Effects of Sewage Sludge on Heavy Metal Accumulation in Soil and Plants, and on Crop Productivity in Aleppo Governorate

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Abstract

Although sewage sludge is a good source of nutrients for plant growth, the presence of heavy metals in sludge can limit its use. We conducted a field study to evaluate the effects of soil application of sludge on heavy metal accumulation in soil and plants and on the productivity of wheat, maize and vetch. There were four treatments: (i) control; (ii) application of inorganic fertilizer according to the recommendation of the Ministry of Agriculture and Agrarian Reforms (MAAR); (iii) application of sludge equivalent to the MAAR-recommended nitrogen application; (iv) application of sludge at double the rate used in (iii). The experiment was conducted at the Kamari Research Station in Aleppo. Analysis of soil before sludge application and after harvest reveals significant build up of some heavy metals. Similarly in crops, heavy metal content increased with the increased application rate of sludge. In terms of other parameters, there was significant increase in organic matter and plant-available soil P levels in sludge-fertilized treatment. There were no significant differences for wheat yield between the sludge-fertilized treatments (2.66 and 2.86 t ha^{-1}) and mineral-fertilized treatment (2.93 t ha^{-1}). Maize yield increased significantly in sludge-fertilized treatments compared to the control (3.88 t ha^{-1}); the highest yield (6.34 t ha^{-1}) was in the treatment fertilized with double the amount of sludge. Vetch production also followed a similar pattern. Based on the results of this study, it is concluded that sludge application to the soil is effective in improving crop yield. It is unlikely that a single factor in sludge was responsible for the yield improvement rather a combination of macro and micronutrients and organic matter supplied by the sludge. The addition of heavy metals to the soil with the application of sludge was minimal.

Keywords: sewage sludge, organic matter, heavy metals, wheat, maize, vetch, Syria

1 Introduction

Sewage sludge is a good source of micro and macronutrients and organic matter (OM) for plants. However, unquantified and unscientific application of sewage sludge can be detrimental to plant growth, animal nutrition, and human health. Crop responses to sludge application vary by source, application rate, plant species, soil type, weather conditions, and management practices (Rabie *et al.* 1996). Application of sewage sludge can improve soil structure and increase infiltration rate, aggregate stability, and soil water holding capacity (Sort and Alcaniz 1999). However, heavy metals in sludge can limit its use (Barriquelo *et al.* 2003), potentially adding high concentrations of Cd, Cu, Ni, Pb, and Zn to soil can cause serious problems to plants and their consumers. The Syrian government is establishing sewage treatment plants in towns and districts, and the annual amount of solid organic waste from these plants is expected to reach 0.2 million t in 2010. There have been few studies carried out in Syria that address the implications of sludge application. Based on a field study, we evaluated the effects of sludge application to soil on heavy metal accumulation in soil and plants and on the productivity of wheat, maize and vetch.

2 Materials and methods

2.1 Soil description

The top 30 cm layer of red soil (Inceptisols) was collected from Kamari Research Station, Aleppo, Syria, and analyzed for the following: organic matter, available P according to Olsen *et al.* (1954); total N using the Kjeldahl method; organic matter by wet oxidation; available K by extracting with 1 mol L^{-1} ammonium acetate (1:5 ratio) and using a flame photometer. Soil organic matter content was 1.23%, total nitrogen level was 0.06%, available concentrations of P and K were 7.5 and 469 mg kg^{-1}. With 23.3% $CaCO_3$, the soil was calcareous in nature. pH was in the alkaline range, and EC1:5 was 0.4. Soil texture was 26% sand, 18% silt, and 56% clay.

2.2 Sludge characteristics

The sludge used in the experiment was sampled and analyzed for physical and chemical properties. The samples were digested using the wet method (Walinga *et al.* 1995) and total N and P were estimated using a Skalar auto analyzer. Total K was estimated by flame photometer.

Inorganic N was extracted using KCl (1:10) and measured using an auto analyzer. Sludge was digested by $HClO_4$ for micronutrient determinations and digested with aqua regia to determine heavy metal concentrations by atomic absorption spectrophotometer. Bulk density of the sludge was 0.86 g cm^{-3}. With pH value of 6.37, the sludge was in acidic in reaction. The salinity level expressed in terms of EC was 3.38 dS m^{-1}. Other characteristics of sludge are given in Tables 1 and 2.

Table 1 Physical and chemical characteristics of sewage sludge used in the study (average of three samples)

Sludge source	Moisture (%)	OM (%)	Total N (%)	K_2O (%)	P (mg kg^{-1})
Aleppo wastewater plant	6.5	40.5	3.70	1.35	132

Table 2 Total concentration of metal ions (mg kg^{-1}) in sewage sludge used in the study (average of 3 samples)

Sludge source	Cd	Ni	Pb	B	Cu	Fe	Mn	Mo	Zn
Aleppo wastewater plant	2.30	78.4	71.6	117	230	2400	159	30	1025
Allowable limits	20	200	800	-	1000	-	-	30	3000

2.3 Experimental design and treatments

A completely randomized complete block design with four replications was used; plot size was 5 ×10 = 50 m^2. There were four treatments: (i) control; (ii) application of inorganic fertilizer according to the recommendation of the Ministry of Agriculture and Agrarian Reforms (MAAR); (iii) application of sludge equivalent to the nitrogen application as recommended by the MAAR; (iv) application of sludge at the rate double that used in treatment 3.

2.4 Cultivation and fertilization

Wheat, maize, and vetch were cultivated for three seasons during 2004-2006 in crop rotation. Nitrogen and P were added as per MAAR recommendations. Sludge was added to soil after calculating the required amount.

3 Results and discussion

3.1 Effect of sludge on nutrient availability status in soil

There were no significant differences in OM content of soil under wheat and maize (Table 3) due to good initial OM content in soil (Table 1). After the third crop in rotation (i.e. vetch), the addition of sludge significantly enriched soil OM especially in T4 where OM increased significantly over control (T1).

Table 3 Total N, available P, and organic matter (OM) in 0-30 cm soil depth after harvesting wheat, maize, and vetch crops.

Treat-ment	Wheat			Maize			Vetch		
	OM	Total N	Available P	OM	Total N	Available P	OM	Total N	Available P
	%		mg kg^{-1}	%		mg kg^{-1}	%		mg kg^{-1}
T1	2.1	0.084 b	4.1 c	2.13	0.106	3.96 b	1.65 c	0.018 b	3.48 b
T2	1.9	0.110 a	7.7 a	1.97	0.100	6.89 b	2.23 b	0.03 ab	7.68 a
T3	2.2	0.092 ab	6.3 ab	2.06	0.103	8.33 b	2.49 ab	0.06 a	6.15 a
T4	2.2	0.103 ab	5.2 bc	2.13	0.107	19.10 a	2.90 a	0.04 a	5.73 ab
LSD	-	0.023	2.0	-	-	8.03	0.45	0.02	2.28

Sludge addition increased total N in soil; in case of wheat rotation, the total N increased by 23% compared with control (Table 3) because of high N in sludge (Table 1). Available P in soil was significantly different between treatments. Previous studies reveal that sludge addition can noticeably increase total N and available P levels in soils (Hernandes *et al.* 1991, Oudeh 2002).

3.2 Effect of sewage sludge on heavy metal accumulation in soil

There was no significant effect of sludge application on heavy metal (Cd, Ni, Pb, and Cr) concentrations in soil after wheat harvest, the first crop in rotation. Cadmium levels were found to higher in post-harvest maize plots where sludge was applied twice. The concentrations of other metal ions also increased after the harvest of vetch, the final crop in rotation (Table 4). In general, heavy metal accumulation was below allowable levels of Cd (0.01-2 mg kg^{-1}), Ni (5-500 mg kg^{-1}), Pb (2-200 mg kg^{-1}), and Cr (10-150 mg kg^{-1}) (Adriano 1986).

Table 4 Cadmium (Cd), nickel (Ni), lead (Pb), and chromium (Cr) levels in soil (mg kg^{-1}) after harvest of wheat, maize, and vetch crops

Treat-ment	Wheat				Maize				Vetch			
	Cd	Ni	Pb	Cr	Cd	Ni	Pb	Cr	Cd	Ni	Pb	Cr
T1	0.125	101.7	8.6	104	0.70 b	124.9	7.9	95.7	0.41	59.2 b	3.72 b	58.3 b
T2	0.140	105.7	8.0	104	0.15 a	120.8	4.7	96.2	0.53	75.7 a	3.93 ab	84.7 a
T3	0.135	96.5	8.0	104	0.13 ab	124.2	8.3	93.2	0.60	68.5 ab	4.50 a	85.2 a
T4	0.130	103.5	7.0	103	0.18 a	124.8	10.4	97.0	0.77	65.0 ab	4.13 ab	75.5 a
LSD	-	-	-	-	0.07	-	-	-	-	13.2	0.66	13.7

3.3 Effect of sewage sludge on heavy metal accumulation in plants

There was no effect of sludge on metal ion concentrations in wheat and maize (grain and straw; Table 5). There was an increase of Cd and Cr concentrations in both grain and straw of vetch. These results are in agreement with those of Chu and Wong (1987). Heavy metal accumulation in all the crops was within allowable limits (Cd 0.05-1.2, Ni 0-4, Pb 0.1-30, and Cr 1-5, all mg kg^{-1}; Adriano, 1986).

Table 5 Cadmium (Cd), nickel (Ni), lead (Pb), and chromium (Cr) concentrations (mg kg^{-1}) in grain and straw of wheat, maize, and vetch

	Wheat				Maize				Vetch			
	Cd	Ni	Pb	Cr	Cd	Ni	Pb	Cr	Cd	Ni	Pb	Cr
Grain												
T1	0.09	0.8	0.20	0.97	0.06	0.27	5.7	3.8	0.51 b	2.8	0.93	59.2 b
T2	0.09	0.8	0.20	0.95	0.09	0.31	6.3	4.0	0.55 b	2.3	1.07	75.7 a
T3	0.08	0.8	0.20	0.97	0.08	0.16	6.2	3.9	0.61 ab	1.8	1.08	68.5 ab
T4	0.09	0.8	0.20	1.04	0.11	0.15	4.5	3.8	0.79 a	1.7	1.09	65.0 ab
LSD	-	-	-	-	-	-	-	-	0.21	-	-	13.2
Straw												
T1	0.18	1.8	0.95	2.10	0.20	0.21	11.1	4.7	0.05 b	3.1	0.29 ab	0.8
T2	0.19	1.2	0.97	2.30	0.21	0.25	11.5	4.7	0.09 ab	3.3	0.23 b	1.1
T3	0.18	1.2	0.98	2.20	0.18	0.18	10.6	3.6	0.12 a	6.6	0.47 a	0.2
T4	0.19	1.3	0.98	2.40	0.21	0.17	12.2	3.8	0.09 ab	6.2	0.40 ab	0.5
LSD	-	-	-	-	-	-	-	-	0.05	-	0.24	-

3.4 Crop yield

There was a significant increase in wheat grain yield from the sludge-fertilized treatments compared with control (Table 6). T4 was the best with significant differences to controls and the chemically fertilized treatment. Similarly for maize grain production, sludge addition was significantly better than control; with T4 the best, significantly more than control and the chemically fertilized treatment. For vetch grain production, sludge addition was significantly better than control. Again, T4 was the best, significantly more than control and the chemically fertilized treatment. Other studies have shown high yields after sludge application, because of its contribution to greater availability of macro and micronutrients in the soil (Barriquelo *et al.* 2003).

Table 6 Grain yield (t ha^{-1}) of wheat, maize, and vetch as affected by the application of chemical fertilizers and sewage sludge application

Treatment	Wheat	Maize	Vetch
T1	2.03 d	1.100 c	9.8 b
T2	2.83 c	1.775 b	9.89 b
T3	3.3 0 b	2.150 b	11.41 b
T4	3.85 a	3.050 a	12.97 a
LSD	0.20	0.450	1.88

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