Land Application of Water Treatment Residuals: Effects on Heavy Metals Availability

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ABSTRACT

Concerns over the possible increase in phytoavailability of water treatment residual (WTR)-applied trace metals to plants have been raised. The fate of WTR metals applied to agricultural soils is not well understood, particularly in the soils of the arid region. This investigation was conducted to assess the effect of WTR application rates on chemical extractability and concentration of Cd, Cu, Ni, and Pb in wheat plants. Five alum rates (0, 10, 20, 30 and 40g kg-1) were applied to three alkaline soils (calcareous, sandy and clayey soils). Wheat (*Triticum aestivum*) seeds were planted in pots after WTR application. Extractable Cd, Cu, Ni, and Pb (as measured by AB-DTPA, and soil solution) were determined after wheat harvest .No adverse effects on plant growth or excessive amounts of metal uptake were noted after application. The metal concentrations in wheat plants were lower in the WTR treatments than in the control and remained well within the values observed for uncontaminated soils. None of the trace metals attained toxic concentrations. However, it is crucial to understand the long-term effects that application of WTR has on metal availability.Correlations between the concentrations of Cd, Cu, Ni, and Pb in roots ,shoots and panicles of wheat plants and soil metals extracted by AB-DTPA and soil solution were variable. The strength of the correlation between metal concentration in plants and extractable levels in soil solution was greater for Pb and Cd than Cu and Ni. Copper concentrations in plants were better predicted by the AB-DTPA extractant. The soil solution better predicted availability of Cd ($r=0.40$, $p < 0.01$) and Pb ($r=0.60$, $p < 0.001$) than AB-DTPA.

INTRODUCTION

Water treatment Residual (WTR) is a by-product from the filtering and purification of drinking water. The disposal of water treatment sludge is, however, a problem for water purification authorities due to its continuous production, the limited area available for disposal, and the possible liabilities it may cause if disposed in sanitary landfill sites (Heil and Barbarick et al.1989,Elliott et al.,1990 , Viraraghavan and Ionescu,(2002) . The reuse of WTR will therefore may provide an economic benefit to utilities and economic and environmental benefits to communities by preserving surface water quality. Alternative uses of the WTR have been investigated (e.g., in brick manufacturing) but without success. The application of the water treatment sludge in soil resolves the problem of the disposal of the residual that at this moment is discarded in the watercourse.

General problems associated with the use of water treatment sludge are the possible occurrence of high concentrations of heavy metals such as cadmium, copper, nickel and lead(Elliott et al., (1990). Therefore, it is essential that the water treatment residual be characterized, evaluated and managed in a safe and environmentally sound manner before it is applied to land. The objective of this study was to evaluate the water treatment sludge for land application by evaluating potential problems that may arise from the use of the sludge and its effectiveness as a liming material.

Some studies have been conducted in Europe and the United States{Ippolito et al.(1999),Dayton and Basta (2001) , Pietz et al.(1998), Heil and Barbarick et al.(1989),Elliott et al.,(1990) ,Viraraghavan and Ionescu,(2002), Sims et al.(2002) }but the conclusions drawn from these investigations are often conflicting. Further, any conclusions drawn from these temperate regions may not be applicable to the situation in Mediterranean climates. Much less is known about the likely fate of WTR metals applied in the arid soils of the Middle East. The objectives of our research were (i) to evaluate the availability of WTR-applied trace metals in three alkaline soils; and (ii) to determine the plant tissue metal uptake response of WTR derived trace of metals immediately available to plants.

MATERIALS AND METHODS

A. Soil characterization:

Three soils with different properties were selected for the study and sampled (generally 0-15 cm depth) from three different locations. One, (clayey soil) was obtained from Kafr Eldwaar, El-bohera Governorate. The second (calcareous soil) was from Borg Elarab, Alexandria Governorate. The third (sandy soil) was from Elbostan region Elbohera governorate. The soils were air dried, passed through a 2-mm sieve and stored in air-tight containers before use.

General soil properties were determined as follows: Soil pH and EC were measured in the soil-paste extracts.

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Soluble cations and anions were determined in soil-paste extract (Richard, 1954). The organic matter content was determined by the method of Walkley and Black (Nelson and Sommers, 1982), cation exchange capacity was determined by IM NaOAc (Rhoades, 1982). Particle size analysis was determined by the hydrometer method (Day, 1965). Calcium carbonate content was determined using calcimeter (Nelson, 1982). Total nitrogen was determined by the Kjeldah/digestion method. Available P was extracted by AB-DTPA test (Soltanpour et al., 1982). Extractable Aluminum was determined colorimetric by 8-Hydroxy quinoline-Butyl Acetate (Bloom et al., 1978).Selected properties of the two soils are summarized in Table (1).

B. Chemical characterization of water Treatment residuals (Alum-sludge)

The chemical properties of Alum-sludge and metal content were determined (Table 2). The pH was determined in 1: 2 sludge / deionized water. Salinity was measured in 1: 2 sludge/deionized water extract. Cation exchange capacity was determined by sodium saturation (Rhoades, 1982). Organic carbon content was determined by Walkley and Black (Nelson and Sommers, 1982). Total Al was determined using the acid ammonium oxalate method (Ross and Wang, 1993).

C-Green house Experiments:

Five alum rates (0, 10, 20, 30 and 40g kg-1) were applied to each soil (calcareous, sandy and clayey soils), thoroughly mixed and placed in pots (2 kg pot^{-1}). Seeds of wheat (Triticum aestivum) cultivar were sown. The seedlings were thinned to 4 seedlings per pot and distilled water was added to bring the soil moisture to 70% of field capacity.

The experiment was arranged in completely randomized design with four replicates. Plants were harvested after 13 weeks Plant shoots, panicles and roots were harvested separately, washed thoroughly with running tap water and rinsed three times with double-deionized water. The plant tissues were dried in a forced air oven at 70°C for 72 h or until constant mass was achieved. Dried samples were ground in a stainless steel Wiley mill to pass a 0.5-mm sieve in preparation for chemical analysis. Subsamples of ground plant material were dry-ashed and treated with $Mg(NO_3)_2$. 6 H_2O 50% and distilled water, heated on hotplate, ashed in muffle furnace at 450°C for 6h, the ash was dissolved in 5ml of HNO_3 (1 : 1), diluted to a constant volume with distilled water and analyzed for Cu, Cd , Ni, and Pb using atomic absorption spectrometry.

D-Soil Solution Extraction:

Soil solution chemistry plays on important role in predicting the bioavailability of nutrients to plants. Therefore, the rapid centrifugation technique of Elkhatib et al.(1987) was used for soil solution extraction in soils treated with and without alum-sludge. After centrifugation, the soil solution was taken for Cu, Cd , Ni, and Pb analyses using atomic absorption spectrometry. The soil solution was used as potential indicator of plant-available heavy metals.

E- AB-DTPA extraction

The ammonium bicarbonate-DTPA extractant solution was also used as a potential indicator of plant-available cadmium, copper, nickel, and lead from soils treated with and without WTR after cultivation (Soltanpour et al., 1982).

G. Data analysis:

Statistical analyses were performed using Statistical Analysis System (SAS Institute, 1994). Heavy metals trace metal concentration data were evaluated by analysis of variance (ANOVA) and by the least significant difference (LSD) mean separation procedures at the 0.05 level of significance. Relationships between plant metal concentrations or plant uptake and AB-DTPA and soil solution extractable heavy metals were determined by Pearson correlation coefficients.

RESULTS AND DISCUSSION

Soils and Water Treatment Residuals (WTR) Characteristics

Soils

Selected properties of the soils used in the study are given in Table (1).The soils differ dramatically in their textures, $CaCO_3$ and organic matter contents. The sandy soil samples represent soil with coarse texture, low contents of $CaCO_3$ and organic matter (O.M). It is classified as (*Typic Torripsamments*). In contrast, the clay soil is (*Typic Torrifluvents*), containing approximately 3 to 10 times as much as clay and organic matter contents. The $CaCO_3$ content and the cation exchange capacity (CEC) are much higher than the sandy soil. The pH of the clay soil is 0.5 unit higher than the sandy soil. The calcareous soil is classified as (*Typic Calciorthids*). The calcium carbonate content in the calcareous soil samples is 6 times higher than that in the clay soil samples. The three studied soils contain concentration of ABDTPA -P range from low (sandy soil) to high (clay soil) .The clay soil contains approximately 2.5 and 1.5 times ABDTPA-P concentration more than that of the sandy and calcareous soils respectively.

Water Treatment Residuals

The chemical characteristics of the WTR are presented in Table (1). The WTR is slightly alkaline within the

Table 1. Selected physical and chemical characteristics of studied soils and water treatment residual (WTR)

Characteristics	Units	Clay	Sandy	Calcareous	WTR
EC*	dSm^{-1}	2.66	3.84	2.92	1.67
pH*		8.13	7.69	8.08	7.45
CaCO$_3$	%	5.79	0.24	35.68	-
Sand	%	59.64	86.82	74.00	--
Silt	%	14.13	2.51	10.15	---
Clay	%	26.23	10.67	15.85	--
Texture		S.C.L	L.S	S.L	--
O.M	%	0.85	0.10	0.46	5.70
CEC	Cmol(+)kg^{-1}	39.13	8.70	26.00	34.78
AB-DTPA-P	mg kg^{-1}	8.13	3.12	5.15	8.32
AB-DTPA- Al	mg kg^{-1}	1.03	0.13	0.08	28.18
Soil solution-P	mg kg^{-1}	1.98	0.89	1.22	0.73
Soil solution-Al	mg kg^{-1}	0.03	0.01	0.02	1.80
T-N	%	0.22	0.03	0.09	0.42
T-P	%	0.09	0.03	0.05	0.19
T-Al	gkg^{-1}	---	---	---	38.01
WHC	gkg^{-1}	259.30	93.80	166.70	470.0

SCL=sandy clay loam; LS=loamy sand; SL=sandy loam

typical range (5-8) adequate for plant growth (Bohn et al., 1985). The EC of WTR (Table1) is well below the 4 dSm^{-1} associated with the high exchange capacity of the WTR indicates its ability to supply cationic nutrients for plant growth. The organic matter content of the WTR is considerably greater than typical levels in soils of arid ecosystems. Only small amount of water soluble P (<.04% of the total P) extracted from WTR implying strong P binding by the WTR. Dayton et al. (2003) reported that low P extractability of WTR was due to the abundance of Al .However, the ABDTPA-P concentration in WTR was very similar. The water holding capacity of DWTR is high (47 %).Therefore; the DWTR could be considered a good ameliorating agent to soil properties (Skene et al., 1995). The WTR contained similar concentrations of heavy metals that are currently found in typical agriculture land (Table 2). The applied WTR has 3.0mg kg^{-1} Cd, 49.0 mg kg^{-1} Cu, 9.40mg kg^{-1} Ni, and 76.0mg kg^{-1} Pb. Copper and Ni concentrations were far below the exceptional quality (EQ) limits for pollutant concentration(USEPA,1993) .

Heavy metals concentration and uptake

The term heavy metal refers to any metallic chemical element that has a relatively high density and is toxic or poisonous at low concentration. Examples of heavy metals include cadmium (Cd), Copper (Cu), lead (Pb) and Nickel (Ni).

Cadmium(Cd)

Cadmium concentration tends to be accumulated in the following order: roots > shoots > panicles (Table3). Soil type, application rate and Soil x rate interaction significantly affected panicles, shoots and roots Cd concentration. Application of WTR at a rate of 20 g kg^{-1} significantly decreased Cd concentration in shoots, roots and panicles of wheat plants grown in all the studied soils. The greatest decreases in Cd concentration in plant parts were noticed when WTR was applied at a rate of 40 g kg^{-1} (Table 3).The uptake of Cd by plants was strongly influenced by soil, WTR application rate and soil x rote interaction. Cadmium plant uptake either was not affected by WTR application (clay soil) or significantly decreased at a WTR application rate of 40g kg^{-1} (calcareous soil). Because a 346% increase in total dry matter production of wheat(Elkhatib etal.2007) grown in sandy soils was attained with WTR application rate of 3o g kg^{-1}, a ignificant increase in Cd uptake was noticed at the same application rate (Table 3).Zhang et al.,2004 revealed that concentrations of water-soluble heavy metals were very low in wastes-amended soils ,therefore the concentration in plant tissues will be low because organic matter is an important carrier for the heavy metals. The presence of heavy metals in WTR increased metal uptake by the plants but did not affect yield (Rengasamy et al., 1980).

Lead (Pb).

Lead concentration tends to be accumulated in the order: roots > shoots > panicles . Lead concentration in shoots, roots and panicles was significantly affected by soil, application rate and soil x application rate interaction (Table 4). In general, Increasing WTR application rats to 20, 30 and 40 g kg^{-1} has resulted in significant decreases in Pb concentration in shoots, roots and panicles of the plants grown in all the studied soils lead uptake by plant was rot influenced by WTR application to calcareous and clay soils. However, in sandy soil, Pb uptake by plants significantly increased as a result of applying WTR at rates of 10 and 20 g kg^{-1}. This can be

Table 2. Concentrations of selected heavy metals in soils, and alum

Metal	Clay	Sandy	Calcareous	WTR	Maximum levels for WTR (mgkg^{-1}DW)®
Total (mgkg^{-1})					
Ni	25.01	14.00	17.02	9.40	145.00
Pb	35.08	14.00	62.20	76.00	300.00
Cu	30.22	43.21	24.06	49.00	750.00
Cd	3.30	2.10	4.50	3.00	11.00
AB-DTPA (mgkg^{-1})					
Ni	4.23	2.48	3.55	2.45	
Pb	1.85	0.27	0.79	1.38	
Cu	3.99	0.52	0.59	10.20	
Cd	0.05	0.06	0.03	0.07	
Soluble (mgl^{-1})					
Ni	0.07	0.04	0.07	0.22	
Pb	0.02	0.03	0.02	0.04	
Cu	0.22	0.16	0.18	0.17	
Cd	0.02	0.01	0.05	0.02	

® USEPA (1993)

Table 3. Cadmium concentrations and plant uptake of wheat plants grown in the three soils as influenced by WTR application rate

WTR rate	Cadmium concentration			Cd uptake
	Panicles	Shoots	Roots	
gkg^{-1}		mgkg^{-1}		µg pot^{-1}
		Clay soil		
Control	3.20	7.00	11.10	12.43
10	3.21	7.22	11.73	14.01
20	2.42	6.64	10.64	13.23
30	2.42	5.86	8.88	13.47
40	1.98	6.06	7.43	13.22
Mean	**2.64**	**6.56**	**9.96**	**13.27**
L.S.D $_{0.05}$	**0.24**	**0.34**	**0.34**	**2.85**
		Sandy soil		
Control	2.42	5.64	7.47	3.90
10	2.62	5.60	7.80	6.44
20	2.04	5.22	7.22	7.11
30	2.00	4.04	6.59	7.90
40	1.62	3.67	5.62	7.00
Mean	**2.14**	**4.83**	**6.94**	**6.47**
L.S.D $_{0.05}$	**0.14**	**0.34**	**0.23**	**1.33**
		Calcareous soil		
Control	2.69	6.64	9.66	10.89
10	2.86	6.87	9.30	12.22
20	2.56	6.15	8.46	12.51
30	2.05	5.66	6.62	11.99
40	1.63	4.42	5.83	8.70
Mean	**2.36**	**5.95**	**7.97**	**11.26**
L.S.D $_{0.05}$	**0.24**	**0.19**	**0.35**	**8.56**
Analysis of variance	F-test			
	PCC	SCC	RCC	CU
Soil	***	***	***	***
Rate	***	***	***	***
Rate x soil	***	***	***	***

*** Significant at 0.001 probability level

PCC panicles-cadmium concentration

SCC shoots cadmium concentration

RCC roots cadmium concentration

CU cadmium uptake

Table 4. Lead concentrations and plant uptake of wheat plants grown in the three soils as influenced by WTR application rate

WTR rate	Lead concentration			Lead uptake
	Panicles	Shoots	Roots	
gkg^{-1}		mgkg^{-1}		µg pot^{-1}
		Clay soil		
Control	9.08	14.50	16.67	28.64
10	8.44	15.62	18.20	31.62
20	7.23	14.63	16.43	30.97
30	5.22	12.04	14.03	27.27
40	3.23	10.64	15.76	23.20
Mean	**6.64**	**13.49**	**16.22**	**28.34**
L.S.D $_{0.05}$	**0.13**	**0.28**	**0.30**	**6.58**
		Sandy soil		
Control	4.44	6.04	10.08	2.62
10	4.06	7.23	10.63	3.53
20	3.23	6.04	9.43	3.79
30	2.22	5.23	6.66	4.73
40	1.62	3.64	5.20	6.01
Mean	**3.11**	**5.64**	**8.40**	**4.14**
L.S.D $_{0.05}$	**0.24**	**0.31**	**0.43**	**1.62**
		Calcareous soil		
Control	6.08	8.50	16.00	6.42
10	5.26	7.63	15.62	6.82
20	4.03	6.00	12.72	6.44
30	3.04	4.42	9.02	6.11
40	1.81	3.21	6.63	4.57
Mean	**4.04**	**5.95**	**11.99**	**6.07**
L.S.D $_{0.05}$	**0.27**	**0.31**	**0.39**	**2.03**
Analysis of variance	F-test			
	PLC	SLC	RLC	LU
Soil	***	***	***	***
Rate	***	***	***	***
Rate x soil	***	***	***	**

, * Significant at the 0.01 and 0.001 probability levels respectively.

PLC: panicles lead concentration

SLC: shoots lead concentration

RLC: roots lead concentration

LU: lead uptake

explained on ground of higher dry matter production due to WTR application.

Nickel (Ni)

Nickel concentration tends to be accumulated in the order: roots > shoots > panicles. Nickel concentrations in shoots, roots and panicles were significantly affected by soil. Application rate significantly affected panicles and shoots Ni concentration (Table5). Ni concentration in shoots and roots was significantly affected by soil x application rate interaction.In general, Increasing WTR application rats to 30g kg^{-1} has resulted in significant decreases in Ni concentration in panicles and shoots of the plants grown in all the studied soils. Nickel uptake by plant was not influenced by WTR application to clay. However, in sandy soil, Ni uptake by plants significantly increased as a result of applying WTR at rates of 10 and 20 g kg^{-1}.In calcareous soil, Ni uptake significantly increased as a result of applying WTR at rate 10 g kg^{-1} .This can be explained on ground of higher dry matter production due to WTR application.

Table 5. Nickel concentrations and plant uptake of wheat plants grown in the three soils as influenced by WTR application rate

WTR rate	Nickel concentration			Nickel uptake
	Panicles	Shoots	Roots	
gkg^{-1}		mgkg^{-1}		µg pot^{-1}
		Clay soil		
Control	3.60	11.50	12.00	17.18
10	3.56	11.40	12.06	18.92
20	3.18	11.48	12.20	20.21
30	2.52	10.26	13.46	20.20
40	3.28	9.44	12.68	21.18
Mean	**3.23**	**10.82**	**12.48**	**19.54**
L.S.D $_{0.05}$	**0.66**	**1.33**	**1.22**	**5.39**
		Sandy soil		
Control	2.06	4.50	9.00	3.52
10	2.30	4.36	10.02	5.75
20	2.18	4.18	10.40	7.02
30	1.84	4.00	10.32	8.29
40	2.58	5.40	8.60	10.64
Mean	**2.19**	**4.49**	**9.67**	**7.06**
L.S.D $_{0.05}$	**0.48**	**0.64**	**1.12**	**2.05**
		Calcareous soil		
Control	3.20	4.66	10.60	9.64
10	3.26	5.08	10.62	11.02
20	3.24	4.62	10.58	12.06
30	3.04	4.26	10.06	12.54
40	2.82	3.72	11.76	10.01
Mean	**3.11**	**4.47**	**10.72**	**11.05**
L.S.D $_{0.05}$	**0.93**	**0.59**	**1.30**	**2.18**
Analysis of variance		F-test		
	PNC	SNC	RNC	NU
Soil	**	***	***	***
Rate	*	**	NS	***
Rate X soil	NS	***	**	*

*,**, *** Significant at the 0.05,0.01 and 0.001 probability levels respectively. NS: not significant

PNC: panicles nickel concentration

SNC: shoots nickel concentration

RNC: roots nickel concentration

NU: nickel uptake

Table 6. Copper concentrations and plant uptake of wheat plants grown in the three soils as influenced by WTR application rate

WTR rate	Copper concentration			Cu uptake
	Panicles	Shoots	Roots	
gkg^{-1}		mgkg^{-1}		µg pot^{-1}
		Clay soil		
Control	1.22	4.50	12.45	7.37
10	1.20	4.43	12.16	8.10
20	1.00	3.46	10.05	7.27
30	0.87	2.80	8.26	6.68
40	1.22	4.18	9.85	9.61
Mean	**1.10**	**3.87**	**10.55**	**7.81**
L.S.D $_{0.05}$	**0.13**	**0.13**	**0.33**	**1.65**
		Sandy soil		
Control	1.04	3.46	7.22	2.62
10	1.06	3.37	5.50	3.53
20	0.92	2.87	4.60	3.79
30	0.90	2.80	4.61	4.73
40	1.06	3.42	6.08	6.01
Mean	**1.00**	**3.18**	**5.60**	**4.14**
L.S.D $_{0.05}$	**0.13**	**0.21**	**0.23**	**0.95**
		Calcareous soil		
Control	1.21	3.87	9.30	6.42
10	1.20	3.75	9.40	6.82
20	1.00	3.09	8.22	6.44
30	0.60	3.00	7.07	6.11
40	0.38	2.22	6.00	4.57
Mean	**0.88**	**3.19**	**7.88**	**6.07**
L.S.D $_{0.05}$	**0.08**	**0.19**	**0.21**	**1.12**
Analysis of variance		F-test		
	PCC	SCC	RCC	CU
Soil	***	***	***	***
Rate	***	***	***	***
Rate xsoil	***	***	***	***

*** Significant at 0.001 probability level.

PCC: panicles copper concentration

SCC: shoots copper concentration

RCC: roots copper concentration

CU: copper uptake

Copper (Cu)

Copper concentration tends to be accumulated in the following order: roots > shoots > panicles. Soil type, application rate and Soil x rate interaction significantly affected panicles, shoots and roots Cu concentration (Table 6). Application of WTR at a rate of 20 and 30 g kg^{-1} significantly decreased Cu concentration in shoots, roots and panicles of wheat plants grown in all the studied soils. The greatest decreases in Cu concentration in plant parts were noticed when WTR was applied at a rate of 40 g kg^{-1} in calcareous soil and a rate of 30 g kg^{-1} in clay and sandy soils (Table 6).

The Cu uptake by plants was strongly influenced by soil, WTR application rate and soil x rate interaction. Cu plant uptake either was not affected by WTR application (clay soil) or significantly decreased at a WTR application rate of 40g kg^{-1} (calcareous soil). Because a high percentage increase in total dry matter production of wheat grown in sandy soils was attained with WTR application rates(Elkhatib etal.2007), a significant increase in Cu uptake was noticed. In general Concentrations in wheat grown at even the highest WTR ate were well within the sufficiency range observed for agronomic crops (Kabata -Pendias and Pendias,1992).

Heavy Metals Extractability after Wheat Harvest

Soil solution

Heavy metals concentrations in soil solution as affected by WTR application is shown in Table(7).significant soil type and WTR rate effects were found for Pb and Cu concentrations in soil solution of the studied soils, but Cd and Ni were not significant soil type, WTR rate and soil x rate interaction. In general, increasing WTR significantly decreased Pb and Cu concentrations in soil solution at a rate of 40 g kg-1 for clay soil and rates of 30 and 40 g kg-1 for sandy and calcareous soils (Table7).Cadmium concentration in soil solution significantly decreased at rates 30 and 40 g kg-1 for sandy and calcareous soils. The general trend of heavy metals in all studied soils as influenced by WTR rates being decreasing soluble heavy metals with increasing WTR rates. The trend in declining extractability could be explained on the bases that the amended soils had higher metal adsorption capacity than the unamended soils. (Hettiarachchi et al.,2003) proposed that increasing WTR application increases the metal adsorption capacity of soil in addition to soil metal concentration; thus, metal availability at high WTR application declines as the specific metal adsorption capacity of the amended soil increases.

Table 7. Soil solution heavy metals concentrations of the three studied soils as influenced by WTR application rate

WTR rate	Soil solution			
	Cd	Ni	Pb	Cu
gkg^{-1}		$mgkg^{-1}$		
		Clay soil		
Control	0.04	0.24	0.25	0.22
10	0.04	0.22	0.26	0.23
20	0.04	0.25	0.20	0.19
30	0.02	0.21	0.11	0.13
40	0.02	0.17	0.11	0.05
Mean	**0.03**	**0.22**	**0.19**	**0.16**
L.S.D $_{0.05}$	**0.04**	**0.14**	**0.10**	**0.10**
		Sandy soil		
Control	0.02	0.33	0.13	0.08
10	0.03	0.26	0.15	0.12
20	0.01	0.22	0.15	0.10
30	0.01	0.23	0.09	0.07
40	0.03	0.22	0.04	0.03
Mean	**0.02**	**0.25**	**0.11**	**0.08**
L.S.D $_{0.05}$	**0.02**	**0.20**	**0.03**	**0.06**
		Calcareous soil		
Control	0.02	0.21	0.15	0.70
10	0.03	0.22	0.18	0.72
20	0.03	0.23	0.13	0.70
30	0.01	0.19	0.05	0.60
40	0.01	0.14	0.02	0.37
Mean	**0.02**	**0.20**	**0.11**	**0.62**
L.S.D $_{0.05}$	**0.01**	**0.12**	**0.04**	**0.27**
Analysis of variance	F-test			
	Cd	Ni	Pb	Cu
Soil	NS	NS	*	***
Rate	NS	NS	***	***
Rate X soil	NS	NS	NS	NS

*, *** Significant at the 0.05 and 0.001 probability levels respectively. NS: not significant

Combined analyses of all soils and rates of WTR application showed significant relationship between Pb concentration in soil solution and Pb uptake by plants (r=0.60 , $p < 0.001$,Fig.1A) or Pb panicles concentration (r=0.84 ,$p < 0.001$Fig.1B).There is a significant relationship between Cd concentrations in soil solution and Cd uptake (r=0.30 ,$p < 0.05$,fig.2A) or Cd panicles concentration (r=0.40 , $p < 0.01$,Fig.2C). The relationship between Cu concentration in soil solution and Cu uptake or Cu panicles was non significant. The Ni concentration in soil solution showed a non significant relationship with Ni panicles or Ni uptake.

Ammonium bicarbonate (AB)-DTPA

Heavy metals concentrations in AB-DTPA extractant as affected by WTR application is shown in Table(8). Significant soil type , WTR rate and soil X rate interaction effects were found for Pb and Cu concentrations in AB-DTPA extractant of the studied soils,but Cd was not affected and soil type affect significantly in Ni concentrations(Table8).In general,Cu and Pb concentrations were significantly decreased with increased WTR rates in calcareous soil from 1.01 to 0.28 mg.kg-1 for Cu and from 1.72 to 0.71 mg.kg-1 for Pb at the rate 40 gkg-1.There is no significant effects of WTR on the extractability of heavy metals in sandy and

Table 8. Extractable heavy metals concentrations of the three studied soils as influenced by WTR application rate

WTR rate	AB-DTPA Extractable			
	Cd	Ni	Pb	Cu
gkg^{-1}		$mgkg^{-1}$		
		Clay soil		
Control	0.06	2.67	2.98	4.86
10	0.06	2.81	2.76	4.80
20	0.05	2.68	1.82	4.21
30	0.03	2.24	1.52	3.60
40	0.06	2.18	2.22	2.51
Mean	**0.05**	**2.52**	**2.26**	**3.99**
L.S.D $_{0.05}$	**0.06**	**1.39**	**0.76**	**1.20**
		Sandy soil		
Control	0.03	2.24	0.63	0.29
10	0.04	2.27	1.00	0.30
20	0.04	2.69	0.87	0.21
30	0.02	2.19	0.65	0.18
40	0.04	2.10	0.32	0.12
Mean	**0.03**	**2.30**	**0.69**	**0.22**
L.S.D $_{0.05}$	**0.04**	**0.66**	**0.45**	**0.08**
		Calcareous soil		
Control	0.04	3.44	1.72	1.01
10	0.03	3.05	1.92	1.10
20	0.01	2.84	1.32	0.80
30	0.01	2.15	0.94	0.47
40	0.04	3.29	0.71	0.28
Mean	**0.03**	**2.95**	**1.32**	**0.73**
L.S.D $_{0.05}$	**0.04**	**1.09**	**0.49**	**0.49**
Analysis of variance	F-test			
	Cd	Ni	Pb	Cu
Soil	NS	*	***	***
Rate	NS	NS	***	***
Rate X soil	NS	NS	**	***

*, **, *** Significant at the 0.05, 0.01 and 0.001 probability levels respectively. NS: not significant

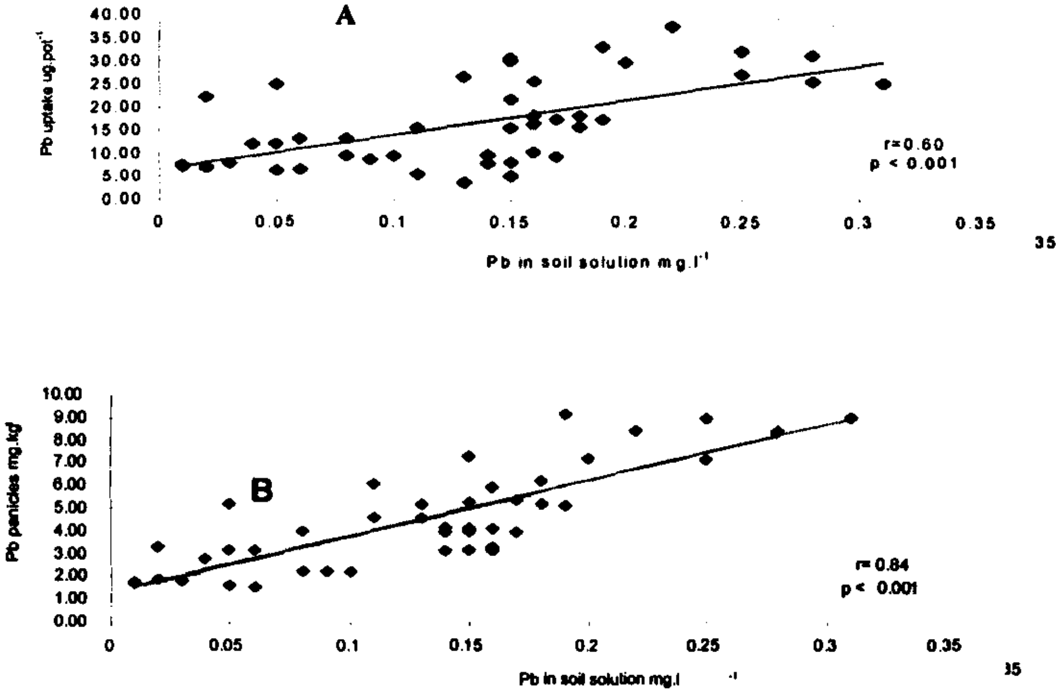

Fig. 1.a. Relationship between Pb in soil solution and Pb uptake (A) or panicles Pb (B) of wheat plants grown in WTR-treated soils.

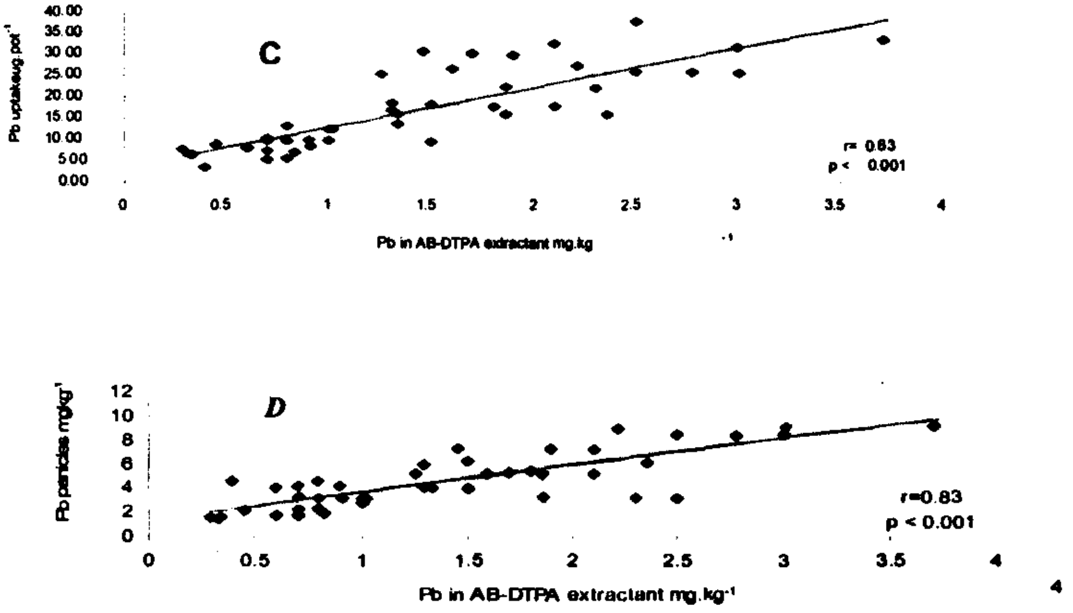

Fig. 1.b. Relationship between Pb in AB-DTPA extractant and Pb uptake (C) or panicles Pb (D) of wheat plants grown in WTR-treated soils.

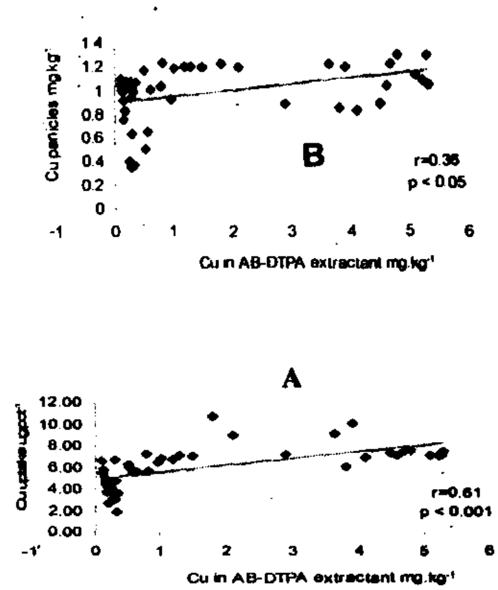

Figure 2. Relationship between Cu in AB-DTPA extract and Cu uptake(A) or Panicles Cu (B) of wheat grown in WTR-treated soils.

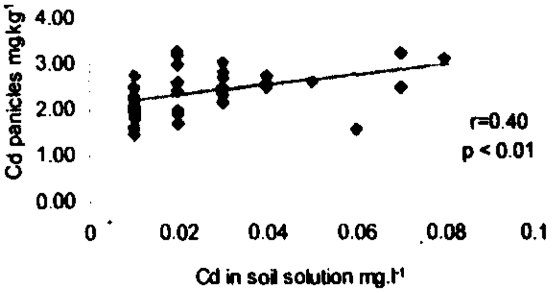

Figure 3. Relationship between Cd in soil solution and Panicles Cd of wheat grown in WTR-treated soils.

clay soils. The observed uptake patterns may be a result of the adsorptive inorganic components (Fe and Al oxy-hydroxide minerals) added to soils with the WTR

(Hettiarachchi etal.,2003). It is crucial to understand the long-term effects that application of WTR has on metal availability.

Combined analyses of all soils and rates of WTR application showed significant relationships with Pb panicles ($r = 0.83$, $P < 0.001$, Fig.1D) or Pb uptake ($r = 0.83$, $p < 0.001$, fig.1B). .On the other hand significant relationships between AB-DTPA extractable Cu and Cu uptake ($r = 0.61$, $p < 0.001$, fig.2A) or Cu panicles concentration ($r = 0.36$, $p < 0.05$ fig.2B) were found. Extractable Ni concentrations showed a non significant relationship with Ni panicles or Ni uptake. Cadmium concentration in soil solution showed a significant relationship with Cd panicles (Fig.3).

REFERENCES

Bloom.P.R.. Weave.R.Mr and Mcbride.M.B.(1978). The spectrophotometric and flurometric determination of aluminum with 8-hydroxyquinoline and butyl acetate extraction.Soil Sci.Soc.Am.J.42:712-716.

Bohn, H.L., Mc Neal, B.L; and O'Connor, G.A.P.(1985). Soil Chemistry 2nd Ed. Wiley, New York.

Day, P.R. (1965). particle fraction and particle size analysis Pp: 545-566.InA.C.Black, D.D. Evans, L.E.Ensminger, J.L.White, and F.E.Clark.(eds)methods of soil analysis. Part I. American Society of .Agronomy, Madison, Wisconsin, USA.

Dayton,E.A., and N.T. Basta.(2001). Characterization of drinking water treatment residuals for use as a soil substitute.Water Environ.Res. 73:52-57.

Dayton,E.A., N.T. Basta, C.A. Jakober, and J.A.Hattey(2003). Using treatment residuals to reduce phosphorus in agricultural runoff .J.Am.Water Works Assoc.95(4): 151-157

Elkhatib,E.A.,J.L.Hern, and T.S.Staley(1987).A rapid centrifugation method for obtaining soil solution. Soil Sci.Soc.Am.J.51:578-583.

Elkhatib,E.A., and A.M.Mahdy. (2007). Land Application of Water Treatment Residuals: Effect on Wheat Yield and the Availability of Phosphorus and Aluminum. International J.Environ Waste Management (in press).

Elliott, H.A., B.A. Dempsey, and P.J. Maille.(1990). Content and fractionation of heavy metals in water treatment sludges. J. Environ. Qual. 19:330–334

Heil, D.N. and Barbarick, K.A.(1989).water treatment sludge influence on the growth of sorgum-sudangrass.J.Environ.Qual.18:292-298.

Hettiarachchi, G.M., J.A. Ryan, R.L. Chaney, and C.M. La Fleur. 2003. Sorption and desorption of cadmium by different fractions of biosolids-amended soils. J. Environ. Qual. 32:1684–1693.

Ippolito, J.A., Barbarick, K.A. and Rendte, E.F. (1999). Co-Application of water treatment residuals and biosolids on two range grasses. J. Environ. Qual. 28:1644-1650.

Kabata-Pendias.A.. and H. Pendias.(1992).trace element in soils and plants.2nd Edition.CRC Press.Baton Rouge.Fa.

Nelson, D.W., and Sommers, L.E.(1982). Total Carbon, Organic Carbon and Organic Matter. Pp.539-549.In

A.L.Page, R.H.Miller, and D.R. Keeney (eds). Methods of Soil Analysis. American Society Of Agronomy. Madison, Wisconsin, USA

Nelson, R.E.(1982). Carbonate and Gypsum. 181-197. In A.L. Page R.H Miller, and D.R. Keeney (eds). Methods of soil analysis. American Society of Agronomy, Madison, Wisconsin, USA.

.Pietz, R.I., C.R. Carlson, J.R. Peterson, D.R. Zenz, and C. Lue-Hing. 1998.Application of sewage sludge and other amendments to coal refuse material: III. Effect on chemical composition. J. Environ. Qual. 18:174–179.

Rhoades, J.D. (1982). Cation exchange capacity Pp.149-157. In A.L.Page, R.H.Miller, and D.R. Keeney (Eds). Methods of soil analysis. American Society of Agronomy, Madison, Wisconsin, USA.

Richards,L.A.(1954).Diagnosis and improvement of saline and alkaline soils.USDA.Handbook 60.US Government Printing Office.Washington,D.C.

Rengasamy, P., Oades, J.M. and Hancock, T.W.(1980) Improvement of Soil Structure and Plant Growth by Addition of Alum Sludge. Commun. Soil Sci. Plant Anal. 11:533-545.

Ross,G.J.,and Wang,C.(1993).Acid ammonium oxalate method.In M.R.Carter (ed) Soil sampling and methods of analysis.Lewis Pub.,Ann Arbor,MI.

SAS Institute.(1994).SAS/STAT User's guide. Version 6.4th ed.SAS Inst., Cary, N.C.

Sims. J.T. and Luka-Mc-Cafferty, N.J. (2002). On farm evaluation of aluminum sulphate (alum) as a poultry litter amendment: effect on litter properties. J. Environ. Qual. 31:2066-2073.

Skene, T.M., Oades, J.M., and Kilmore, G. (1995). water treatment sludge: a potential plant growth medium. Soil Use and Management 11:29-33.

Soltanpour,P.N.,J.B. Jones Jr., and S.M. Workman(.1982.) P.55-57.Optical emission spectrometry. In A.L. Page et al.(ed.) Methods of soil analysis. Part 2.Chemical and biological properties.2nd ed.ASA and SSSA, Madison,WI.

U.S. Environmental Protection Agency. 1993. Standards for the use and disposal of sewage sludge. 40CFR, Part 503. Fed. Regist. 58:9248–9415.

Viraraghavan, T., and M. Ionescu.(2002). Land application of phosphorus-laden sludge: A feasibility analysis. J. Environ. Manage. 64:171–177

الملخص العربي

إضافة مخلفات معلجة مياه الشرب إلي الأراضي: التأثير علي صلاحية العناصر الثقيلة

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أعرب بعض البحاث عن تحفظهم علي إضافة مخلفات معالجة مياه الشرب (الشبة) إلي الأراضي الزراعية تخوفا من زيادة تركيز العناصر الثقيلة في التربة وبالتالي زيادة إمتصاصها بواسطة النبات خاصة في ظل عدم الفهم الكامل لمصير وتحولات العناصر الثقيلة في الأراضي المناطق الجافة. ولذلك تم إجراء هذا البحث لتقييم تأثير إضافة معدلات متزايدة من الشبة علي تركيز وصلاحية بعض العناصر الثقيلة (النحاس – النيكل – الرصاص – اكادمبوم) في أراضي ممثلة للمناطق الجافة. وفي هذه التجربة تم أستخدام خمس معدلات من الشبة (صفر، ١٠، ٢٠، ٣٠، ٤٠جم /كجم أرض) وإضافتهم إلي ثلاث أنواع من الأراضي (رملية- طنية- جيرية) وزراعة نبات القمح في تجربة صوبة زراعية. أيضا تم إستخلاص العناصر الثقيلة الصالحة من الأراضي باستخدام طريقتي المحلول الأراضي، مستخلص AB-DTPA ولقد أوضحت النتائج عدم وجود أي تأثير صار لمعدلات إضافة الشبة علي نمو النبات وكذلك علي تركيز النحاس والكادميوم والرصاص والنيكل في النبات. وعلي العكس تماما فلقد أظهرت النتائج إنخفاض تركيز هذه العناصر في النباتات النامية في الأراضي المضاف إليها الشبة مقارنة بالكنترول أيضا أظهرت النتائج وجود علاقة معنوية قوية بين تركيزات النحاس والرصاص والكادميوم في النبات وتركيز هذه العناصر في مستخلص AB-DTPA، المحلول الأراضي كما أظهرت النتائج عدم وجود علاقة إرتباط قوية بين تركيزات النيكل في النبات وتركيزات النيكل في كلا من المحلول الأراضي ومستخلص AB-DTPA