Evaluation of gamma irradiation for bio-solid waste management

P.H. Rathod

Institute of Soil, Water and Environmental Science,
Volcani Centre, ARO, P.O. Box 6,
Bet-Dagan 50250, Israel
E-mail: paresh11879@yahoo.com

J.C. Patel

B.A. College of Agriculture,
AAU, Anand – 388 110, Gujarat, India
E-mail: jcp_110@yahoo.co.in

M.R. Shah

SHRI facilities, BARC Centre,
Gajarawadi, Vadodara, Gujarat, India
E-mail: mrshri@sanchar.net

Amit J. Jhala*

Department of Agriculture,
Food and Nutritional Science,
University of Alberta,
Edmonton, T6G 2P5, AB, Canada
Fax: +1-780-492-4265
E-mail: jhala@ualberta.ca
*Corresponding author

Abstract: Gamma irradiation is a form of pure energy which is currently used most widely for food and waste irradiation. To evaluate the potential of gamma irradiated sludge for its suitability as a soil amendment in agriculture, field experiments were carried out in a root crop, carrot (*Daucus carota*). Treatments consisting of three sources of manure (Farmyard Manure (FYM), gamma-irradiated sewage sludge and non-irradiated sewage sludge), each at three different levels (5, 10 and 15 t ha^{-1}), were compared. The growth parameters and yield of carrot was not significantly influenced by the three sources of manure or their different levels. Values for EC, pH, organic carbon, total N, available P and K, metallic micronutrients (Zn, Mn, Fe, Cu) and heavy metals (Ni, Cd, Pb, Co) indicate no adverse effect on soil properties.

Keywords: gamma-irradiation; sewage sludge; irradiated sludge; hygienisation; farmyard manure; heavy metals.

Copyright © 2008 Inderscience Enterprises Ltd.

Reference to this paper should be made as follows: Rathod, P.H., Patel, J.C., Shah, M.R. and Jhala, A.J. (2008) 'Evaluation of gamma irradiation for bio-solid waste management', *Int. J. Environment and Waste Management*, Vol. 2, Nos. 1/2, pp.37–48.

Biographical notes: Paresh H. Rathod received his Bachelor's Degree in Agriculture from the B.A. College of Agriculture, Gujarat Agricultural University, Anand, India, in August 2000. He received his Master's Degree with a major in Agricultural Chemistry and Soil Science in December 2003 from the same university with a research project aiming to study persistence of dinitroaniline herbicides in soil. Recently, he was granted an Israeli Government Scholarship for research study and working under Pinchas Fine at Institute of Soil, Water and Environmental Science, Volcani Centre, ARO, Israel. His focus is on the phytoremediation of soil contaminated with heavy metals.

Jyotindra C. Patel is an Assistant Professor in the Department of Agricultural Chemistry and Soil Science, B.A. College of Agriculture, Anand Agricultural University, Anand, India. His research interests are in the areas of soil conservation, soil fertility and soil reclamation research. He received his BS from the BA College of Agriculture, GAU, Anand and MS in Agricultural Chemistry and Soil Science from the Gujarat Agricultural University, Navsari, Gujarat, India.

Mahesh R. Shah is presently an employee of the Bhabha Atomic Research Centre (BARC) and holds the position of office-in-charge at the Sewage Hygienisation Research Irradiator (SHRI) facilities, Vadodara, Gujarat, India. His area of research is radiation technologies (gamma-radiation) and its uses in agriculture especially to treat municipality sewage waste.

Amit J. Jhala received his Degree in Agriculture from the B.A. College of Agriculture, Gujarat Agricultural University, Gujarat, India and his MSc with a major in Agronomy from the same university. He was selected for a Belgium Government Scholarship by the Ministry of Human Resource Development, Government of India to conduct one year of research at Ghent University, Belgium. Presently, he is pursuing his Doctorate Degree with Dr. Linda Hall at the University of Alberta, Canada. His areas of research include environmental biosafety of transgenic crops, risk assessment of Plant with Novel Traits (PNT's) and biosolid waste management and herbicide resistant weeds and crops.

1 Introduction

Increasing population and urbanisation have made biosolid treatment an important component of disposal and waste management (Benton and Wester, 1998). Since the last two decades, municipal sewage sludge has been applied to soil for agricultural use as an organic manure (Krogman et al., 1997). If municipal biosolid waste is released untreated, it can endanger human health, as it contains a high load of pathogenic bacteria and viruses (Ahmed and Sorensen, 1997) in addition to heavy metals and useful micronutrients (Jung et al., 2002). Several methods are available, including anaerobic digestion, composting and thermal disinfection to make the sludge biologically and chemically safe (APHA-AWWA-WPCF, 1989).

Sewage sludge generated in wastewater treatment plants through conventional primary and secondary treatment processes generally undergoes further stabilisation before its disposal on land. The waste water sludge generated by a sewage plant is very odorous and contains a high level of pathogens (Wen et al., 1995) which limits the reuse of this waste which is otherwise a rich source of nutrients (Gautam et al., 2005).

Studies have proven the efficacy of ionising radiations for treating water and sewage (Lowe et al., 1956; Pikav and Shubin, 1984). Disinfection by gamma radiation offers an attractive alternative in the treatment of water, waste water and sludge (Getoff, 1992; Waite et al., 1992). Some practical advantages of irradiated sewage sludge are:

- no requirement for a withholding period between application and crop harvesting or livestock grazing (Wen, 2002)
- on drying, it could be powdered easily and does not have bad odour
- increases the mobility of Pb, Cu and Zn in soil (Campanella et al., 1989)
- gamma rays can remove a wide variety of organic contaminants and disinfect the sludge (Borrely et al., 1998) of harmful micro-organisms.

Radiation techniques have been widely studied to purify drinking water and food (Woods, 2000) but the application of these techniques to recycle the sewage effluents and their practical applicability at the field level is not well documented (Jung et al., 2002; Pikav and Shubin, 1994) and no data were found on the use of gamma irradiated sludge in carrot (*Daucus carrota*). The objective of this study was to evaluate the practical applicability of gamma irradiated sewage sludge at the field scale and its comparison with FYM and non-irradiated sludge in terms of growth parameters, soil physical properties, chemical properties of carrot root and leaves, micronutrients and heavy metals.

2 Materials and methods

2.1 Sampling of bio-solids

In 1992, the Government of India, Department of Atomic Energy, commissioned a Sludge Hygienisation Research Irradiator (SHRI) near the Gajerawadi municipal sewage treatment plant at Vadodara city in Gujarat, India. Gamma irradiated and non-irradiated manures were provided by SHRI for this experiment. The raw materials for biosolids were from the households and textile industries. The waste from each industry followed the standard guidelines: Biological Oxygen Demand (BOD) less than 1000 mg/l, lipids less than 150 mg/l and phenols less than 1 mg/l. The raw sewage, as well as treated effluents, were exposed to gamma rays (dose of 3 kGy, cobalt – 60 source) to disinfect the pathogens at SHRI (Gautam et al., 2005). Then, gamma irradiated and non-irradiated sewage sludge was transported in a special truck to the field site at ECFP, Anand, which is 50 km away from SHRI. Farm Yard Manure (FYM) was purchased from a local dealer in Anand.

2.2 Treatment and field experiment details

Field experiments were carried out during the *rabi* (winter, October–February) season of the year 2003–2004 on the ECFP farm, Regional Research Station (RRS), Anand Agricultural University, Anand, Gujarat, with a carrot crop (variety: Pusa Kesar, plot size: 4.0×1.8 m). The seed of the carrot crop was purchased from the local market in Anand. Irradiated and non-irradiated sewage sludge was incorporated into the soil at a depth of 15–20 cm. Treatments were laid out in a Factorial Randomised Complete Block Design (FRBD). Each block had nine treatments and each treatment was replicated three times. Treatments consisted of three sources of manure (S_1: FYM, S_2: Irradiated sewage sludge and S_3: Non-irradiated sewage sludge) each at three different levels (L_1: 5 t ha^{-1}, L_2: 10 t ha^{-1} and L_3: 15 t ha^{-1}).

2.3 Sample preparation and chemical analysis

Carrot roots were collected as they matured and weighed for yield determination. Growth parameters such as plant stand, girth and length of produces were also measured. Three plant samples from each net plot were collected for analysis of edible parts and leaves. Soil samples (0–20 cm depth) were collected by using pipe auger at the end of the growing season. The samples were air-dried, crushed to pass through a 2 mm sieve and stored for analysis. Plant and soil samples were analysed using standard methods (Jackson, 1973). The data were subjected to analysis of variance using the FRBD statistical analysis package (Chandel, 1970).

The sewage sludge had a pH close to neutral, high organic matter, high total N content and high content of micronutrients in bio-available forms. Some selected physico-chemical characteristics of manures are given in Table 1. The differences in chemical properties between irradiated and non-irradiated sludge were not significant. The farmyard manure used was of exceptionally good quality, with 1.8 % N content. 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). The higher concentration of heavy metals in irradiated sewage sludge in comparison to FYM was natural because the raw material of sewage sludge was municipality waste, collected from several industries.

The soil of the experimental site was alluvial in nature, and the texture ranged from loamy sand to sandy loam (*Typic Ustocrepts*) and was locally known as '*Goradu*'. The nitrogen content was low; the available phosphorus and potash contents were medium.

Table 1 Physico-chemical characteristics of manures used in this experiment

Characteristics	*Farmyard manure (FYM)*	*Irradiated sewage sludge*	*Non-irradiated sewage sludge*
pH (1:2.5)	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 (ppm)	11.05	50.16	49.08

Table 1 Physico-chemical characteristics of manures used in this experiment (continued)

Characteristics	*Farmyard manure* (*FYM*)	*Irradiated sewage sludge*	*Non-irradiated sewage sludge*
Mn (ppm)	15.00	38.22	25.53
Fe (ppm)	3300.00	7130.00	6807.00
Cu (ppm)	1.41	1.91	2.19
Ni (ppm)	6.96	10.20	12.23
Cd (ppm)	0.95	1.06	1.45
Pb (ppm)	9.07	14.25	14.00
Co (ppm)	4.18	6.20	6.40

3 Results and discussion

The study summarises the results of physico-chemical properties of soil treated with different sources and levels of manure and yield and plant analysis of carrot crop.

3.1 Yield and growth parameters

The yield of carrot was not significantly influenced by the various sources of manure (S_1, S_2 and S_3) as well as their different levels (L_1, L_2 and L_3). However, a higher yield response (133.50 q ha^{-1}) was observed with the irradiated sludge treatment (S_2) (Table 2). Fauziah and Rosenani (1999) also obtained a non-significant trend for corn (*Zea mays*) yield due to application of irradiated and non-irradiated sewage sludge. Whereas, Motaium (1999) and Gagan et al. (1991) reported higher yield in tomato (*Lycopersicon esculentum* Family: Solanaceae) and methi (*Trigonella foenum-graecum* L. Family: Leguminosae) due to application of irradiated sewage sludge.

Table 2 Influence of irradiated sewage sludge on yield and growth parameters of carrot

Treatment	*Yield* (q ha^{-1})	*Plant stand* (*No. plot*$^{-1}$)	*Root length* (cm)	*Root girth* (cm)
Source of manure (*S*)				
S_1	128.18	486.89	23.18	12.82
S_2	133.50	518.00	25.46	14.20
S_3	128.48	512.67	24.75	13.34
CD (5%)	NS	NS	NS	NS
Levels of manure (*L*)				
L_1	124.75	493.44	23.81	12.84
L_2	126.25	512.44	24.29	13.76
L_3	139.14	511.97	25.29	13.76
CD (5%)	NS	NS	NS	NS
S x L	NS	NS	NS	NS
CV (%)	15.78	7.10	10.64	7.58

CD = Critical Difference; CV = Coefficient of Variation; q = Quintal.

The effect of irradiated sludge on the growth parameters of carrot i.e., plant stand, root length, root girth have been studied (Table 2). The results did not vary statistically and support the yield data as discussed above. The results point out that the sewage sludge materials (both irradiated and non-irradiated) were as good as conventional farmyard manure. Experiments on rice (*Oriza sativa*), chickpea (*Cicer arietinum*) and methi (*Trigonella foenum-graecum* L.) also suggested the beneficial and safe recycling of gamma-irradiated sludge for agricultural use (Gagan et al., 1988, 1989, 1991).

3.2 Soil analysis

Soil physico-chemical properties such as electrical conductivity (total salts), pH, total nitrogen, available phosphorus and potash, available metallic micronutrients (Zn, Mn, Fe, Cu) and available heavy metals (Ni, Cd, Pb, Co) have been studied and are presented in Tables 3 and 4. There was no significant difference for total soil nitrogen among different sources of manure at any level. Magnavacca and Graino (2000) revealed that manures with relatively low rates of irradiated sludge may increase NO_3^- in soil due to nitrification in comparison with similar rates of non-irradiated sludge, whereas Wen et al., (1995) observed that release of NH_4^+ indicate a negative effect of irradiation on N availability. Sewage sludge amended soil should not remain unplanted for a long period of time, to minimise the risk of N leaching and ground water contamination (Correa et al., 2006).

Table 3 Influence of irradiated sewage sludge applied to carrot crop on soil EC, pH and major nutrients

Treatment	*Total nitrogen* (%)	*Available P_2O_5* (kg ha^{-1})	*Available K_2O* (kg ha^{-1})	*Organic carbon* (%)	*pH* (*1:2.5*)	*EC* (*1:2.5*) (dS m^{-1})
Source of manure (*S*)						
S_1	0.028	62.48	231.2	0.33	7.76	0.13
S_2	0.033	89.40	251.5	0.39	7.81	0.14
S_3	0.030	80.12	216.8	0.35	7.76	0.14
CD (5%)	NS	9.52	17.0	NS	NS	NS
Levels of manure (*L*)						
L_1	0.026	77.30	219.2	0.31	7.73	0.13
L_2	0.033	80.14	220.4	0.39	7.83	0.14
L_3	0.033	84.56	259.9	0.38	7.77	0.14
CD (5%)	NS	NS	17.03	0.05	0.07	NS
S x L	NS	NS	NS	NS	0.13	NS
CV (%)	14.71	11.80	7.31	14.61	0.93	10.18

Table 4 Influence of irradiated sewage sludge applied to carrot crop on soil metallic micronutrients and heavy metals

Treatment	*DTPA extractable micronutrients* (ppm)				*DTPA extractable heavy metals* (ppm)			
	Zn	*Mn*	*Fe*	*Cu*	*Ni*	*Cd*	*Pb*	*Co*
Source of manures (*S*)								
S_1	1.49	45.86	18.60	1.87	0.58	0.13	0.93	0.46
S_2	1.64	42.24	18.25	1.84	0.83	0.11	1.08	0.48
S_3	1.63	37.77	19.77	1.92	0.73	0.14	0.89	0.44
CD (5%)	NS	NS	NS	NS	NS	NS	NS	NS

Table 4 Influence of irradiated sewage sludge applied to carrot crop on soil Metallic micronutrients and heavy metals (continued)

Treatment	*DTPA extractable micronutrients* (ppm)				*DTPA extractable heavy metals* (ppm)			
	Zn	*Mn*	*Fe*	*Cu*	*Ni*	*Cd*	*Pb*	*Co*
Levels of manure (*L*)								
L_1	1.50	38.08	15.80	1.80	0.71	0.12	0.82	0.45
L_2	1.59	38.99	18.00	1.78	0.69	0.13	0.93	0.46
L_3	1.67	48.79	22.82	2.04	0.73	0.13	1.15	0.46
CD (5%)	NS	6.45	2.79	NS	NS	NS	NS	NS
S x L	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	9.58	15.43	14.84	16.64	20.65	22.87	20.79	16.56

DTPA = Diethylenetriamine penta-acetic acid.

Gamma irradiated sludge materials increased available phosphorus (89.4 kg ha^{-1}) and potash (251.5 kg ha^{-1}) content in soil significantly over that of other treatments. As the levels of manure increased, the available phosphorus and potash in soil also increased (Table 3). Almost all major sources of organic wastes such as sewage sludge and livestock manure often contain plenty of P (USEPA, 1993; OMAF, 1990). So, it was confirmed that sewage sludge was a good source of P and K. In an experiment on sugarcane, Magnavacca (1999) not only observed 30% increase over the control in P yield but also increased P content in sugarcane. Wen et al. (1999a) reported that K applied with organic wastes was equally available as fertiliser 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 is immediately available, so results from literature about K availability are not consistent. The available potash was also significantly influenced by levels of manures and maximum K was obtained in L_3 (259.9 kg ha^{-1}). Organic carbon and pH of soil were also slightly influenced by different levels of manure (L_1, L_2 and L_3) (Table 3).

In the present study no significant difference among treatments for soil metallic micronutrients (Zn, Mn, Fe, Cu) in different source of manures was observed but the available Mn and Fe increased with increase in the levels of manure (L_1, L_2 and L_3). (Table 3) with maximum Fe (22.82 ppm) and Mn (48.79 ppm) when the maximum level of manure (L_3:15 t/ha) was applied. Wen et al. (2002) also reported that Zn applied in sludge or manure composts did not increase the soil's Zn availability index.

The data indicate no significant differences in heavy metals in the soil from any source or level of manure, and concentrations of heavy metals in soil remain lower than standard limits, while El Motaium and Badawy (2002) observed increases in the contents of DTPA extractable Cd, Co, Ni and Pb with increasing rates of sludge.

3.3 *Plant analysis*

Concentrations of major nutrients (N, P and K), metallic micronutrients (Fe, Mn, Zn, Cu) and heavy metals (Ni, Cd, Pb, Co) in carrot roots and leaves are reported in Tables 5 and 6. The data revealed that except for N and Fe, none of the other parameters were influenced by the source of manure (S) in carrot root analysis (S_1, S_2 and S_3) (Table 5). In comparison to FYM, Fe content was significantly higher in irradiated and non-irradiated sludge treatments (S_2 and S_3) but there was no statistical difference between S_2 and S_3 in both N and Fe. P content in carrot roots was observed lower in the sludge treated plot as compared to farmyard manure plots. The low availability of P in sludge treatment was likely caused by Fe which precipitated phosphorus. Zapata and Zaharah (2002) concluded that addition of triple superphosphate in sewage sludge increases the concentration of P as compared to sludge alone in wheat crops. The irradiation of sludge increased phytoavailability of Zn for bean pods. Increasing rate of sludge application also increases other cations like Ca and Mg; however, increasing the rate of manure compost decreased crop Ca and Mg concentrations (Wen et al., 1999b). Kirkham (1980) also reported that the concentration of K in plants receiving irradiated sludge was similar to those in plants with non-irradiated sludge.

Table 5 Influence of irradiated sewage sludge on chemical properties of carrot root

Treat	*Major nutrients* (%)			*Micronutrients* (ppm)				*Heavy metals* (ppm)			
	*N**	*P*	*K*	*Zn*	*Mn*	*Fe*	*Cu*	*Ni*	*Cd*	*Pb*	*Co**
Source of manures (*S*)											
S_1	0.56	0.72	1.84	15.63	30.38	259.18	16.95	6.17	2.48	4.72	1.62
S_2	0.67	0.66	1.84	17.62	23.72	309.19	18.87	7.08	2.64	5.72	1.72
S_3	0.67	0.67	1.87	17.11	26.93	316.09	16.48	5.92	2.10	5.39	1.50
CD (5%)	0.09	NS	NS	NS	NS	72.41	NS	NS	NS	NS	NS
Levels of manure (*L*)											
L_1	0.60	0.62	1.73	15.68	25.61	343.80	18.30	6.08	2.30	5.22	1.45
L_2	0.61	0.70	1.85	16.92	23.03	247.08	17.19	7.50	2.27	5.11	1.39
L_3	0.69	0.75	1.96	17.76	32.39	285.62	16.81	5.58	2.64	5.50	2.00
CD (5%)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.49
S x L	0.16*	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.85*
CV (%)	14.5	19.5	20.1	18.4	2.7	24.8	27.9	20.0	19.1	19.9	30.4

*Interactions between sources and levels of different manures for N and Co in carrot roots were significant and the interaction effect is presented in Table 7.

Table 6 Influence of irradiated sewage sludge on chemical properties of carrot leaves

Treat	*Major nutrients* (%)			*Micronutrients* (*ppm*)				*Heavy metals* (*ppm*)			
	*N**	*P*	*K*	*Zn*	*Mn**	*Fe*	*Cu*	*Ni*	*Cd*	*Pb*	*Co*
Source of manures (*S*)											
S_1	0.95	0.47	1.02	40.49	180.01	1371	26.61	18.67	2.34	14.50	8.83
S_2	1.01	0.49	1.06	45.04	195.09	1435	28.49	15.83	2.46	16.56	9.92
S_3	0.97	0.50	0.99	41.64	190.16	1300	424.62	18.50	2.39	15.7	10.08
CD (5%)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Levels of manure (*L*)											
L_1	0.92	0.50	0.86	38.08	184.23	1278	26.69	17.75	2.22	15.72	9.50
L_2	0.99	0.47	0.98	43.34	192.20	1367	25.18	17.00	2.40	15.06	9.67
L_3	1.02	0.50	1.24	45.74	188.90	1460	28.25	18.25	2.57	16.00	9.67
CD (5%)	NS	NS	0.30	NS	NS	NS	NS	NS	NS	NS	NS
S x L	0.23*	NS	NS	NS	59.26*	NS	NS	NS	NS	NS	NS
CV (%)	13.50	15.59	29.09	25.65	18.22	19.84	21.29	16.54	20.56	15.40	0.00

*Interactions between sources and levels of different manures for N and Mn in carrot leaves were found to be significant and data are given in the Table 8.

Except for Co, none of the other parameters were influenced by the level of manures (L) in carrot root. Co content was influenced by the level of manure (L) and recorded a maximum (2.00 ppm) when the level of manure was maximum (15 t ha^{-1}), followed by L_2 and L_1. There was also a statistical difference among treatments and the interaction effects of manure source and level on the Co and N content of carrot root are presented in Table 7. The data indicate that maximum nitrogen content in carrot root was recorded in the S_2L_3 treatment combination. However, maximum Co content was observed in the S_1L_3 treatment combination which was on par with S_2L_3, S_3L_3, S_3L_2 and S_2L_1 treatment combinations.

Table 7 Interaction effect of manures and its levels on nitrogen (%) and DTPA extractable cobalt (ppm) contents of carrot root

	Nitrogen (%)			*Co* (ppm)		
	Source of manure (*S*)			*Source of manure* (*S*)		
Level of manure (*L*)	S_1	S_2	S_3	S_1	S_2	S_3
L_1	0.44	0.64	0.72	1.35	1.67	1.33
L_2	0.61	0.62	0.61	1.02	1.33	1.83
L_3	0.64	0.76	0.67	2.50	2.17	1.93
CD (5%)		0.016			0.85	

The analysis of the chemical property of carrot leaves indicates that there was no significant effect of the source or level of manures, except in potash. The effect of the level of manure was observed in potash and maximum K_2O content in carrot leaves was recorded in L_3 (1.24%) followed by L_2 and L_1 (Table 7). The interaction effect of source and level of manure was observed in N and Mn and data are summarised in Table 8, indicating that the maximum nitrogen content (1.22%) was recorded in the S_2L_3 treatment combination followed by S_1L_2 (1.09%), S_3L_3 (1.05%) and S_3L_2 (1.00%) treatment combinations which were statistically at par. In the case of Mn, maximum Mn content was recorded in the S_1L_3 treatment combination which was on par with all other treatment combinations, except S_1L_1 and S_1L_2 (Table 8). Athalye et al. (1999) observed that the application of irradiated sewage sludge to soil @ 1 to 8 t ha^{-1} maintained N, P, K concentrations in plants and showed no signs of attaining enhanced levels of heavy metals due to repeated addition of sludge. Zhao et al. (2005) also revealed that concentration of Cd, Zn, Cu and Pb in *B. chinensis* was lower than the national standard limit with the application of irradiated sludge. Mobility of heavy metals (Pb, Cu, Mn and Zn) in sewage sludge may be increased after UV irradiation (Campanella et al., 1989).

Table 8 Interaction effect of manures and its levels on nitrogen (%) and DTPA extractable Mn (ppm) contents of carrot leaves

	Nitrogen (%)			*Mn* (ppm)		
	Source of manure (*S*)			*Source of manure* (*S*)		
Level of manure (*L*)	S_1	S_2	S_3	S_1	S_2	S_3
L_1	0.96	0.93	0.87	149.93	188.10	201.98
L_2	1.09	0.89	1.00	168.82	210.48	205.97
L_3	0.79	1.22	1.05	233.95	177.78	158.75
CD (5 %)		0.23			59.26	

4 Conclusion

The yield and growth parameters of carrot revealed that the irradiated sewage sludge materials were as good as the conventional farmyard manure. In fact, a slightly higher yield was achieved with the use of irradiated sludge. There was no significant difference in yield by the use of different levels of manures and, hence, it is enough to apply manure at the rate of 5 t ha^{-1} in carrot crop. No harmful effect of sludge due to any toxic substance was noticed. The nutrient concentrations in carrot root and plant leaves also indicated no adverse effects. Some favourable effects were noticed in certain nutrient concentrations i.e., Fe and N content in carrot roots. The data also revealed that increasing the level of manures increases the Co concentration in plant but it was less than prescribed limit. Concentrations of heavy metals in soil and plants were within the prescribed limits.

Acknowledgements

The authors would like to acknowledge N.K. Kalyanasundaram and Jagdish C. Patel for their valuable contribution in this research work. The author thanks the Board of Research on Nuclear Science (BRNS), Bhabha Atomic Research Centre (BARC), Mumbai (India) for financial assistance for this project.

References

Ahmed, A.U. and Sorensen, D.L. (1997) 'Autoheating and pathogen destruction during storage of dewatered biosolids with minimal mixing', *Water and Environmental Research*, Vol. 69, pp.81–94.

APHA-AWWA-WPCF (1989) *Standard Methods for the Examination of Water and Wastewater*, 17th ed., American Public Health Association and Water Environment Federation, American Public Health Association, 2015 Fifteen street, Washington DC 2005, USA.

Athalye, V.V., Ramachamdran, V., Patel, D.U. and D'Souza, T.J. (1999) 'Uptake of macronutrients and heavy metals by maize-green gram crops from in Inceptisols amended with normal and irradiated sewage sludge', *Report of the 4th Research Co-ordination Meeting of the FAO/IAEA Co-ordination Research Project* on the use of irradiation sewage sludge to increase soil fertility and crop yields and to preserve the environment during 20–24 September, Malaysia.

Benton, M.W. and Wester, D.B. (1998) 'Biosolids effects on tobosograss and alkali sacatonin a Chihuahuan desert grassland', *Journal of Environmental Quality*, Vol. 27, pp.199–208.

Borrely, S.I., Cruz, A.C., Del Mastro, N.L., Sampra, M.H.O. and Somessari, E.S. (1998) 'Radiation processing of sewage and sludge', *A Review Prog. Nucl. Energy*, Vol. 33, Nos. 1–2, pp.3–21.

Campanella, L., Ferri, T, Petronio, B.M. and Piccolo, A. (1989) 'Effect of speciation in sludges on the adsorption of leached metals from soil', *Science and Total Environment*, Vol. 79, pp.223–231.

Chandel, S.R.S. (1970) *A Handbook of Agricultural Statistics*, 4th ed., Achal Prakashan Mandir Parmat, Kanpur-1, India, pp.287–298.

Correa, R.S., White, R.E. and Weatherley, A.J. (2006) 'Risk of nitrate leaching from two soils amended with biosolids', *Water Resources*, Vol. 33, No. 4, pp.453–462.

El Motaium, R.A. and Badawy, S.H. (2002) 'Heavy metals (Cd, Co, Ni and Pb) accumulation in tomato plants and soils amended with irradiated and non-irradiated sewage sludge', *Egyptian Journal of Soil Science*, Vol. 42, No. 3, pp.521–543.

Fauziah, C.I. and Rosenani, A.B. (1999) 'Domestic sewage sludge application to corn after five cycles: effect on yield and elemental uptake and accumulations in the soil', *Report of the 4th Research Co-ordination Meeting of the FAO/IAEA Co-ordination Research Project* on *The Use of Irradiation Sewage Sludge to Increase Soil Fertility and Crop Yields and to Preserve the Environment*, During 20–24 September, Malaysia.

Gagan, A., Pandya, L., Prakash, P.D. and Modi, V.V. (1988) 'Effect of gamma-irradiated sludge on the growth and yield of rice (*Orysa sativa* L. var. GR-3)', *Environment Pollution*, Vol. 51, No. 1, pp.63–73.

Gagan, A., Pandya, L., Sachidanand, S. and Vinod, V.M. (1989) 'Potential of recycling gamma-irradiated sewage sludge for use as fertilizer: A study on chickpea (*Cicer arietinum*)', *Environment Pollution*, Vol. 56, No. 2, pp, 101–111.

Gagan, A., Pandya, L., Banerjee, S. and Modi, V.V. (1991) 'Perspectives f recycling gamma irradiated sewage sludge in agricultural application: a study on methi (*Trigonella foenum-graecum* L.: *leguminosae*)', *Environment Pollution*, Vol. 72 No. 3, pp.225–237.

Gautam, S., Shah Mahesh, R., Sunil, S. and Arun, S. (2005) 'Gamma irradiation of municipal sludge for safe disposal and agricultural use', *Water Environment Research*, Vol. 77, No. 5, pp.472–479.

Getoff, N. (1992) 'Radiation processing of liquid and solid industrial wastes', *Proceedings 'Application of Isotopes and Radiation in Conservation of the Environment' Karlsruhe*, International Atomic Energy, Vienna, Australia, March 1992, pp.153–159.

Jackson, M.L. (1973) *Soil Chemical Analysis*, Prentice-Hall of India Pvt. Ltd., New Delhi.

Jung, M.C., Thornton I. and Chon, H.T. (2002) 'Arsenic, Sb and Bi contaminations of soils, plants, waters and sediments in the vicinity of the Dalsung Cu-W mine in Korea', *The Science of the Total Environment*, Vol. 295, pp.81–89.

Kirkham, M.B. (1980) 'Availability of metals in irradiated sewage sludge', *Journal of Agriculture and Food Chemistry*, Vol. 28, pp.663–665.

Krogman, U., Boyles, L.S., Martel, C.J. and McComas, K.A. (1997) 'Biosolids and sludge management', *Water and Environmental Research*, Vol. 69, pp.534–549.

Lowe, H.N., Lacy, W.G., Surkiewicz, B.F. and Yaeger, R.F. (1956) 'Destruction of micro-organisms in water, sewage and sewage sludge by ionizing radiation', *J. Am. Wat. Works Assoc*., Vol. 48**,** pp.1363–1372.

Magnavacca, C. and Graino, J.G. (2000) 'Additional advantages of irradiation treatment of sewage sludge for agriculture use', *Proceedings of International Symposium on Nuclear Techniques in Integrated Plant Nutrient, Water and Soil Management*, 16–20 October, IAEA, Vienna, Australia, IAEA-CSP- 11/p, ISSN 1563-0153.

Magnavacca, C. (1999) 'Evaluation of irradiated sewage sludge as an industrial crop fertilizer using nuclear techniques', *Report of the 4th Research Co-ordination Meeting of the FAO/IAEA Co-ordination Research Project on the Use of Irradiation Sewage Sludge to Increase Soil Fertility and Crop Yields and to Preserve the Environment*, during 20–24 September, Malaysia.

McCaslin, B.D. and O'Connor, G.A. (1982) *Potential Fertilizer Value of Gamma-Irradiated Sewage Sludge on Calcareous Soils*, Bulletin, Agricultural Experiment Station,-New Mexico State-University, No. 692, p.52, Las Cruces, New Mexico, USA.

Motaium, E.L. (1999) 'Crop production and heavy metals in sandy and calcareous soils amended with irradiated and non-irradiated sewage sludge', *Report of the 4th Research Co-ordination Meeting of the FAO/IAEA Co-ordination Research Project on the Use of Irradiation Sewage Sludge to Increase Soil Fertility and Crop Yields and to Preserve the Environment*, during 20–24 September, Malaysia.

Ontario Ministry of Agriculture and Food (OMAF) (1990) *Field Crop Recommendations*, Publication 296, Ontario Ministry of Agriculture and Food, Ottawa, Canada, p.6.

Pikav, A.K. and Shubin, V.N. (1984) 'Radiation treatment of liquid waste', *Radiation Physics and Chemistry*, Vol. 24, pp.77–97.

United States Environmental Protection Agency (USEPA) (1993) *Environmental Regulations and Technology: Use and Disposal of Municipal Wastewater Sludge*, USEPA, 503.48, US Government Printing Office, Washington DC.

Villar, M.C., Beloco, M.C., Acea, M.J., Cabaneiro, A., Gonzalez-Prieto, S.J., Carballas, M., Dfaz-Ravina, M. and Carballas, T. (1993) 'Physical and chemical characterization of four composted urban refuses', *Bioresour. Technol*., Vol. 45, pp.105–113.

Waite, T.D., Kruger, P., Bryan, E. and Swinwood, J.F. (1992) 'Irradiation treatment of water and waste', *Proceedings 'Application of Isotopes and Radiation in Conservation of the Environment'*, Karlsruhe, International Atomic Energy, Vienna, Australia, March, pp.143–152.

Wen, G., Bates, T.E., Voroney, R.P., Yamanoto, T., Chikushi, J. and Curtin, D. (2002) 'A yield control approach to assess phytoavailability of Zn and Cu in irradiated, composed sewage sludges and composted manure in field experiments: I Zinc', *Plant and Soil*, Vol. 246, pp.231–240.

Wen, G., Bates, T.E. and Voroney, R.P. (1995) 'Evaluation of nitrogen availability in irradiated sewage sludge, sludge compost and manure compost', *Journal of Environmental Quality*, Vol. 24, No. 3, pp.527–534.

Wen, G., Bates, T.E., Voroney, R.P., Yamamoto, T., Cjikushi, J. and Curtin, D. (2002) 'A yield control approach to assess phytoavailability of Zn and Cu in irradiated, composted sewage sludge and composted manure in filed experiments: I. Zinc', *Plant and Soil*, Vol. 246, pp.231–240.

Wen, G., Bates, T.E., Voroney, R.P., Winter, J.P. and Schellenberg, M.P. (1999a) 'Potassium availability with application of sewage sludge, and sludge and manure composts in fiend experiments', *Nutrient Cycling in Agroecosystems*, Vol. 47, pp.233–241.

Wen, G., Bates, T.E., Voroney, R.P., Winter, J.P. and Schellenberg, M.P. (1999b) 'Influence of application of sewage sludges, and sludge and manure composts on plant Ca and Mg concentration and soil extractability in field experiments', *Nutrient Cycling in Agroecosystems*, Vol. 55, pp.51–61.

Woods, R.J. (2000) 'Radiation processing: current status and future possibilities', *Journal of Radioanalytical and Nuclear Chemistry*, Vol. 243, No. 1, pp.255–260.

Zapata, F. and Zaharah, A.R. (2002) 'Phosphorus availability from phosphate rock and sewage sludge as influenced by the addition of water soluble phosphate fertilizer', *Nutrient Cycling in Agroecosystems*, Vol. 63, pp.43–48.

Zhao, Y.F., Wang, Z.H., Fu, R. and Jun, Y-S. (2005) 'Effect of application of sewage sludge on growth and quality of crops', *Journal of Anhui Agricultural University*, Vol. 32, No. 2, pp.216–220.