Pak. J. Bot., 39(7): 2511-2517, 2007.

EFFECTS OF UN-TREATED SEWAGE SLUDGE ON WHEAT YIELD, METAL UPTAKE BY GRAIN AND ACCUMULATION IN THE SOIL

MUHAMMAD ALI KHAN[1*], T.G. KAZI[2], R. ANSARI[3], S.M. MUJTABA, B. KHANZADA, M.A. KHAN, M.U. SHIRAZI AND S. MUMTAZ

[1]*Nuclear Institute of Agriculture (NIA), Tandojam,*
[2]*National Centre of Excellence, University of Sindh, Jamshoro,*
[3]*Department of Botany, University of Karachi, Karachi, Pakistan.*

Abstract

The high nutrients and organic matter contents of sewage sludge make it an excellent fertilizer to enhance soil fertility and crop production. However, presence of metals is a major problem for such a utilization of sludge. In Pakistan, there are only two-sewage treatment plant, one in Islamabad and the other in Karachi. Due to not having sewage treatment facility, in the country on wide scale, usually sludge is directly mixed with agricultural soil. As the sewage sludge, produced in municipal station, is highly toxic, therefore, there is a danger for the uptake of toxic metals by plant and accumulation in the soil. The present study describes the effects of un-treated sewage sludge on wheat yield and uptake of metals by grain as well as addition of metals to the soil. The treatment consisted of sewage sludge @ 10, 20, 40 & 80 Mg ha^{-1}, keeping 120:60:60 NPK as a standard application rate (control). The results indicated that the sewage sludge @ 80 Mg ha^{-1} yielded significantly ($p \leq 0.05$) higher when compared with control. Sewage sludge increased the levels of Zinc (Zn) and Cadmium (Cd), within the permissible limits, in wheat grain; whereas no significant increase was observed in Copper (Cu) and Lead (Pb). Analysis of soil showed significant increases in AB-DTPA-extractable Zinc and Copper and non-significant increases in 0.1N HCl-extactable Lead and Cadmium. It may be concluded that application of sewage sludge was good for improving crop yield but it was also a source of metals. Therefore monitoring of metals, in soils as well as in plant parts, should always be carried out in case of continuous use of sewage sludge.

Introduction

The management and disposal of sewage sludge in an economically and environmentally acceptable manner, is one of the society's most pressing problem. Land application offers a potential means for using this waste material in agriculture, in contrast to current disposal practices of land filling and incineration (Mehmet, 2003).

In fact the concept of using organic wastes as fertilizer is not new. Before the industrial age in the 1940s, when synthetic nitrogenous fertilizers were not widely available, animal manures and human wastes were the primary supplement to agricultural soil for improving crop yield around the world. Land application of sewage sludge as fertilizer enables to recycle nutrients and eliminate the need to use commercial fertilizers in cropland (Chino *et al*., 1992). Applying sludge to agricultural soils improves soil physical and biological properties because it contains organic matter and plant nutrients (Chaudri, *et al*., 2001). It can significantly increase crops yield over control (Chattopadhyay *et al*., 1992). However sewage sludge contains elevated levels of phytotoxic metals (Misra & Mani, 1991). Thus, one has to be very conscious when using sewage sludge in agricultural soil.

*Corresponding author E-mail: alipaec@hotmail.com

In developing countries like Pakistan, so far very little attention has been focused on the pre treatment of urban and industrial wastes. In Pakistan, there are only two-sewage treatment plant, one in Islamabad and the other in Karachi (Rabia & Mushtaque, 2003). Due to not having sewage treatment facility, in the country on wide scale, usually sludge is directly mixed with agricultural soil as a supplemental fertilizer. In absence of pretreatment facility to remove exceeding toxic metals, it is feared that presence of toxic metals accelerates their uncontrolled absorption in various parts of the plants during growth as well as accumulation in the soil, which in turn creates numerous health hazards (Bride, 1995; McGrath *et al*., 1994). Keeping this fact, in view, present study was, therefore, undertaken to find out the effects of un-treated sewage sludge on wheat yield and metals contents in soil and wheat grain.

Material and Methods

This research study was conducted at Nuclear Institute of Agriculture (NIA) Tandojam during the rabi season of 2001-02, 2002-03 and 2003-2004. The presented results are the grand mean of three years study. A piece of land measuring 5 x 25 m was selected at the farm. It was divided into 5 equal plots measuring 5m x 4 m. Sewage sludge was collected from municipal station of Tandojam city. Characteristics of soil and sewage sludge including EC, pH and Texture is given in Table 1. It was dried under the shade for about 45 days, sieved and applied to each plot @ 10, 20, 40, & 80 $Mgha^{-1}$. The sludge was thoroughly mixed with spade. After irrigation, as soaking dose, sowing of wheat variety Sarsabz (evolved by NIA, Tandojam) was carried out as per randomized complete block design (RCBD) in triplicate. Yield and yield components i.e., grain yield, total dry matter yield, 1000-grain weight were recorded for three years. Three soil samples (0-30 cm depths) from each plot were collected from different sites before sowing and at the harvest stages. Soils of each plot were mixed thoroughly, air- dried and passed through a 2 mm sieve. Texture analysis of soils was determined by Hydrometer method (Bouyoucos, 1965). The pH was measured on a pH meter (made by PCSIR, Model LPM 1.4) and the electrical conductivity ($dS\ m^{-1}$) on a conductivity meter (WTW Model LF 530) in a 1:2.5 soil/ water suspension. Total nitrogen was determined by Kjeldahl method (Kjeldahl, 1883). Extractable phosphorus, potassium, zinc and copper were estimated by Ammonium bicarbonate diethylene triamine penta acetic acid (AB-DTPA) method (Soltanpour, 1985), available nitrogen by alkaline- potassium permanganate method (Subbiah & Asija, 1956); available lead and cadmium were determined by shaking 10 g soil in a 1:10, 0.1 N HCl using a rotary shaker for the period of sixteen hrs (Combs & Dowdy, 1982). Total metals (Zn, Cu, Pb, Cd) in soil and sludge were determined through atomic absorption spectrometer (Hitachi- 150-20) after digestion with $HClO_4$: HNO_3 (Table 1). Organic matter was determined following the method of Walkley & Black (1934). Metals (Zn, Cu, Pb, and Cd) in wheat grain were determined by atomic absorption spectrometer following a wet digestion using $HClO_4$: HNO_3 digestion mixture (1:5).

Statistical analysis: The data were statistically analyzed using appropriate statistical programme. Analysis of variance (AOV) techniques were applied to test the overall significance of the data, while Duncan Multiple Range Test (DMRT) at $p \leq 0.05$ was used to compare the treatment means.

Table 1. Characteristics of soil and sewage sludge.

Characteristics	Soil	Sewage sludge
Textural class	Loamy	
pH	7.5	7.23
EC.$_{25°C}$ (dsm^{-1})	0.76 (1:2.5)	1.5 (1:2.5)
C (g Kg^{-1})	6.0	87.0
Total N (g Kg^{-1})	1.0	4.0
C/N	6.0	21.75
AB DTPA extractable-P (mg Kg^{-1})	8.5	17.4
AB DTPA extractable-K(mg Kg^{-1})	238.0	113.0
Available nitrogen (mg Kg^{-1}) ($KMnO_4$-Extractable)	40	65.0
Organic matter (%)	1.0	12.5
Metals (mg Kg^{-1})		
Zn	120	441
Cu	38	51
Pb	10.4	21.9
Cd	0.9	2.3

Table 2. Yield and yield contributing characters of wheat as affected by the amendments of sewage sludge.

Treatments	GY(Kg ha^{-1})	TDMY(Kg ha^{-1})	1000 g wt
T_0	2010 b	6474 b	35.25 b
T_1	961 e	2961 e	31.43 d
T_2	1321 d	4039 d	34.50 c
T_3	1880 c	5439 c	34.61 c
T_4	2513 a	7655 a	37.61 a
LSD	**61.86**	**546.5**	**0.507**

Means followed by same letter are not significant at p ≤0.05 according to DMRT.
T_0 = Control (120:60:60, NPK), GY= Grain yield
T_1 = sewage sludge @ 10 Mgha^{-1}, TDMY= Total dry matter yield
T_2 = sewage sludge @ 20 Mgha^{-1}
T_3 = sewage sludge @ 40 Mgha^{-1}
T_4 = sewage sludge @ 80 Mgha^{-1}

Results and Discussion

The responses of wheat crop to different doses of sewage sludge are shown in Table 2. There was a gradual increase in the grain yield with the increased rate of sewage sludge. Significantly ($p<0.05$) higher grain yield was observed in the treatment T_4 (2513 Kg ha^{-1}) followed by control (2010 Kg ha^{-1}) and T_3 (1880 Kg ha^{-1}). However in the treatment T1 (961 Kg ha^{-1}) and T_2 (1321 Kg ha^{-1}) significantly low grain yield was observed. As the rate of sewage sludge in the treatment T_1 and T_2 (i.e. 10 and 20 Mg ha^{-1}) was low as compared to other treatment (i.e. 40 and 80 Mg ha^{-1}), thus plant could not uptake essential nutrients in these treatment due to which low yield was observed. Significantly higher yield in the treatment T_4 might be due to highest rate of sewage sludge which is in good agreement with the findings of Dorn *et al.*, (1985) who reported that highest sewage sludge application rate supplied more nutrients to plant, consequently yield is increased. A gradual increase in Total Dry Matter Yield (TDMY) was observed with the increasing sewage sludge application rate. The data showed that T_4 (7655 Kg ha^{-1}) had significantly higher TDMY followed by control (6474 Kg ha^{-1}) and T_3 (5439 Kg ha^{-1}). The marked response in TDMY in control, T_4 and T_3 might be due to high availability of nutrients in these treatments i.e. in control due to availability of NPK and in T_4 and T_3 due to highest application rate. In the same way the possible reason for significantly low dry matter yield in T_1 (2961 Kg ha^{-1}) and T_2 (4039 Kg ha^{-1}) is due to low nutrient supply causing poor plant growth (Niane, 1987, Mass *et al*., 1996). Data regarding 1000-grain weight showed similar pattern as in grain yield and TDMY.

Analysis of metal ions in soil and wheat grain: The data showed that zinc contents of soil were increased from marginally low to an adequate level by the sewage sludge application (Table 5). Maximum increase in Zn contents (6.75 mg Kg^{-1}) was observed at the highest rate of sludge application (T_4 i.e. 80 Mg ha^{-1}) compared to control (1.76 mg Kg^{-1}) followed by T_3 (5.87 mg Kg^{-1}) and T_2 (4.76 mg Kg^{-1}). However this increase was below the phytotoxicity levels of Zn (130 mg Kg^{-1}) as reported by Alloway & Ayers (1997). In this study the increase in the extractable soil Zn concentration was proportional to the increase in the sewage sludge rates applied to soil. These results are similar to those obtained by Korack & Fanning (1985) and Rappaport *et al*., (1988).

Within the treatments the highest Zn contents in wheat grain were produced by T_3 (60.68 mg Kg^{-1}) followed by T_1 (59.31 mg Kg^{-1}) (Table 4). Non- significant variations were observed between T_2 (54.53 mg Kg^{-1}) and T_4 (57.53 mg Kg^{-1}). The lowest Zn contents in control (32.33 mg Kg^{-1}) might be due to the fact that a) no sewage sludge was applied in this treatment b) As urea was applied in control thus due to the presence of nitrogen, soil pH increased (7.54) (Table 3), which caused Zn precipitation as its oxides and hydro-oxides thus made un-available to plants. Hooda & Alloway (1996) also documented a negative influence of higher pH on Zn transfer into wheat grain.

Analysis of soil samples for copper contents showed that the Cu concentration of soil was significantly increased by the application of sewage sludge (Table 5). Maximum increase in Cu contents was found in T_4 (3.01 mg Kg^{-1}) followed by T_3 (2.76 mg Kg^{-1}) and T_2 (2.13 mg Kg^{-1}) as compared to control (1.66 mg Kg^{-1}). These findings are in good agreement with the results of Adao Luiz *et al.,* (2003) who found that diethylene triamine penta acetic acid (DTPA) extractable Cu-concentration increased with the increasing sewage sludge rate, again corroborating the results of Korack & Fanning (1985) and Rappaport *et al*., (1988).

The trend, on the other hand, was reverse in case of copper in wheat grain. There was no significant effect of sewage sludge application on the copper content of wheat grain (Table 4). This might be due to alkaline nature of the soil i.e., pH is higher than 7 (Table 3). This result are in line with Reddy *et al*., (1996) who pointed out that soils having pH 7 to 9 inhibited the copper availability in soils and consequently their uptake by plants. Organic matter (Data not presented) also tied up the excess amount of Cu thus made unavailable to plant. Land disposal of sewage sludge is unlikely to cause copper toxicity in plants except in cases where very heavy repeated applications are made to acidic soil (Sloan *et al*., 1997).

Of the elements presently known to exist in substantial quantities in sewage sludge, cadmium gave the greatest cause of concern. Cadmium contents were increased non-significantly, with the increasing rate of sewage sludge in the sludge amended soil. Maximum increase was observed in the treatment T_4 (0.06 mg Kg^{-1}) (Table 5). Bride *et al*., (2000) found that there was marked increase in the Cd content above control levels in those soils that received the higher loadings of sewage sludge (greater than 180 Mg ha^{-1}). In this study the rate of sewage sludge applied was not as much higher. These findings confirm the results of Bride *et al*., (2000).

Table 3. pH of soil after the application of sewage sludge.

Treatments	pH
T_0	7.54
T_1	7.31
T_2	7.54
T_3	7.02
T_4	6.90

Table 4. Metal contents in wheat grain as affected by application of different levels of sewage sludge.

Treatments	Zn (mg Kg^{-1})	Cu (µg Kg^{-1})	Cd (µg Kg^{-1})	Pb (µg Kg^{-1})
T_0	32.33 c	65	24.00 c	102.7
T_1	59.31 a	60	27.33 c	105.0
T_2	54.53 b	65	27.67 c	108.3
T_3	60.68 a	65	32.33 b	104.3
T_4	57.53 ab	60	37.33 a	104.3
LSD	**4.197**	**NS**	**4.599**	**NS**

Means followed by same letter are not significant at $p \leq 0.05$ according to DMRT.

Table 5. Effect of sewage sludge application on metal contents of soil (mg Kg^{-1}).

Treatments	Zinc (Zn)	Copper (Cu)	Lead (Pb)	Cadmium (Cd)
T_0	1.76 e	1.66 d	0.25	0.042
T_1	2.95 d	1.70 d	0.31	0.048
T_2	4.76 c	2.13 c	0.36	0.049
T_3	5.87 b	2.76 b	0.40	0.056
T_4	6.75 a	3.01 a	0.42	0.060
LSD	**0.057**	**0.057**	**N.S**	**N.S**

Means values followed by same letter are not significant at $p \leq 0.05$ according to DMRT.

Cadmium contents of wheat grain showed significant variations between different treatments (Table 4). The highest Cd value was found in T_4 (37.33 µg Kg^{-1}) followed by T_3 (32.33 µg Kg^{-1}) and the lowest in control (24.00 µg Kg^{-1}). However T_1 (27.33 µg Kg^{-1}) and T_2 (27.67 µg Kg^{-1}) showed almost the same contents with only slight variation. The lower and non- significantly differed values of Cadmium in T_0, T_1 and T_2 and higher and significantly differed values in T_3 and T_4 could be attributed to higher and lower pH values in these treatments. In T_0, T_1 and T_2 pH of the soil are comparatively higher (7.54, 7.31, and 7.54 respectively) thus low Cd was translocated into grain while in T_3 and $T_{4,}$ the case was opposite because pH of the soil in these treatments is comparatively lower (7.02 and 6.90 respectively) thus comparatively higher Cd was up taken. This fact was corroborated by Oliver *et al*., (1997) who reported that the higher pH would minimize Cd availability for plant uptake since the proportion of Cd ions that are hydrolyzed would be higher and there would be greater number of adsorption site.

Lead contents of sludge-amended soil were increased non-significantly with the increasing rate of sewage sludge (Table 5) corroborating the results of Bride *et al*., (2000), and Teresa *et al*., (1991). Results indicated that there was no significant effect of different treatments on the uptake of Pb contents, showing lower or no translocation of

Lead into the grain (Table 4). This might be due to the fact that sewage sludge addition improves organic matter fraction of the soil and Pb has a strong capability, in the presence of organic matter, to combine with other ions to form a stable compound (Haar, 1991).

Conclusion and recommendation: This study showed that sewage sludge application @ 80 Mg ha^{-1} yielded even higher than those obtained with the equivalent NPK rate applied as chemical fertilizer (control). However this application rate is not recommendable because of very high rate and to avoid the possible risk of metals uptake and accumulation in the soil. The recommendable rate is 40 Mg ha^{-1}. At this rate, however, yield is to some extent low but the possible risks of metal uptake and accumulation in the soil are very less. This study consisted of continuous use of sewage sludge for three years, thus in the 3rd year slight increase in heavy metal accumulation in soil has been noted. It is recommended that sewage sludge application should be discontinued after three years and can be continued again after two years break. However monitoring of soil and grain for heavy metal accumulation is necessary. More continuous long-term experiments are needed to improve the understanding of the effects of sewage sludge on soil fertility and crop yield to contribute to the development of sustainable agricultural practices.

Acknowledgement

We are thankful to Mr. Saqib Ali Memon (NIA, Tandojam) for composing and typing the manuscript.

References

AdaoLuiz, M., B. Ordinocleante and A. Otavio. 2003. Copper, nickel and zinc phytoavailability in an oxisole amended with sewage sludge and liming. *Sci, Agric*., 60(4): 1-13.

Alloway, B.J. and D.C. Ayers. 1997. Inorganic pollutant. P. 208-209. In: *Chemical Principles of Environmental pollution* (2nd Eds). *Blackie Academics and Professional*, London, New York.

Bouyoucos, G.J. 1965. Hydrometer method for making particle size analysis of soil. *Agron. J*., 54: 464-465.

Bride, M.B. 1995. Reactions controlling heavy metal solubility in soils. *Advances in Soil Sci*., 10: 1-57.

Bride, M.B., E. Martinez and L. Evans. 2000. Trace metal solubility and speciation in a calcareous soil 18 years after No-till sludge application. *Soil Sci.,* 165(8): 646-656.

Chattopadhyay, N., M. Dutta and S.K. Gupta. 1992. Effect of city waste composts and fertilizer on the growth, nutrient uptake and yield of rice. *J. Indian Soc. Soil. Sci*., 40: 464-468.

Chaudri, A.M., C.M. Allain, S.H. Badawy, M.L. Adams, S.P. McGrath and B.J. Chambers. 2001. Cadmium content of wheat grain from a long-term field experiment with sewage sludge. *J. Environ. Qual*., 30: 1575-1580.

Chino, M., S. Goto and R.A. Youssef. 1992. Behaviour of zinc and copper in soil with long term application of sewage sludge. *Soil Sci. Plant Nutr*., 38(1): 159-167.

Combs, S.M. and R.H. Dowdy. 1982. The effect of extraction techniques on Cd, Cu, Ni and Zn extraction from degraded materials and correlation with plant uptake. *Comm. Soil Sci. Plant Anal*., 13: 87-102.

Dorn, C.R., C.S. Reddy, D.N. Lamphere, J.V. Gaeuman and R. Lanese. 1985. Municipal sewage sludge application on Ohio farms: Health effects. *Environ, Res.,* 38: 332-359.

Haar, G.J. 1991. Composition of airborne lead particles. *Nature,* London., 232: 553-554.

Hooda, P.S. and B.J. Alloway. 1996. The effect of liming on heavy metals concentration in wheat, carrots and spinach grown on previously sludge applied soils. *J. Agric, Sci*., 127: 289-294.
Kjeldahl, J. 1883. A new method for the determination of nitrogen in organic matter. *Z. Anal. Chem*., 22: 366.
Korack, R.F. and D.S. Fannings. 1985. Availability of applied heavy metals as a function of type of soil material and metal source. *Soil Sci*., 140: 23-34.
Mass, E.V., S.M. Lesch, L.E. Erancois and C.M. Grieve. 1996. Contribution of individual culms to yield of salt stressed wheat. *Crop Sci*., 6: 142-147.
McGrath, S.P., C. Keller and S.J. Dunham. 1994. Trace metal leaching through a soil grassland system after sewage sludge application. *J. Environ. Qual*., 31: 1550-1560.
Mehmet, A. B.2003. The effects of sewage sludge applications on the yield, growth, nutrition and heavy metal accumulation in apple trees growing in dry onditions. *Turk. J. Agric*., 27: 285-292.
Misra, S.G. and D. Mani. 1991. Soil pollution. pp. 43-80. *Ashish Publishing House*, New Delhi, India.
Niane, A.B. 1987. Response of rice to nitrogen split application on a salt affected soil. *Int. Rice Res., News letter*, 12: 27.
Oliver, D.P., C. Penfold, J. Derrick, G. Cozens and K.G. Tiller. 1997. Cadmium concentration in grain grown under organic farming systems and using alternative fertilizer. *Technical Report*, 13/1997, CSIRO.
Rabia, H. and A.K. Mushtaque. 2003. Effect of land application of sewage sludge on heavy metal contents in soil and plant, soil fertility and wheat yield. *Pak. J. Soil. Sci.,* 22(3): _____.
Rappaport, B.D., D.C. Martens, Jr. Reneau and R.B. Simpson. 1988. Metal availability in sludge-amended soils with elevated metal levels. *J. Environ. Qual*., 17: 42-47.
Reddy, M.R. and H. Perkins. 1996. Effect of biosolids applications on trace elements in wheat grain. *Soil Sci. Sos. Am. Proc*., 38: 229.
Sloan, J.J., R.H. Dowdy, M.S. Dolan and D.R. Linden. 1997. Long-term effects of biosolids applications on heavy metal bioavailability in agricultural soils. *J. Environ. Qual*., 26: 966-974.
Soltanpour, P.N. 1985. Use of ammonium bicarbonate DTPA soil test to evaluate elemental availability and toxicity. *Comm. Sci. Soil and Plant Anal*., 16: 323-338.
Subbiah, B.V. and G.L Asija. 1956. A rapid procedure for the determination of available nitrogen in soils. *Curr. Sci.,* 25: 259-260.
Teresa, H., M. Juan and A. Fran 1991. Influence of sewage sludge application on crop yields and heavy metal availability. *Soil Sci. Plant Nurition*., 37(2): 201-810.
Walkley, A. and I.A. Black. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.,* 4: 29-38.

(Received for publication 14 February 2006)