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EFFECTS OF SLUDGE ON THE METALS LEVELS OF VARIOUS EDIBLE CROPS GROWN IN THE FIELD

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ABSTRACT

A field experiment was conducted to determine the uptake of metals by six vegetables crops i.e., lettuce (*Lactuca sativa*), chard (*Beta vulgaris* L.), carrots (*Daucus carota* L.), radish (*Raphanus sativus* L.), pepper (*Capsicum annum*) and tomato (*Solanum lycoperscum*) grown on soil amended with urban sewage sludge under semi-arid climatic condition of Tunisia. Sludge was applied at four rates, i.e., 0, 20, 40 and 60 t DM per ha. Selected crops were grown in randomized plots. Two successive crops were conducted preceded by sludge application. Results showed that Metal content in edible plant parts was different according to the species. For cadmium, the mean content decrease with the following order tomato > chard > radish > pepper > lettuce = carrots. However, lettuce had the highest zinc contents. Differences are also observed according to the plant organ. For example, most of heavy metals were more concentrated in the vegetative parts of fruiting crops than in fruit tissue except for Cd in tomato fruit. Sewage sludge applications modified the content of Cd, Co, Fe, Pb and Zn in plant tissues. Cd and Zn contents were always increased in all selected plants. Cobalt and lead were increased in the edible parts of vegetative and fruiting tissues but they weren't affected in edible root. The iron evolution was variable according to crops. Sewage sludge additions didn't affect copper and manganese contents.

Keywords: edible crops, metals, sewage sludge.

1. INTRODUCTION

The wastewater treatment has been expanded greatly in Tunisia with the construction of many new wastewater treatment plants and the consequent production of larger quantity of sewage sludge. These large quantities raise the problem of treatment and disposal. The use of sludge in agriculture and horticulture is one of the most popular disposal options as it allows the recycling of plant nutrients. However, potentially toxic elements and pathogenic agents represent a potential risk to human health. Phytotoxic effect of the trace metals included in sludge was appeared on vegetables grown on soil amended with sewage sludge during long term tests occurred in England (Juste *et al.*, 1995). The metals availability has often been assessed by methods of soil extraction using different reagents (Lebourg *et al.*, 1996) but the plant uptake is the best measure of metal availability because it related all factors on relation with (Juste, 1988). Moreover, plant uptake of metals represents a direct pathway for contamination of human food chain when sludge is added (Chaney, 1990 and Jamali *et al.*, 2008).

Many studies (Sommers, 1977; Colin, 1979; Alexandre *et al.*, 1979; Catroux *et al.*, 1981; Davis *et al.*, 1982; USEPA, 1983; L'hermite, 1991; Metcalf and Eddy, 1991; Juste *et al.*, 1995 and N.R.C, 1996) have looked at the sludge characterization and their agricultural use. In Tunisia, researches on the effects of sludge amendment on soil and the uptake of metals by plants have been initiated (Bahri, 1987; 1995a and 1995b; Bahri *et al.*, 1997; Rejeb, 1990; Rejeb and Bahri, 1995; Rejeb *et al.*, 2003) and request to determine the best uses for sewage sludge. Previous investigations have essentially limited to forage and industrial crops. Recently, Interest was to study vegetables and market gardening feasibility on soils amended by sludge.

The purpose of this study was to determine the sludge effects on the metal uptake and accumulation in tissues of six garden crops representing different classes of edible organs, leaves (lettuce and chard), roots (radish and carrot) or fruits (peppers and tomato).

2. MATERIALS AND METHODS

2.1 Experimental practice

The field experiment was located in the experimental farm of Oued Souhil (INRGREF) in North-Eastern Tunisia (to about 60 kms of Tunis). This area is characterized by semi-arid climatic conditions. The study was conducted on sandy-loam soil developed on alluvial deposits with a pH of 7.5 and a low organic matter. The purpose of the experiment was to determine the effects of increasing rates of sludge on the yield and on the minor elements content of plants. The crops used were: lettuce (*Lactuca sativa*), chard (*Beta vulgaris* L.), carrots (*Daucus carota* L.), radish (*Raphanus sativus* L.), pepper (*Capsicum annum*) and tomato (*Solanum lycoperscum*). Each specie was grown on a separate set of plot. Sludge was applied at four rates i.e., 0, 20, 40 and 60 t DM per ha on 50 m² plots before the seedling. Every treatment was replicated five times in a randomized block design. Two successive crops were conducted preceded by sludge application. At maturity the crops were harvested. Crops were irrigated with water of well situated on the parcel with negligible content of microelements.

2.2. Chemical sludge characteristics

Sludge was collected at the SE1 Hammemet treatment plant. Sludge was an aerobically digested sludge dehydrated on drying beds. Amounts of element added to soil as sludge are presented in the Table-1.

Table-1. Characteristics of sewage sludge: N and C (in %DM) and total metal concentrations (in mg kg^{-1} DM except Fe expressed in g kg^{-1} DM).

			% DM			**mg kg^{-1} DM**						
Parameters	**% DM**	**pH**	**C**	**N**	**C/N**	**Cd**	**Co**	**Cu**	**Fe** 0/00	**Mn**	**Pb**	**Zn**
content	47%	6.7	36,8	3,09	11,9	5	17,7	212	9,4	108	449	510

DM: Dry matter

This sludge is rich in carbon, nitrogen and total phosphorus. The C/N ratio is about 12 indicating an appropriate stabilization. The pH is about 6.7. The electrical conductivity is about 7 i.e., a high salinity contents. Sludge is fairly charged in magnesium and poor in sodium and potassium. Total microelement contents are raised fairly but lower to the European and American norms. Iron, zinc and copper are more represented comparatively to the other elements.

2.3. Analysis and measure

Different parts of the plant were analyzed for Cd, Cu, Fe, Mn, Ni, Pb and Zn by flame atomic absorption spectrophotometry after nitro - perchloric acid digestion for sludge, the analyzed parameters are : pH (NF T90-008 (1:2 :sludge / water)), electrical conductivity (CE) (NF T 90-0301 (1/5 : sludge / water at 25°C), volatile matter (MV at 450°C), organic carbon (Anne method), Kjeldahl nitrogen (NF T 90-110), trace elements (diacid liberalization (HF-$HClO_4$) and determined by atomic absorption spectrophotometry (Perkin Elmer 2380).

Variance analysis was used as statistical methods with level of significance of 95%.

The concentration ratio «CR» according to Cottenie *et al*., 1983 is expressed by:

$$CR = \frac{\text{Element content in plants of amended parcels}}{\text{Element content in control plants}}$$

It measures the uptake pattern for each element and can warn and detect the risk of contamination of the food chains.

The ratios (Zn/Cu) and (Cd/Zn) were measured in plant and sludge. Relative contents were used to assess the distribution of metals in different organs (root was used as unity reference).

3. RESULTS AND DISCUSSIONS

3.1. Distribution of metals in different parts of plant

The distribution of metals in different organs was presented in Figure-1.

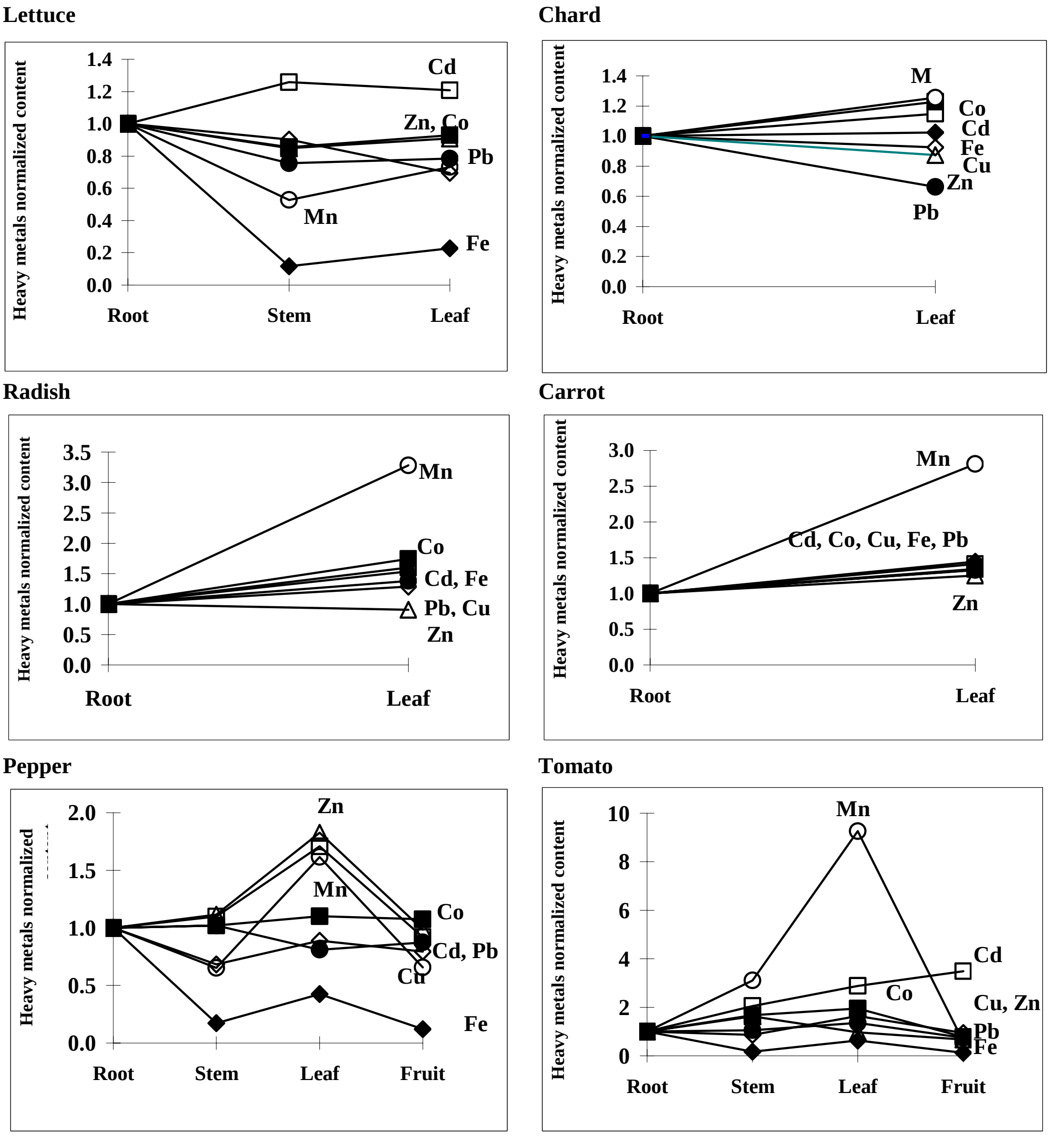

Figure-1. Distribution of trace elements according to species organs in lettuce, chard, radish, carrot, pepper and tomato.

Copper, iron, manganese and lead were more concentrated in roots than in the other organs of lettuce. However, cobalt and zinc were rather distributed between leaves and roots. Only the cadmium migrated significantly in stems and leaves. The same sequence gotten was found for lettuce grown on a clay loam soil (Bahri *et al*., 1997). In Swiss chard, most trace elements (cobalt, copper, manganese, iron and zinc) were homogeneously concentrated in the different parts of plant, with the exception of lead, which was more concentrated in the roots. In carrot and radish, all heavy metals (Cd, Co, Cu, Fe, Pb and Zn) are equally distributed in the upper part and roots except for manganese which was higher in leaves. Copper, cobalt and lead were uniformly concentrated in the different organs of pepper. While cadmium, manganese and zinc concentrations were higher in leaves and decreased significantly in the other parts of plant. Iron levels decreased in the following order: roots, leaves, stems and fruits. In tomato, the lowest amounts of trace elements were recorded in fruits except for Cd which increased in the following order: roots, stems and fruits. This could be related to the large mobility of Cd (Juste and Solda, 1977; Bjerre and Scherup, 1985). However, according to Hemphill *et al*., (1982) and Djebali (2005), a large amount of Cd is retained by the roots which constitute a barrier to barricade the transfer of the contaminant to the upper part of plant.

3.2. Effect of sludge on heavy metals content in edible organs of crops

Sludge application increased cadmium and zinc contents in the upper part of lettuce (Table-2) with very high “CR” notably at a rate of 120 t/ha. During Swiss chard cultivation, the sludge affected significantly these elements in leaves (Table-2) during the two fields but not systematically to all cuts. Increases were important until

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70% for Cd and about for Zn comparatively to control plants.

Table-2. Total analysis for selected elements of edible vegetative tissue (Swiss chard and lettuce).

Metal contents (in mg kg^{-1} DM)														
Swiss chard leaves (1st sludge application - 1st cut)														
Sludge applied	**Cd**	**CR**	**Co**	**CR**	**Cu**	**CR**	**Fe**	**CR**	**Mn**	**CR**	**Pb**	**CR**	**Zn**	**CR**
0	1.27		2.10		12.0		459.0		38.4		27.9		36.7	
40	1.92	1.51	2.19	1.04	13.8	1.15	446.0	0.97	34.8	0.91	24.3	0.87	38.8	1.06
80	1.81	1.43	2.25	1.07	14.4	1.20	446.2	0.97	35.6	0.93	27.2	0.97	45.0	1.23
120	2.17	1.71	2.60	1.24	15.6	1.30	585.0	1.27	36.0	0.94	33.7	1.21	46.0	1.25
Swiss chard leaves (1st sludge application - 2nd cut)														
0	2.75		2.50		10.5		297.0		35.2		16.9		31.3	
40	3.00	1.09	2.25	0.90	10.9	1.04	382.0	1.28	23.4	0.67	17.3	1.02	34.0	1.09
80	3.25	1.18	2.50	1.00	11.3	1.08	378.0	1.27	23.4	0.67	16.4	0.97	40.0	1.28
120	3.75	1.36	2.33	0.93	12.9	1.22	437.0	1.47	27.6	0.78	21.8	1.29	37.5	1.20
Swiss chard leaves (1st sludge application - 3rd cut)														
0	2.75		1.90		8.25		155.0		17.5		10.8		30.0	
40	3.35	1.22	1.95	1.03	8.15	0.99	243.0	1.57	18.3	1.04	13.0	1.26	32.0	1.07
80	3.05	1.11	2.05	1.08	7.81	0.95	254.0	1.64	20.8	1.19	19.1	1.76	30.0	1.00
120	3.30	1.20	2.90	1.53	9.25	1.12	250.0	1.61	22.9	1.31	17.9	1.65	30.0	1.00
Swiss chard leaves (2nd sludge application -1st cut)														
0	1.55		2.05		5.70		411.0		26.9		21.1		31.0	
40	1.25	0.81	2.20	1.07	5.60	0.97	459.0	1.12	29.0	1.08	21.4	1.02	35.6	1.15
80	1.50	0.97	2.00	0.98	6.30	1.11	462.0	1.12	25.2	0.94	21.2	1.01	35.0	1.13
120	1.75	1.13	2.50	1.22	6.80	1.19	456.0	1.11	23.5	0.88	19.4	0.92	49.0	1.58
Swiss chard leaves (2nd sludge application - 2nd cut)														
0	1.30		2.05		6.10		360.0		31.1		6.30		31.3	
40	1.65	1.27	3.15	1.54	5.80	0.95	417.0	1.16	28.0	0.90	13.0	2.08	33.1	1.06
80	1.35	1.04	2.75	1.34	6.90	1.13	391.3	1.09	23.4	0.75	14.4	2.31	52.0	1.66
120	1.20	0.92	3.20	1.56	8.10	1.33	404.0	1.12	26.2	0.84	10.6	1.69	68.5	2.19
Lettuce leaves (2nd sludge application)														
0	0.90		0.95		8.75		395.0		24.6		7.00		84.0	
40	0.80	0.89	1.60	1.68	10.50	1.20	344.0	0.87	28.6	1.16	7.65	1.09	152.0	1.81
80	0.85	0.94	1.75	1.84	10.35	1.18	2.47.0	0.63	23.9	0.97	6.40	0.91	129.0	1.54
120	1.70	1.89	3.80	4.00	10.40	1.19	295.0	0.75	29.4	1.19	8.70	1.24	102.0	1.21
Lettuce stems (2nd sludge application)														
0	1.55		2.70		15.8		143.0		20.8		12.0		90.0	
40	1.60	1.03	2.50	0.93	13.2	0.83	139.0	0.97	20.5	0.99	14.4	1.20	88.0	0.98
80	2.31	1.49	2.60	0.96	13.1	0.83	119.0	0.83	19.7	0.95	17.4	1.45	99.0	1.10
120	2.20	1.42	2.05	0.76	14.3	0.91	145.0	1.01	21.6	1.04	17.6	1.47	158.0	1.76

CR: Concentration ratio

Cadmium and zinc contents progressively increased in roots of radish (Table-3) with the level of sludge application especially during the first crop and in pepper fruits (Table-4) mainly during the second cultivation. For pepper, the concentration ratios (CR) exceed the value 2 for Cd. Cadmium concentrations of carrot roots and tomato fruits were raised (Table-4). The percentage increase over control was about 30 to 40%.

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Table-3. Total analysis for selected elements of edible roots (Carrot and Radish).

Metal contents (in mg kg^{-1} DM)														
Sludge applied	**Cd**	**CR**	**Co**	**CR**	**Cu**	**CR**	**Fe**	**CR**	**Mn**	**CR**	**Pb**	**CR**	**Zn**	**CR**
t/ha	**Carrot roots** (2nd sludge application)													
0	0.95		1.50		8.20		631		15.9		11.3		35.0	
40	0.90	0.95	1.75	1.17	8.45	1.03	673	1.07	17.5	1.10	13.0	1.16	36.8	1.05
80	1.35	1.42	1.90	1.27	8.65	1.05	613	0.97	17.2	1.09	11.5	1.02	42.0	1.20
120	1.25	1.32	1.65	1.10	8.50	1.04	649	1.03	17.3	1.09	11.5	1.02	38.8	1.11
Radish roots (1st sludge application)														
0	2.69		2.33		8.00		381.0		21.50		10.4		58.5	
40	2.70	1.00	2.25	0.97	8.25	1.03	424.0	1.11	20.00	0.93	11.1	1.07	80.6	1.38
80	2.65	0.99	2.10	0.90	9.00	1.13	482.0	1.27	22.50	1.05	11.1	1.07	85.0	1.45
120	4.31	1.60	1.75	0.64	10.44	1.30	553.1	1.45	24.38	1.13	9.50	0.92	100.0	1.71
Radish roots (2nd sludge application)														
0	1.25		2.00		12.00		455.0		30.0		9.5		45.0	
40	1.25	1.00	2.25	1.13	9.50	0.79	387.5	0.85	30.0	1.00	9.0	0.95	75.0	1.67
80	1.25	1.00	2.75	1.38	12.00	1.00	465.0	1.02	30.0	1.00	11.0	1.16	100	2.22
120	2.00	1.60	2.75	1.38	13.00	1.08	457.5	1.01	22.5	0.75	12.0	1.26	92.5	2.06

CR: Concentration ratio

Table-4. Total analysis for selected elements of edible fruits (Pepper and tomato).

Metal contents (in mg kg^{-1} DM)														
	Cd	**CR**	**Co**	**CR**	**Cu**	**CR**	**Fe**	**CR**	**Mn**	**CR**	**Pb**	**CR**	**Zn**	**CR**
Tomato fruits (1st sludge application)														
0	4.00		1.00		15.4		96.0		10.8		9.67		30.3	
40	5,45	1.36	1.25	1.25	16.5	1.07	109.0	1.14	12.8	1.18	8.15	0.84	33.9	1.12
80	4,25	1.06	1.25	1.25	15.6	1.01	108.0	1.13	11.2	1.04	7.33	0.76	33.9	1.12
120	5,20	1.30	1.35	1.35	14.1	0.92	120.0	1.25	11.0	1.02	8.75	0.91	34.8	1.15
Pepper fruit (1st sludge application)														
0	1.56		1.60		10.3		107.0		9.20		14.7		35.4	
40	1.58	1.01	1.83	1.15	10.2	0.99	105.0	0.98	10.0	1.09	16.4	1.12	39.3	1.11
80	1.50	0.96	2.08	1.30	10.3	1.00	105.0	0.98	10.1	1.10	15.0	1.02	37.9	1.07
120	1.50	0.96	2.05	1.28	10.4	1.01	101.3	0.95	9.25	1.01	16.5	1.13	38.8	1.09
Pepper fruit (2nd sludge application)														
	Cd	CR	Co	CR	Cu	CR	Fe	CR	Mn	CR	Pb	CR	Zn	CR
0	0.35		4.40		10.7		108.0		7.70		3.19		38.1	
40	0.65	1.86	4.50	1.02	10.6	1.00	107.5	1.00	9.65	1.25	9.06	2.84	45.1	1.18
80	0.85	2.43	4.70	1.07	10.3	0.97	138.0	1.28	9.38	1.22	13.8	4.31	46.6	1.22
120	0.80	2.29	4.94	1.12	10.7	1.00	122.5	1.13	8.00	1.04	14.0	4.39	48.8	1.28

CR: Concentration ratio

Some researches indicated also that Cd and Zn in plant tissues increase with sludge application (Hinesly *et al*., 1979; Chang *et al*., 1982 and Lutrick *et al*., 1982; Morel, 1985; Frost and Ketchum, 2000; Zaier, 2006). Zn accumulation can affect seeds when sludge is rich in metals (Juste and Solda, 1977 and Sims and Kiline, 1991). The cadmium is also absorbed and easily transferred to the aerial parts of the plants when sludge is added (Juste and Solda, 1977; 1980 Morel *et al*., 1988). According to some studies (Chang *et al*., 1982 and Sheaffer *et al*., 1979), increases in Cd and Zn plant contents are related to the sludge rates. This was not always the case and sludge could have no effect on the cadmium and zinc content (Berthet *et al*., 1984 and Mellbye *et al*., 1982).

The rapid transfer of cadmium and zinc from soil amended with sludge to plant is ascribed to the high mobility of these elements (Juste and Solda, 1977; Morel, 1985 and Morel *et al*., 1988). Morel *et al*., (1985) suggest that Cd and Zn offer a relatively low affinity for the root mucilage. Hence, their retention in the rhizosphere is moderate in relation to the other metals.

Cobalt accumulations occurred in edible parts of lettuce, Swiss chard (50%) and tomato (30%) treated with sewage sludge.

Sludge significantly raised lead in the upper parts of lettuce, Swiss chard and pepper. Pepper fruits accumulated 4 times more lead on the 120 t/ha treatment than on the control. It is remarkable to note that edible root don't show increases in the cobalt and lead contents. However, lead is known to be retained in the root system (Jarvis and Jones, 1976; Berthet *et al*., 1984 and Morel, 1985).

The iron modification has been varied between species. The Fe content of lettuce decreased and concentration ratio are lower than 1. This result is similar to that found by several authors (Juste and Solda, 1986; Morel, 1985 and Morel *et al*., 1988) and decreases are often associated with the Fe/Zn antagonism. Whereas Fe content in Swiss chard and radish rose with applications of sludge. Increases may have been due to the very high content in sludge. The other edible crops data show no significantly effect.

At harvesting, copper and manganese didn't accumulate in the edible crops in this study with sludge application which may be a result of immobilization of remaining metal by organic matter.

Several researches showed that sludge application could increase the metal soil content and might cause on the long term an excessive accumulation incompatible with the necessary safety for crops (Adler, 2001). So, heavy metal contamination in soil could represent several hazards for environment and man. But, most study indicates that metal sludge contents are relatively low compared with the other agricultural fertilizers. They also found that metal contents were significantly lower in plants on soils with high pH (Peles *et al*., 1998 and Jamali *et al*., 2007). This is very important to reduce potential health risk of sludge application on agricultural land.

3.3. Relative means metal concentrations in edible parts of crops

Metal contents of different edible organ have been compared in Table-5. Pepper fruit used arbitrarily as a unity reference.

Table-5. Relative means metal concentrations in edible parts of crops. pepper fruit used arbitrarily as a unity reference.

	Pepper	Tomato	Lettuce	Chard	Radish	Carrot
Cd	1	4,59	0,69	3,99	1,33	0,65
Co	1	0,39	0,62	0,71	0,68	0,51
Cu	1	1,85	0,98	0,87	0,96	0,79
Fe	1	0,90	2,53	3,26	3,82	5,44
Mn	1	1,41	2,72	2,87	2,64	1,78
Pb	1	0,69	0,59	1,32	0,74	0,83
Zn	1	1,14	2,84	0,94	1,95	0,94

Results reveal a net difference between the amounts of metals accumulated in the crops. The mean Cd concentration ratios ranged from a low of 0, 6 for lettuce and carrot root to a high of 4 for tomatoes and Swiss chard. Our carrot and tomato results were in contrast to the data noted by Wolnik *et al*., 1985 but, they agree with those of tomato annotated by Dowdy and Larson, 1975 and BAZZAZ in **I**.N.R.A .-S.C.P.A.R.P., 1979. The lowest cadmium accumulation in lettuce disagrees with the most reports. As pointed out by (Garcia *et al*., 1981Gomez and Juste, 1982; Jackson and Alloway, 1991; Garate *et al*., 1993 and Tonneau, 2003), lettuce generally accumulated high concentrations of cadmium and could reflect metal levels in soil.

The highest Co and Cu concentrations were found respectively in pepper and tomato fruits. Fruit of tomato and pepper had the lowest iron concentrations. The other species concentrate it at high levels about two times more in lettuce, three times more in the Swiss chard, four times in the radish and five times in the carrot. The Mn concentration ratios for lettuce, Swiss chard and radish were about 3 times higher than pepper. The highest lead concentrations were found in Swiss chard followed by pepper. For Zn, lettuce and radish concentrations were respectively 3 and 2 times higher than other crops. Tonneau (2003), found the same result for lettuce.

3.4. Zn/Cu and Cd/Zn ratios of selected edible crops

Since important interest of ratios of Zn to Cu and Cd to Zn in plant tissue for a human health, assessment of Zn/Cu and Cd/Zn ratios has been done in edible parts of crops (Table-6). Zinc is known to have a marked protective effect on cadmium toxicity (Keith Furr *et al*., 1976). The cadmium metabolism seems to be related to the relative contribution of Zn, Cu and Fe (Lebaq, 1986).

Table-6. Zn/Cu and Cd/Zn ratios of selected edible crops.

	Loading sludge t/ha	Edible parts					
		Pepper	Tomato	Lettuce	Chard	Radish	Carrot
Zn/Cu	0	3.35	2.16	8.91	3.77	5.17	4.27
	40	3.72	2.26	9.27	3.92	8.77	4.33
	80	3.92	2.49	11.66	4.32	8.80	4.82
	120	4.21	2.40	14.06	4.39	8.21	4.56
Cd/Zn	0	0.039	0.164	0.012	0.129	0.038	0.027
	40	0.047	0.163	0.009	0.230	0.025	0.025
	80	0.042	0.154	0.009	0.140	0.021	0.032
	120	0.039	0.194	0.012	0.200	0.033	0.032

Cd/Zn and Zn/Cu ratios were respectively 0.010 and 2.4 in applied sludge. According to some authors, sewage sludge with a low Cd/Zn ratio can reduce the transfer of Cd in food chains.

The highest Zn/Cu ratios were found in lettuce with a value exceeding 10%. The data show that radish had also high ratios in order of 8. These high ratios were attributed to the high zinc concentration and no to low copper level. Tomatoes had the lowest ratios “2”. This was a result of high contents of copper. Zn/Cu ratios were about 3.5 in Pepper and Swiss chard and about 5 in carrot. Zn/Cu ratios increased with added sludge especially in lettuce and radish.

The Cd/Zn ratios range from 0.01 in lettuce leaves to about 0.17 in Swiss chard leaves and tomato fruits. These high ratios in tomatoes and Swiss chard resulted from very high Cd concentrations rather than from low Zn content. Dowdy and Larson (1975) noted also a high Cd/Zn ratios in tomatoes but they attributed it to low zinc contents and no to excessive cadmium concentrations. The Cd/Zn ratios were similar in radish and Swiss chard. Ratios of Cd/Zn in selected edible crops exceed those of sludge (0.010) except for lettuce.

4. CONCLUSIONS

Metal contents of the selected edible crops were affected differently by sludge applications. Many factors including especially the nature of element and the spicy could determine this variability. Metal content in edible plant parts collected on control plots was different according to the species. For cadmium, the mean content varied from 0.25 to 5.5 $mgkg^{-1}$ dry matter, and decrease with the following order tomato > chard>radish>pepper>lettuce=carrots. However, lettuce had the highest zinc contents. Sharp differences are also observed according to the plant organ. For lettuce, only the cadmium was accumulated in leaves more than in roots whereas for Swiss chard, this element was evenly distributed. For edible root crops, distribution didn’t differ for roots and leaves. For fruit vegetables, all trace elements were clearly less in fruits of pepper or tomato except for cadmium which migrated in tomato fruits with high amounts.

Applications of sewage sludge modified the content in Cd, Co, Cu, Fe and Zn in all plant tissues. Cd and Zn increased significantly with added sludge. Increases in cadmium reached 5.5 mg kg^{-1} DW in tomato. Whereas, the iron evolution was variable and sometimes contradictory.

From one crop to another and for a given crop, from one harvest to another, a large range of variation was observed in metal plant content for all elements and all selected species. However, metal contents in the all edible tissues are below tolerable limits. The use of sludge for vegetable production may induce increases in concentration of metals, either essential or not in plant tissues and especially in the edible parts. Nevertheless, loading rates used in this field experiment were higher than applied by farmers. Further, this experiment which was conducted under natural conditions and with regular farming practices, showed a wide rang of variation due to sludge application, much lower than that observed between two following harvests or crops. Hence, risk of contamination of legumes by metals following sludge application should be rather low. Nevertheless, soil quality should be frequently controlled, and sludge quality should be constantly improved to ensure the quality of legumes on the long-term.

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