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Research article

Interrelationships of metal transfer factor under wastewater reuse and soil pollution

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A B S T R A C T

The transfer of heavy metals under soil pollution wastewater reuse was studied in a Greenhouse experiment using a randomized block design, including 6 treatments of heavy metals mixtures composed of Zn, Mn, Cd, Co, Cu, Cr, Ni, and Pb, where each metal was taking part in the mixture with 0, 10, 20, 30, 40, 50 mg/kg respectively, in four replications. The *Beta vulgaris* L (beet) was used as a test plant.

It was found that the metal transfer factors were statistically significantly related to the: (i) DTPA extractable soil metals, (ii) the soil pollution level as assessed by the pollution indices, (iii) the soil pH, (iv) the beet dry matter yield and (v) the interactions between the heavy metals in the soil. It was concluded that the Transfer Factor is subjected to multifactor effects and its real nature is complex, and there is a strong need for further study for the understanding of its role in metal-plant relationships.

1. Instruction

With the rapid economic development, water shortage has become an important factor and the social development. However, the shortage of well irrigation water faced in many regions of the world, necessitated the use of municipal wastewater for the irrigation of crops, including the vegetables, and this reuse has become a common practice in urban and peri-urban ecosystems of many countries, (Chang et al., 2014).

The application of treated wastewater for agricultural purposes has been evaluated as the most convenient recycling option for environmental and economic reasons, in spite of the fact that the treated wastewater apart from the plant nutrients and organic matter which are extremely useful components for plant growth, the waster also contains variable levels of heavy metals, which at high concentrations may be very toxic.

Plants have a natural ability to extract elements from soil and to translocate them between roots, shoot, and fruits. Studies have shown that long-term irrigation with wastewater considerably increased the contents of toxic heavy metals in soils (Singh et al., 2004).

The transfer of metals from soil to plant root may be evaluated by means of the transfer factor (TF) (Cui et al., 2004), which under wastewater reuse may be subjected to changes under soil pollution due to the effect of various factors of soil.

The accumulation of heavy metals in plants has been studied in relation to the transfer factor (TF) from soils to plants (Klocke et al., 1984). The TF quantifies the metal bioavailability differences and is an indicator of the extent of metal mobility (Kachenco and Singh, 2006). In fact, the TF is considered by some workers as the key parameter of the heavy metal accumulation in plants (Nan et al., 2002; Puschenreiter and Horak, 2000; Dudka et al., 1996). The process of metal transfer from soil to plants, according to Nan et al. (2002) is very important, because it is the main pathway of human exposure to soil contamination under condition of soil heavy metal accumulation.

In view of the significance of metal TF, there have been some limited efforts to study some of the important factors affecting the function of TF in relation to translocation of metals from soil to plants, with the view to shed more light into the metal accumulation in plants. In this respect, Kalavrouziotis et al. (2012a) stresses that one basic factor is the level of the metals in soil, and any factor that effects this level, such as: plant uptake, metal fixation, metal leaching etc may affect the TF indirectly. Streit and Stumm (1993), support that the kind of heavy metals is also another factor that

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Table 1
Physical and chemical characteristics of the experimental soil.

S %	C %	Si %	pH	EC mS/cm	OM %	$CaCO_3$%	VW g/cm^3
56	12	32	6.17	0.206	2.11	0.00	1.48
Cd mg/kg	Co mg/kg	Cr mg/kg	Ni mg/kg	Pb mg/kg	N-NO_3 mg/kg	P mg/kg	-
0.042	0.424	0.026	2.777	0.856	25	6	–
K mg/kg	Mg mg/kg	Ca mg/kg	Fe mg/kg	Zn mg/kg	Mn mg/kg	Cu mg/kg	B mg/kg
75	260	>2000	20.09	2.32	33.58	88.55	0.25

S-sand, C=Clay, Si = silt, EC = electrical conductivity, OM-organic matter, VW- volume weight.

affects the TF. The temperature seems to also affect the level of the TF according to Antoniadis and Alloway (2001). The soil reaction (pH) is also one important factor which affects the TF (Kachenco and Singh, 2006). Another factor which plays some role in the TF is the organic matter (Antoniadis and Alloway, 2001; McBridge, 1995). Furthermore, according to Klocke et al. (1984), plant species is related to the TF.

Unfortunately, the existing information regarding the factors affecting the TF under conditions of wastewater reuse and soil pollution with heavy metals, is very limited.

The aim of the present work is to investigate the effect on the TF under the enrichment of soil with heavy metals and wastewater reuse for the irrigation of the vegetable *Beta vulgraris* L. by studying the following factors: (i)- level of soil heavy metals, and (ii)-soil reaction. (iii)-Also the relation of TF to soil pollution indices, and (iv)- the relation to the soil heavy metal interactions.

The ultimate purpose of the research conducted is to evaluate the significance of TF, with the view to shed more light for the further understanding of its role in the heavy metal accumulation in *Beta vulgaris* L (garden beet) plants, and generally in plants.

2. Materials and methods

The transfer of heavy metals from polluted soil, enriched with a mixture of metals, to *Beta vulgaris* L. roots was assessed by studying Transfer Factor (TF). Transfer Factor is defined as the ratio of plant dry matter metal concentration (Mpc) to the concentration of the same metal in soil (Mpc) (Cui et al., 2004).

$$TF = (Mpc)/(Mpc)$$

The experimental soil which was used for the present study, was collected from the top layer (0–30 cm depth) of a non cultivated agricultural area of Elias Prefecture. The soil was a light textured sandy loam (SL), suitable for the growth of root crop, as is the beet. It was slightly acid, with low electrical conductivity, and medium content in organic matter, and of course lacking completely $CaCO_3$ due to its acid pH, with a volume weight compatible with its particle size composition (1.48 g/cm^3). Its heavy metal composition was very low. The soil's physical and chemical characteristics are reported in Table 1.

2.1. Preparation of the pots

A quantity of soil was collected and transferred into the experimental site. It was sieved by means of a plastic 3 mm sieve. A quantity of 10.5 kg of this soil with a moisture content 5% was transferred in each plastic pot of rectangular shape with dimensions 50 × 20 × 16 cm (length x width x depth), corresponding to 10 kg of dry soil. Each treatment (T1, T2, …, T6) was composed of a mixture of heavy metals i.e. Zn, Mn, Cd, Cu, Co, Cr, Ni and Pb. in the form of chemical compounds $ZnSO_4$ $7H_2O$, $MnSO_4$ H_2O, $CuSO_4$ $5H_2O$, $Na_2Cr_2O_7$ $2H_2O$, $Co(NO_3)_2$ $6H_2O$, $Ni(NO_3)_2{\cdot}6H_2O$, $Cd(NO_3)_2$ $4H_2O$, Pb $(NO_3)_2$), the concentration of each metal being 0, 10, 20, 30, 40 and 50 mg per kg soil for$_2$the six treatments, respectively. The bottom of the pots was closed, so that there was no loss of metals due to leaching. Each of the above mixtures was replicated 4 times being applied in each of the four pots, respectively. After the preparation of 24 pots according to the above procedure, the sowing took place. The test plant used was the garden beet (*Beta vulgaris,* L). The plants were irrigated with treated municipal wastewater. The irrigation was applied regularly according to the soil field capacity (FC) as well as to percent wilting point (PWP). The FC of the light SL experimental soil was 18% and the PWP 8% (Saxton and Rawls, 2006). The total volume of treated wastewater added to each pot during the period of plant growth was 47 L per pot.

2.2. Chemical analyses

2.2.1. Soil analysis

The soil samples, which were taken from the pots during the mid period of plant growth, were dried at 70 °C under ventilation for 48 h and they were then analyzed by means of internationally-accepted classical methods, as follows: soil mechanical analysis by Bouyoucos (1951) modified by Gee and Bauder (1986) and Gee and Or (2002). Organic matter by the wet digestion procedure of Walkley and Black (1934); $CaCO_3$ by the method of Bernard, pH by

Table 2
Mean concentration of soil heavy metals determined at the period of the beet harvesting (N = 24 and each value is average of 4 samples).

Treatments	Heavy metals in soil (mg kg^{-1})															
	Zn		Mn		Cu		Cd		Co		Cr		Ni		Pb	
	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
T1	4.05	0.85	82.16	9.10	95.92	11.85	0.93	0.50	0.70	0.25	0.04	0.01	2.70	0.62	2.09	0.57
T2	10.01	1.53	72.41	12.89	114.76	16.24	10.22	1.94	2.98	0.5	0.10	0.06	11.09	2.30	8.27	1.70
T3	17.51	3.50	61.30	11.14	131.03	17.70	20.51	3.39	4.80	0.90	0.20	0.09	18.98	3.73	15.99	2.95
T4	20.72	2.37	55.92	3.45	122.75	12.53	23.43	2.39	7.48	0.55	0.41	0.02	21.84	2.61	18.44	2.64
T5	30.68	6.88	69.69	15.36	139.22	26.46	37.92	6.65	15.53	3.92	1.32	0.38	32.86	6.16	28.99	4.20
T6	39.73	6.57	84.40	17.30	152.16	21.20	47.08	7.44	22.41	2.42	3.08	0.57	39.13	5.11	39.89	6.28

SD = standard deviation.