat of entry of heavy metals to ground water (Mor et al., 2006b), (iii) no requirement for a withholding period between application and crop harvesting (Wen et al., 2002), (iv) the capability of the radiation to alter the structure of organic molecules, thus leading to a decrease in the biochemical oxygen demand (BOD) and the chemical oxygen demand (COD), (v) physiochemical alteration in the suspended solid, which leads to the formation of more compact sludge and an increased ability to settle (Suess et al., 1983).

Radiation techniques have been widely studied in terms of purifying drinking water and food (Woods, 2000), but the application of these techniques in recycling sewage effluent and practical applicability at filed level is not well documented (Jung et al., 2002; Pikav and Shubin, 1984). Although the concept of using ionizing radiation for sewage sludge treatment purposes was initially conceived nearly five decades ago, it is only in recent years that there have been some reports on the potential role of radiation in the treatment of sewage sludge in terms of effective hygienization prior to its application to agricultural soils. In several countries, such as Germany, India, and Italy, the use of irradiation systems to disinfect liquid sludge prior to its application to farm land has been successfully adopted (Swinwood et al., 1994).

Gamma irradiated sewage sludge (GISS) is qualitatively different from the sludge obtained by conventional treatment methods, and yet, there is no data available on use of GISS in onion (*Alium cepa*). For this reason, an endeavor to study the manurial effect of GISS on plant growth and soil fertility was launched. The specific objectives of this study are as follows: (1) to characterize the effects of irradiated and non-irradiated sewage sludge on the physical and chemical properties of both soil and plant life; (2) to quantify the benefits of sewage sludge in terms of increasing crop yield and improving soil fertility (including macro- and micronutrient availability); and (3) to assess the extent (if any) of soil and crop contamination caused by sludge-derived heavy metals.

2. Materials and methods

The present study was conducted at the experimental farm, located at the Regional Research Station, Anand Agricultural University (AAU), in Gujarat, India. The experimental field was cropped with onion for 2 consecutive years (2003–2004 and 2004–2005). The field plots received the same sewage sludge application during each year, infected the same plot (randomization), and utilized the same experimental fields for both years. The soil of experimental site was alluvial in nature, locally known as '*Goradu*', with the texture ranging from loamy sand to sandy loam (*Typic Ustocrepts*). The soil was low in nitrogen and medium in phosphorus and potash contents. The climatic zone represents semi-arid and sub-tropics with hot summer and cool winter.

2.1. *Irradiation of sewage sludge*

Irradiation facilities for treatment of sewage sludge have been constructed in many countries around the world. The first large scale plant was ''Geiselbullach Gamma Sludge Irradiator'', which was constructed in Germany in 1973. India's Sludge Hygienization Research Irradiator (SHRI) is the second largest plant in the world, and it was built in co-operation with the Government of the State of Gujarat and the Vadodara Municipal Corporation in 1992. The objective is to treat the entire sludge output of about 110 m^3 day^{-1} from the Gajerawadi Sewage

Table 1 – Physico-chemical characteristics of fertilizers used in this experiment.

Parameter	Farmyard manure (FYM)	Gamma-irradiated sewage sludge (GISS)	Non-irradiated sewage sludge (NISS)
pH	6.42	6.81	6.64
Nitrogen (%)	1.80	2.30	2.00
P_2O_5 (%)	0.48	0.19	0.23
K_2O (%)	0.26	0.15	0.18
Organic matter (%)	35.56	37.65	42.57
Zn (mg kg^{-1})	11.05	50.16	49.08
Mn (mg kg^{-1})	15.00	38.22	25.53
Fe (mg kg^{-1})	3300.00	7130.00	6807.00
Cu (mg kg^{-1})	1.41	1.91	2.19
Ni (mg kg^{-1})	6.96	10.20	12.23
Cd (mg kg^{-1})	0.95	1.06	1.45
Pb (mg kg^{-1})	9.07	14.25	14.00
Co (mg kg^{-1})	4.18	6.20	6.40

Treatment Plant and use the hygienized sludge as a fertilizer (for more details see Swinwood et al., 1994).

SHRI has two separate yet identical irradiation circuits; each comprised of a silo, irradiation chamber, and recycling system. Both irradiation chambers have a maximum cobalt-60 loading capacity of about 500 kCi. At a dose of 3–4 kGy, each irradiation circuit can handle approximately 100–120 m^3 day^{-1} of sludge. First, the liquid sludge must pass through a silo, and then a measured volume of 3 m^3 is fed into the irradiation vessel. The sludge is then circulated by a pump for a predetermined duration, in order to prevent settling and to impart the desired dose. Once completing this process, the sludge is drained into a storage tank and subsequently pumped into drying beds (for more details read Gautam et al., 2005). With the present cobalt-60 loading and a batch operation of 3 days of incubation in the open circulation loop system, the total coliform count in non-irradiated sludge (cfu/ml) was 3×10^3, whereas in irradiated sludge, no coliform count was observed (Gautam et al., 2005).

The GISS and NISS were transported to the experimental site at experimental Farm, AAU, Anand, located 50 km away from SHRI, Vadodara. The farm yard manure (FYM) used in this study was purchased from a local dealer in Anand, and the heavy metal content in this sewage sludge was below the maximum permitted limit established by the United States Environmental Protection Agency (USEPA, 1993).

2.2. *Field experimentation and treatment details*

Field experiments were conducted during the 2003–2004 and 2004–2005 winter seasons (October through March) in a root crop: onion (*Alium cepa*, cultivar: Nasik Red, plot size: 4.0 m × 1.8 m). The onion seeds were purchased from a local market in the city of Anand. All three fertilizers were planted at a soil depth of about 15–20 cm. The experiment was laid out in a three by three factorial randomized complete block design (FRBD) with three fertilizer treatments (S_1: FYM; S_2: GISS; and S_3: NISS) and three levels of fertilizers (L_1: 5 t ha^{-1}, L_2: 10 t ha^{-1} and L_3: 15 t ha^{-1}). Each block had nine treatments and each treatment was replicated three times.

2.3. *Chemical analysis of sewage sludge*

The sludge was sun dried in a drying bed located at the field for a period of 1 week. The temperature averaged about 30 °C, with the initial moisture of about 85–90%. The dried sludge

Table 2 – Influence of various fertilizers and their levels on growth parameters and yield of onion.

Treatment	Yield (q ha^{-1})			Plant stand (No. $Plot^{-1}$)			Bulb girth (cm)		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
Source of fertilizers (S)									
S_1	32.31	28.22	30.27	287.60	240.83	264.25	20.47	18.50	19.49
S_2	32.75	28.52	30.63	286.90	241.17	264.03	20.49	19.20	19.85
S_3	30.31	28.75	29.53	287.10	241.17	264.14	20.30	19.20	19.75
S.Em. ±	1.40	0.57	0.75	2.80	1.39	1.60	0.18	0.89	0.45
CD (5%)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Level of fertilizers (L)									
L_1	33.58	27.13	30.36	258.10	240.83	262.97	20.78	18.24	19.51
L_2	31.17	28.59	29.73	286.70	240.33	263.50	20.24	18.49	19.37
L_3	30.62	30.01	30.35	289.90	242.00	265.94	20.23	20.19	20.21
S.Em. ±	1.40	0.57	0.75	2.80	1.39	1.60	0.18	0.89	0.45
CD (5%)	NS	1.61	NS	NS	NS	NS	NS	NS	NS
S × L	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV%	13.18	5.98	10.61	3.01	1.73	2.57	2.63	14.08	9.78

was crushed and then sieved to pass through a 2 mm mesh sized sieve. The heavy metal content of sewage sludge was determined by using a digestion system with the program: 0.5 g sludge dry weight (DW) + 10 ml diacid mixture (HNO_3 + $HClO_4$ in 2:1 ratio). The digested solution was analyzed for micronutrients and heavy metal content using AA Spectroscopy (Chemito AA203) (for more details, read Arnesen and Singh, 1998). Additional chemical properties of the sludge were analyzed using standard methods mentioned in Section 2.4.

2.4. Plant harvest and chemical analysis

Onion bulbs were harvested as they matured (roughly 4 months of planting) and then weighed for yield determination purposes. Growth parameters, such as plant stand per net plot area and girth of onion bulb, were also recorded. Three plant samples from each net plot were collected in order to analyze the onion bulbs and leaves. Plant samples were dried in an oven at a temperature of 60 °C, followed by digestion with diacid mixture (HNO_3 + $HClO_4$ in 2:1 ratio) for chemical analysis. The metallic micronutrients and heavy metals were analyzed by using AAS (Chemito, AA203). Soil samples (0–20 cm depth) were collected at the end of each growing season using a pipe auger. The samples were air-dried, crushed to pass through a 2 mm mesh sieve, and then preserved for analysis. Plant and soil samples were analyzed using the following standard methods: the organic carbon was analyzed using the Walkley and Black method, the organic N via the Kjelhdahl's method, the available P_2O_5 using the Olsen's method, and the available K_2O by means of the flame photometry method (Jackson, 1973).

2.5. Statistical analysis

An analysis of variance (ANOVA) was performed on the untransformed data from each growth seasons (2003–04 and 2004–05). The pooled data from both winters was also calculated in order to test for differences among treatments at the 5% level of significance ($P < 0.05$); this was done using the factorial randomized complete block design (FRBD) statistical analysis package (Chandel, 1970). Each value represents the mean of at least three plants in each growth season. The significant and non-significant of a given variance was determined by calculating the S.Em. ± and CD values. The coefficient of variation (CV%) was also calculated via standard formula (Chandel, 1970).

3. Results and discussion

3.1. Chemical analysis of fertilizers

The results of the physico-chemical analysis of all three fertilizers used in these experiments are shown in Table 1. The GISS and NISS contained a pH close to neutral, while FYM was slightly acidic in comparison. Particularly at high application rates, sludge application may increase the phytoavailability of micronutrients. The high organic matter content of GISS (37.65%) and NISS (42.57%) may significantly improve the physical properties of the soil. A higher concentration of heavy

Table 3 – Influence of various sources and levels of fertilizers on soil pH, organic carbon and major nutrients.

Treatment	pH (1:2.5)			Organic carbon (%)			Organic nitrogen (%)			Available P_2O_5 (kg ha^{-1})			Available K_2O (kg ha^{-1})		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
Source of fertilizers (S)															
S_1	7.74	8.07	7.90	0.23	0.14	0.19	0.020	0.012	0.016	94.68	119.14	106.91	259.50	282.60	271.03
S_2	7.99	8.07	8.03	0.25	0.17	0.21	0.021	0.014	0.018	99.53	98.34	98.97	279.50	304.78	292.13
S_3	7.98	8.12	8.05	0.22	0.16	0.19	0.019	0.014	0.016	82.96	101.70	92.34	271.80	302.44	287.13
S.Em. ±	0.07	0.03	0.04	0.01	0.01	0.01	0.001	0.001	0.001	3.97	9.64	5.22	5.80	7.36	4.67
CD (5%)	0.21	NS	NS	NS	NS	NS	NS	NS	NS	11.91	NS	NS	NS	NS	13.45
Level of fertilizers (L)															
L_1	7.82	8.12	7.97	0.22	0.16	0.19	0.018	0.014	0.016	75.47	88.25	81.86	249.70	277.53	263.61
L_2	7.98	8.08	8.03	0.22	0.16	0.19	0.019	0.014	0.017	89.65	108.41	99.07	277.00	304.67	290.85
L_3	7.91	8.05	7.98	0.27	0.14	0.20	0.023	0.012	0.018	112.07	122.52	117.29	284.00	307.62	295.83
S.Em. ±	0.07	0.03	0.04	0.01	0.01	0.01	0.001	0.001	0.001	3.97	9.64	5.22	5.80	7.36	4.67
CD (5%)	NS	NS	NS	0.04	NS	NS	0.003	NS	NS	11.91	NS	15.02	17.30	20.81	13.45
S × L	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	23.29
CV%	2.68	1.07	2.03	16.05	22.03	18.82	16.05	22.03	18.82	12.90	27.18	22.97	6.39	7.44	6.99

Table 4 – Influence of various fertilizers and their levels on available metallic micronutrients in soil.

Treatment	DTPA–Zn (ppm)			DTPA–Mn (ppm)			DTPA–Fe (ppm)			DTPA–Cu (ppm)		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
Source of fertilizers (S)												
S_1	1.73	1.19	1.46	10.37	9.81	10.09	8.23	8.40	8.31	2.18	1.17	1.67
S_2	1.84	1.32	1.58	10.83	12.33	11.58	7.67	9.90	8.79	2.06	1.19	1.62
S_3	1.54	1.72	1.63	9.29	11.65	10.47	9.13	8.59	8.86	2.36	1.04	1.70
S.Em. ±	0.15	0.08	0.09	0.51	0.34	0.31	0.51	0.20	0.28	0.11	0.05	0.06
CD (5%)	NS	0.22	NS	NS	0.95	NS	NS	0.56	NS	NS	NS	NS
Level of fertilizers (L)												
L_1	1.40	1.19	1.30	8.22	10.69	9.46	8.34	8.31	8.32	2.22	1.01	1.61
L_2	1.65	1.44	1.54	9.16	11.19	10.17	7.83	9.01	8.42	2.08	1.07	1.57
L_3	2.06	1.60	1.83	13.11	11.90	12.51	8.86	9.56	9.21	2.31	1.32	1.81
S.Em. ±	0.15	0.08	0.09	0.51	0.34	0.31	0.51	0.20	0.28	0.11	0.05	0.06
CD (5%)	0.46	0.22	NS	1.45	NS	NS	NS	0.56	NS	NS	0.14	NS
S × L	NS	0.39	NS	2.51	1.65	NS	NS	0.97	NS	NS	0.25	NS
CV%	26.94	16.86	23.49	15.11	8.98	12.14	18.48	6.61	13.50	15.01	13.46	15.43

DTPA = diethylene triamine pentaacetic acid.

metals in sewage sludge in comparison to FYM was natural given that the raw sewage sludge was obtained from municipality waste, house hold sewage sludge, and several industrial wastes.

The Cd concentration of all the fertilizers was much lower than the tolerance limit of 39 mg kg^{-1} established under the USEPA rule (USEPA, 1993), and also a great deal lower than the mean concentration for the US sludge of 7 mg kg^{-1}(Table 1). Likewise, Pb, Zn, Cu and Ni concentrations in all three fertilizers were lower than the USEPA limit of 300, 1500, 2800 and 420 mg kg^{-1}, respectively (USEPA, 1993). There was little difference between the chemical properties of GISS and NISS (Table 1). This is in agreement with the result obtained by El Motaium and Badawy (2002). The FYM used was of exceptional quality with 1.8% N content, whereas, comparatively more N content was observed in GISS (2.3%) and NISS (2%); however, but it was vice a versa with the P and K content (Table 1). The radiation process of reducing sewage sludge pathogens did not significantly increase the chemical extractability of nutrients or heavy metals (McCaslin and O'Connor, 1982).

3.2. *Effect on growth parameters and yield*

The onion bulb yield was not significantly influenced by the various sources of fertilizers (S_1, S_2 and S_3) or their different levels (L_1, L_2 and L_3) (Table 2). The maximum yield response (32.75 q ha^{-1}) was observed in the first growing season (2003–2004) with GISS (Table 2). In the second winter, the maximum yield was recorded with NISS, although statistically it was not significant with the other two treatments. A similar trend was observed in various levels of fertilizers. In the first growing season, the maximum yield was recorded when fertilizers were applied at the rate of 10 t ha^{-1} and in the second year (2004–2005), with S_3 (Table 2). The interaction effect of various sources and levels of fertilizers was also insignificant in yield of onion bulb.

Yields were slightly lower in the second year in comparison to those of the first year (Table 2). Insignificant yield response among these three sources of fertilizers, even at high rates of applications, might be due to high fertility or large fertility gradients. Fauziah and Rosenani (1999) also obtained a non-significant trend in corn (*Zea mays*) yield due to the application of irradiated and non-irradiated sewage sludge. Whereas, Motaium (1999) and Pandya et al. (1991) reported a higher yield in tomato (Lycopersicon esculentum Family: Solanaceae) and methi (*Trigonella foenum-graecum* L. Family: Leguminosae) when the irradiated sewage sludge was applied. The results indicate that the sewage sludge materials (both irradiated and non-irradiated) were of equal quality in comparison to the conventional FYM in terms of onion yield. Experiments on rice (*Oriza sativa*), chickpeas (*Cicer arietinum*) and methi (*Trigonella foenum-graecum* L.) also advocated the beneficial and safe recycling of GISS for agricultural uses (Pandya et al., 1988, 1989, 1991).

The effects of fertilizers on the growth parameters of onion (i.e., plant stand and bulb girth) have been studied (Table 2). The results did not vary statistically and supported the yield data as discussed above. However, the highest bulb girth was recorded in GISS treatment. In an experiment on chickpeas (*Cicer arietinum*), Pandya et al. (1989) revealed that inhibition in root length, fresh weight, and the dry weight of the plant were found to be nullified with GISS treatment in comparison to NISS treatment; this indicates that NISS was detrimental to the growth of the chickpea plants. No symptoms of heavy metal toxicity, such as chlorosis or necrosis, were observed in any part of onion plants regardless of the treatment used. In another study, the beneficial effects of composted sludge on the biomass of seedlings, height of shoots, as well as on the length of pine seedlings roots were observed in Russia (Selivanovskaya and Latypova, 2006). In cucumbers, seedling dry matter, Fe, Mn, B, Zn, Cu, Mo and Cd were found to be increased with increasing sewage sludge application, but decreased with increasing FYM application (Sensoy et al., 2006); this was contradictory to our results.

Accordingly, sewage sludge can be used in the same manner as the FYM on sandy loam soil, since it has provided a significant amount of organic matter and nutrients, which is required for the growth, development, and yield of onion crop.

Table 5 – Influence of various fertilizers and their levels on DTPA extracted soil heavy metals.

Treatment	DTPA–Ni (mg/kg)			DTPA–Pb (mg/kg)			DTPA–Cd (mg/kg)			DTPA–Co (mg/kg)		
	2003–2004	2004–2005	Pooled	2003–2004	2004–2005	Pooled	2003–2004	2004–2005	Pooled	2003–2004	2004–2005	Pooled
Source of fertilizers (S)												
S_1	0.48	0.20	0.34	0.79	0.44	0.62	0.21	0.070	0.14	0.53	0.17	0.36
S_2	0.67	0.24	0.45	0.92	0.57	0.73	0.23	0.075	0.15	0.48	0.28	0.38
S_3	0.71	0.27	0.49	0.74	0.58	0.66	0.22	0.087	0.15	0.51	0.21	0.36
S.Em. ±	0.04	0.02	0.02	0.03	0.03	0.02	0.01	0.006	0.01	0.04	0.01	0.01
CD (5%)	NS	NS	NS	NS	0.09	NS	NS	NS	NS	NS	0.04	NS
Level of fertilizers (L)												
L_1	0.58	0.20	0.40	0.78	0.46	0.62	0.21	0.068	0.14	0.49	0.21	0.35
L_2	0.57	0.25	0.44	0.81	0.50	0.65	0.20	0.076	0.14	0.50	0.22	0.36
L_3	0.65	0.26	0.46	0.87	0.60	0.73	0.26	0.087	0.17	0.54	0.24	0.39
S.Em. ±	0.04	0.02	0.02	0.03	0.03	0.02	0.01	0.006	0.01	0.04	0.01	0.01
CD (5%)	NS	NS	NS	NS	0.09	NS	NS	NS	NS	NS	NS	NS
S × L	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV%	21.75	24.33	24.21	12.74	18.16	14.87	14.94	21.46	17.53	20.96	17.02	16.30

3.3. Effect on soil characteristics

Soil physico-chemical properties such as pH, organic carbon, organic N, available phosphorus and potash, available metallic micronutrients (DTPA extracted Zn, Mn, Fe, Cu) and available heavy metals (DTPA extractable Ni, Cd, Pb, Co) have been studied and are presented in Tables 3–5, respectively. There was no significant difference in pH, organic carbon and organic soil nitrogen among different sources of fertilizers at any rate (Table 3); this indicates that sludge can be used as a substitute for conventional FYM in supplying total soil nitrogen. Magnavacca and Graino (2000) revealed that fertilizers with relatively low rates of irradiated sludge may increase NO_3^- in the soil; this is due to nitrification in comparison with similar rates of non-irradiated sludge. In contrast, Wen et al. (1995) observed that release of NH_4^+ causes a negative effect of irradiation on N availability. Sewage sludge amended soil should not remain unplanted for a long period of time in order to minimize the risk of N leaching and ground water contamination (Correa et al., 2006).

The organic carbon and pH levels of the soil were slightly influenced by different sources and levels of fertilizers; however, the effects were non-significant for all of the treatments studied (Table 3). The addition of fertilizers with high carbon content generally increased the soil carbon concentration, but in this study, the treatment effects of different rates of fertilizers were non-significant. Some studies have linked the change in soil organic carbon with the climate and tillage practices (Burke et al., 1989). The addition of fertilizers and less intensive tillage with residue management has been shown to increase the soil organic carbon (Eghball et al., 1994). However, in this study, the soil was tilled twice by deep plowing, followed by harrowing; this was done in order to remove the remains of previous harvests, consequently, this may have affected carbon content of soil.

GISS treatment increased the available phosphorus (99.53 kg ha^{-1} in the first year of application) and potash (292.13 kg ha^{-1}; pooled effect) content in soil significantly in comparison to other treatments (Table 3). As the level of fertilizers increased, the available phosphorus and potash in the soil also increased in both the years (Table 3). However, the pooled data indicates that the maximum available P was received in S_1 treatment, when applied at the maximum rate of 15 t ha^{-1}; whereas available K_2O was found in S_2 treatment when applied at maximum level (L_3). Available potash was also significantly influenced by the levels of fertilizers and maximum K was obtained in L_3 (295.83 kg ha^{-1} pooled data). Thus, it was confirmed that sewage sludge was a good source of P and K. This may be due to the fact that almost all major sources of organic wastes, such as sewage sludge and livestock manures, often contain plenty of P (USEPA, 1993; OMAF, 1990). In an experiment on sugarcane, Magnavacca (1999) not only observed 30% increase in sugarcane yield, but also reported increased P content in plants through the application of sludge.

In this study, no significant difference among treatments for diethylene triamine pentaacetic acid (DTPA) extractable soil metallic micronutrients (Zn, Mn, Fe, Cu) in different source of fertilizers was observed, although the available Mn and Fe increased with increase in the level of fertilizer applications

Table 6 – Interaction effects of source of fertilizers and their different levels on available K_2O in soil, Fe content in onion bulb and leaves and Pb content in onion leaves (pooled data).

Level of fertilizer (L)	Available K_2O (kg ha^{-1})			Onion bulb–Fe (mg/kg)			Onion leaves–Fe (mg/kg)			Onion leaves–Pb (%)		
	Source of fertilizer (S)			Source of fertilizer (S)			Source of fertilizer (S)			Source of fertilizer (S)		
	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3
L_1	250.41	280.34	260.07	308.63	306.56	303.32	654.29	645.93	881.22	6.69	6.66	6.76
L_2	271.94	301.21	299.41	295.75	327.82	320.47	713.79	892.16	816.15	6.99	6.76	9.14
L_3	290.74	294.85	301.91	466.60	423.15	250.47	687.51	1090.97	759.48	7.91	9.54	8.46
S.Em. ±	8.09				23.82			56.87			0.47	
CD (5%)	23.29				68.59			160.85			1.32	

(Table 4). Wen et al. (2002) also reported that Zn applied to sludge or fertilizer composts did not increase the soil Zn availability index. The highest Fe content (8.86–9.56 mg kg^{-1}) and Mn content (11.90–13.11 mg kg^{-1}) was recorded when the higher level of fertilizer (15 t ha^{-1}) was applied (Table 4).

A non-significant difference was observed in DTPA extractable heavy metals (Ni, Pb, Cd, Co) in soil of any fertilizer source or level (Table 5). The highest concentrations of Ni, Pb, Cd and Co in pooled data using different sources of fertilizer were 0.49, 0.73, 0.15 and 0.38 mg kg^{-1}, respectively and in different levels of fertilizers 0.46, 0.73, 0.17 and 0.39 mg kg^{-1}, respectively at 15 t ha^{-1}(Table 5).

The interaction effect of different sources and levels of fertilizer on soil K was found to be statistically significant ($P \leq 0.05$), and suggest that the maximum K was recorded in L_3S_3 treatment combination, which was statistically non-significant with L_2S_2, L_2S_3, L_3S_2, L_3S_1 and L_1S_2 (Table 6). Wen et al. (1999) reported that K applied with organic wastes was equally as available as fertilizer K, except with low rates of irradiated sludge application (10 Mg ha^{-1}); whereas Villar et al. (1993) observed that about half of the K in organic wastes was immediately available, thus results obtained from past literature regarding K availability in soil are not consistent. Results show that the application of sewage sludge increased the supply of mineral elements (especially K) to the soil. This may be because the high temperature and irrigation could have favored mineralization of organic matter from the applied sludge, by, releasing mineral nutrients and metals from sludge into the soil. However, the conditions for continuous improvement of sewage sludge quality must be met and possible negative influences on soil mineral nutrient status must be avoided through the use of suitable sewage sludge treatment.

As a result, the concentration of heavy metals in soil remain lower than the standard limits of USEPA (USEPA, 1993), as well as that of EU standard of 300–400, 750–1200 and 20–40 mg kg^{-1}, respectively for Ni, Pb and Cd (Dewil et al., 2006). This may be due to the increasing level of humic substances through the addition of sludge, which may form complex compounds with heavy metals through chelation. As a result, humic substances may decrease their solubility in organic matter. On the other hand, El Motaium and Badawy (2002) observed increases in the content of DTPA extractable Cd, Co, Ni and Pb with application of sludge. A number of the advanced sludge treatments such as thermal hydrolysis and Fenton's peroxidation have been discussed by Dewil et al. (2006). In an incubation experiment with anaerobically digested sewage sludge, Debosz et al. (2002) revealed that there was no accumulated effect on the fraction of soil in wet-stable aggregates or on the microbiological properties.

3.4. *Effect on plant analysis*

The impact of different fertilizer sources and levels on the concentration of major nutrients (N, P and K), metallic

Table 7 – Influence of various fertilizers and their levels on concentration of major nutrients in onion bulb.

Treatment	Organic N (%)			Total P (%)			Total K (%)		
	2003–2004	2004–2005	Pooled	2003–2004	2004–2005	Pooled	2003–2004	2004–2005	Pooled
Source of fertilizers (S)									
S_1	1.68	1.67	1.67	0.82	0.80	0.81	1.12	1.02	1.07
S_2	2.09	1.74	1.92	0.80	0.81	0.81	1.23	1.02	1.12
S_3	1.77	1.66	1.72	0.84	0.80	0.82	0.98	1.06	1.02
S.Em. ±	0.10	0.08	0.06	0.04	0.04	0.03	0.05	0.01	0.03
CD (5%)	0.29	NS	NS	NS	NS	NS	0.16	NS	NS
Level of fertilizers (L)									
L_1	1.80	1.51	1.65	0.80	1.02	0.80	1.01	1.02	1.02
L_2	1.77	1.75	1.76	0.82	1.04	0.81	1.12	1.04	1.08
L_3	1.97	1.82	1.90	0.84	1.03	0.83	1.91	1.03	1.11
S.Em. ±	0.10	0.08	0.06	0.04	0.04	0.03	0.05	0.01	0.03
CD (5%)	NS	0.22	NS	NS	NS	NS	NS	NS	NS
S × L	NS	NS	NS	NS	NS	NS	NS	0.06	NS
CV%	15.91	13.82	15.03	14.97	16.33	15.65	14.26	3.44	10.69

Table 8 – Influence of various fertilizers and their levels on concentration of micronutrients in onion bulb.

Treatment	Zn (mg/kg)			Mn (mg/kg)			Fe (mg/kg)			Cu (mg/kg)		
	2003–2004	2004–2005	Pooled	2003–2004	2004–2005	Pooled	2003–2004	2004–2005	Pooled	2003–2004	2004–2005	Pooled
Source of fertilizers (S)												
S_1	39.52	23.87	31.68	7.98	7.71	12.85	426.40	287.53	356.99	9.06	10.22	9.64
S_2	39.27	27.05	33.16	7.66	14.87	11.25	424.90	280.17	352.51	9.70	10.72	10.21
S_3	41.68	25.88	33.32	8.83	14.99	11.91	343.60	239.27	291.42	8.38	10.61	9.50
S.Em. ±	4.26	1.05	2.18	0.75	0.93	0.60	26.10	8.73	13.75	0.64	0.71	0.43
CD (5%)	NS	NS	NS	NS	NS	NS	NS	24.69	39.60	NS	NS	NS
Level of fertilizers (L)												
L_1	38.56	24.21	31.37	6.78	13.71	10.24	366.60	245.71	306.17	8.95	10.26	9.61
L_2	38.91	25.87	32.39	8.54	16.21	12.36	362.40	266.92	314.68	8.58	10.29	9.44
L_3	43.21	26.71	34.40	9.14	17.66	13.40	465.80	294.34	380.07	9.62	10.99	10.31
S.Em. ±	4.26	1.05	2.18	0.75	0.93	0.60	26.10	8.73	13.75	0.64	0.71	0.43
CD (5%)	NS	NS	NS	NS	2.63	NS	77.90	24.69	39.60	NS	NS	NS
S × L	NS	NS	NS	3.87	NS	NS	135.05	NS	68.59	NS	NS	NS
CV%	31.78	12.33	28.24	27.52	17.62	21.03	19.75	9.74	17.49	21.29	20.71	18.58

micronutrients (Zn, Mn, Fe and Cu) in onion bulbs and leaves are depicted in Tables 7–9, respectively. The 2-year experiment data revealed that except for Fe, all other major nutrients such as organic N, P and K (Tables 7 and 9) and other micronutrients like Zn, Mn, Cu (Table 8) were not significantly impacted by various sources and levels of fertilizers in onion bulb and leaves, respectively (the data on influence of fertilizers on micronutrients in onion leaves are not shown). The highest metallic micronutrients were found in plants that had received an increased level of fertilizers (15 t ha^{-1}; Table 8). However, the concentration of Cu and Zn in onion bulbs and leaves remained below the phytotoxic concentrations given by Kabata-Pendias and Pendias (1992), which is 10 mg kg^{-1} for each. A similar trend was reported by Athalye et al. (1999), which also revealed that the application of irradiated sludge to soil at the rate of 1–8 t ha^{-1} maintained N, P and K concentrations in plants. Kirkham (1980) also reported that the concentration of K in plants receiving irradiated sludge were similar to those in plants with NISS. Iron (Fe) content in onion bulbs was significantly ($P \leq 0.05$) higher in S_1 (FYM), although statistically at par with S_2 (GISS) (Table 8). This may be due to the increasing organic matter, which subsequently increases humic substances, which then increases the permeability of cell walls; this may facilitate the uptake of certain plant nutrients.

The interaction effects of various sources and levels of fertilizers on Fe content in onion bulb and leaves and Pb content in onion leaves were significant ($P \leq 0.05$) (Table 6). The highest Fe content (466.60 mg kg^{-1}) in onion bulbs was recorded in S_1 treatment (FYM), when applied at the rate of 15 t ha^{-1}. This was statistically similar to GISS treatment applied at the same rate. But in onion leaves, significantly more Fe and Pb were found in GISS treatment when applied at the rate of 15 t ha^{-1} (Table 6).

The impact of various sources and levels of fertilizer on heavy metals in plant leaves were also non-significant (Ni, Cd, Pb and Co; data not shown, except Pb in interaction effect). Trace metal concentrations increased with the rate of fertilizers, but none reached toxic concentrations, and all were well within the range considered sufficient for agricultural crops. The concentration of Cd in onion bulbs and leaves also remained below the phytotoxic limit of 5 mg kg^{-1} (data not shown) given by Kirchmann (1994). A similar trend was also reported by Athalye et al. (1999), which also reported that the application of 1–8 t ha^{-1} irradiated sludge did not enhance the level of heavy metals, despite repeated application. Zhao et al. (2005) also revealed that the concentrations of Cd, Zn, Cu and Pb were lower than the National Standard limit with the application of irradiated sludge in *B. chinensis*. In an experiment on the safe disposal of sludge, Gautam et al. (2005) concluded that treatment with gamma radiation was efficient in the elimination of coliform bacteria and prevention of regrowth; therefore, irradiated sludge can be directly used as an amendment in agricultural crops. It can also be used as a medium for growth of *Rhizobium* sp in obtaining a biofertilizer. In contrast to our results, Campanella et al. (1989) suggested that mobility of heavy metals (Pb, Cu, Mn and Zn) in sewage sludge may increase after UV irradiation. Generally, the highest availability of trace metals is during the period immediately following sludge application, and no significant

Table 9 – Influence of various fertilizers and their levels on concentration of major nutrients in onion leaves.

Treatment	Organic N (%)			Total P (%)			Total K (%)		
	2003–2004	2004–2005	Pooled	2003–2004	2004–2005	Pooled	2003–2004	2004–2005	Pooled
Source of fertilizers (S)									
S_1	2.85	2.03	2.44	0.35	0.51	0.43	1.30	1.17	1.24
S_2	2.24	2.11	2.17	0.34	0.52	0.43	1.56	1.19	1.38
S_3	2.97	2.33	2.64	0.34	0.50	0.42	1.33	1.16	1.24
S.Em. ±	0.18	0.10	0.10	0.03	0.02	0.02	0.07	0.05	0.04
CD (5%)	0.53	NS	NS	NS	NS	NS	0.22	NS	NS
Level of fertilizers (L)									
L_1	2.11	2.16	2.13	0.32	0.46	0.39	1.26	1.05	1.15
L_2	3.09	2.13	2.61	0.33	0.53	0.43	1.41	1.22	1.32
L_3	2.86	2.17	2.52	0.38	0.54	0.46	1.51	1.26	1.38
S.Em. ±	0.18	0.10	0.10	0.03	0.02	0.02	0.07	0.05	0.04
CD (5%)	0.53	NS	NS	NS	NS	NS	NS	0.13	NS
S × L	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV%	19.95	13.29	17.75	22.56	11.41	16.09	15.99	11.71	14.42

changes in metal accumulation by plants are likely to remain after 3 years of initial sludge application (Chang et al., 1997). A possible explanation for this may be that with time, metals may perhaps convert into less available forms.

Results suggest that sewage sludge applied to onion crop did not affect the quality of onion bulbs and leaves. The analyses of major nutrients, micronutrients, and heavy metals (data of heavy metals in onion bulbs and leaves are not presented here) have proved that gamma irradiated sewage sludge from SHRI, Vadodara is useful as a type of soil fertilizer. The results of this study also indicate that after the application of GISS, the level of micronutrients and heavy metals remain below the prescribed maximum limit by USEPA. Due to the chemical and biological characteristics of GISS, it can be used as an amendment on sandy loam soil. There was no significant difference noticed between GISS and NISS treatments, in terms of mineral nutrient supply to soil and plant; this suggests that gamma irradiation has no negative impact on soil or plant health. Both Fe content in onion bulbs and leaves and Pb content in plant leaves were significantly higher when treated with GISS. This fact should be taken into account when the recommendation of sewage sludge is established for this crop. The results also revealed that organo-mineral resources, such as municipality sludge, could be an acceptable substitute of FYM or commercially produced chemical fertilizers. They can also contribute to the enhancement of mineral nutrients and organic matter content of soil without any unintended effect, such as elevated levels of heavy metals in soil and plant, with an advantage of proper disposal of municipal sludge. Similar results have been obtained in carrot (*Daucus carota*) (Rathod et al., 2008).

4. Conclusion

Recycling municipal sewage sludge as an amendment can help maintain soil nutrient levels. Several studies have shown that it may also stimulate various aspects of soil fertility. However, efficient use also requires knowledge about the quality of individual bio-solids, with respect to manurial value and safety for human and environment. This is important given that the application of sewage sludge may also increase the concentration of heavy metals in soil and plant. The GISS treatment was compared with conventional FYM in terms of manurial value and its impact on soil and plant health. The study focused on onion crop within the climatic conditions of middle-west India. The yield and growth parameters of onion (*Alium cepa*) revealed that the GISS material of equal quality as the conventional FYM. In fact, a slightly higher yield was attained using GISS. The application of different levels of fertilizers did not trigger a significant difference in yield production. No harmful effect of sludge due to any toxic substance was noticed even at higher rates (15 t ha^{-1}). The nutrient and heavy metal concentrations in onion bulbs and leaves also indicated no adverse effects. Some favorable effects were noticed in certain nutrient concentrations, i.e. Fe and N content in onion bulbs. The data also revealed that concentrations of heavy metals in soil and plant were within the prescribed limits of the USEPA. Although there was no significant difference between GISS and NISS in comparison to conventional FYM treatments in terms of increasing the level of heavy metals in this experiment, we suggest to use the GISS for better hygienization in long-term use.

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