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ORIGINAL PAPER

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HEAVY METAL ACCUMULATION IN VARIOUS TISSUES OF RADISH (*Raphanus sativus*) GROWN UNDER DIFFERENT RATIOS OF ORGANIC AMENDMENTS

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ABSTRACT

Root vegetables have greater risk of metal contamination from compost application to soil than other horticultural crops. Moreover, soil organic amendments pose potential environmental hazards. The objective of the present study was to examine the heavy metal uptake in different tissues (petiole, blade, skin, pulp) of *Raphanus sativus* exposed to organic amendments doses. The impact of the above materials on heavy metal concentration of the soil and plant development parameters were also evaluated. A pot experiment was established with eight treatments arranged in a randomized complete block design and four replicates. Co-compost of sewage sludge and olive wastes at 100, 200, 300 m^3 ha^{-1}, composted olive leaves, olive tree pruning wastes, olive mill pomace and poultry manure at 100, 200 m^3 ha^{-1}, commercial liquid organic fertilizer at 50 Kg ha^{-1} with or without inorganic NPK fertilization and a no fertilizing control, were applied to plants. The results showed that sewage sludge application strongly increased the yield and improved radish size cultivated in silt loam soil. The edible radish part had the lowest Fe, Mn, Cu, Zn, and Cr content, whereas the highest Mn, Cu, Zn, Cr was found in the blade and increased Fe, Ni, Pb were recorded in the skin. Organic treatments gave higher Fe, Mn, Cu, Zn amount in both aerial plant tissues compared to the control soil, while Ni, Pb, Cr of all the radish parts were not affected by treatments. This study suggested that organic amendments application gave low permissible levels of all metal content in radish tissues and increased radish productivity. Therefore, organic materials used herein can be applied for normal plant growth without metal contamination of the plant and the soil.

Key words: soil, compost, sewage sludge, heavy metals, yield, plant tissues

INTRODUCTION

Pollution of the soil environment by heavy metals has become a global problem [Tóth et al. 2016]. Heavy metals are toxic even at low concentration due to their cumulative nature. They can be absorbed by plants and may be transferred *via* food chain to humans and livestock [Fytianos et al. 2001]. Excessive amount of metals reduces the soil quality and productivity, inhibits many enzymes and thus, they are able to disrupt metabolic processes in plants [Alloway 2013]. Heavy metals are non-biodegradable and can be very persistent in the environment; therefore, there is high risk of food contamination, they can pose serious threats to human health and to the ecosystems [D'Mello 2003]. Metals can be present in contaminated soil, water, in pesticides and in various organic amendments. They can be taken up directly by plant root system and then accumulated in the tissues. In recent years, it is a common practice to use sewage sludge and various compost mixtures to improve fertility of the soil and increase the plant growth and yields [Haghighi et

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al. 2016, Naiji and Souri 2018, Sönmez et al. 2017]. Moreover, the application of such amendments could decrease the dependence on chemical fertilizers, providing significant advantages. Another benefit of them is the reduction of the environmental pollution by using this alternative way for their disposal. Despite the aforementioned advantages, the major constraint in a land application of both sludge and composts is the contamination of soil with heavy metals and organic pollutants that may have adverse effects on crop plants [Gu et al. 2012]. For that reason, the European countries follow certain thresholds on the concentration of heavy metals present in sewage sludge that is used in agriculture [Witter 1996]. Measurement of heavy metals in organic amendment is important prior to their application to agricultural land, because there is a risk of toxic element accumulation in the soil [Mishra and Tripathi 2008].

Many studies investigated the effect of sewage sludge and manure composts application on several crops such as corn [Grotto et al. 2015], cucumber [Waqas et al. 2014], cabbage, broccoli [Antonious et al. 2012] and spinach [Turkmen et al. 2004]. However, different soils, plants and composition of organic materials used in each case gave various results without a general conclusion, the accumulation of heavy metals can be more problematic in the case of root vegetables such as *R. sativus.*

R. sativus, is an edible root vegetable that is grown and consumed throughout the world as a crunchy salad vegetable. Radishes are a good source of phytochemicals such as phenols, flavonoids and vitamin C [Kim et al. 2014]. Other chemical constituents that are present in *R. sativus* include alkaloids, nitrogen compounds, coumarins, enzymes, fatty acids, organic acids, phenols, pigments, polysaccharides, sulfur compounds, phytoalexins, β-carotene.

So far, there is limited information relative to the effect of different organic amendments on the concentration of heavy metals in various parts of vegetables. Such information is important in order to understand the effect of heavy metals in the normal development and in the accumulation of these metals, especially in edible parts of plants.

Therefore, the objectives of this investigation were to assess the effect of three organic amendments applied in different rates, on the concentration of various elements (Ca, Mg, P, K, Fe, Mn, Cu, Zn, Ni, Pb, Cr) in different plant tissues (petiole, blade, skin, pulp) of *R. sativus*. The impact of the above materials on heavy metal concentrations of the soil was also examined as well as the plant development parameters.

MATERIAL AND METHODS

Experimental design. A greenhouse pot experiment was established at the Department of Agriculture, Technological Educational Institute of Crete between May and July 2016 with an average minimum and maximum air temperatures during this period 14 and 32°C, respectively. Three radish seeds (*R. sativus* cv. 'Red hazera') were sown to each of 7 L plastic pot, arranged in a randomized complete block design with 8 treatments and 4 replicates. The experimental treatments consisted of three organic amendments at different applications rates; detailed information on them is provided below. Each plot consisted of 6 pots (derived as 4 replications/treatment × 6 pots/replication for each treatment), which were kept 50 cm apart. The distance between the plots was 80 cm and the replicates were 100 cm from one another. The soil used in this study was silt loam and had the characteristics shown in Table 1. Tap water was periodically added to maintain soil field capacity. Standard cultivation practices were used, while Methiocarb (200 g L^{-1}) and Cyromazine (0.5 g L^{-1}) were applied in order to control insects of *Thrips* and *Liriomyza* genus, respectively.

Organic materials. Soil amendments were: 1) co-compost of sewage sludge and olive wastes (CSO) at ratio 1 : 2.2; it was produced by composting the sewage sludge resulting from an anaerobic digestion treatment and agricultural by-products, specifically branches and twigs pruned from olive trees; this mixture was kept in piles approximately 3 m high, which was regularly turned and watered over a 6-month period to ensure appropriate composting conditions (turned windrow system), 2) composted olive leaves, olive tree pruning wastes, olive mill pomace and poultry manure (CLOMP) at ratio 1 : 1 : 0.16 : 0.16, and 3) commercial liquid organic fertilizer (CF). The composts were carefully mixed with the soil in a proportion allowing an amendment equivalent to 100, 200, 300 m^3 ha^{-1} for CSO and 100, 200 m^3 ha^{-1} for CLOMP. CF was applied at 50 kg ha^{-1}, following the recommendations of the supplier, with or without standard inorganic fertilization of 200 mg kg^{-1} N, 50 mg kg^{-1} P and 400 mg kg^{-1} K. Control treatment consisted of the soil without organic amendments. Chemical analyses of the above materials are described in Table 2.

Table 1. Physicochemical characteristics of soil used in the present study

Sand (%)	27.60
Silt (%)	70.00
Clay (%)	2.40
Total $CaCO_3$ (%)	34.44
Organic matter (%)	1.94
pH	8.02
E.C. (S m^{-1})	4.38
K (mg kg^{-1})	175.8
P (mg kg^{-1})	42.05
NO_3-N (mg kg^{-1})	109.95
Fe (mg kg^{-1})	2.10
Mn (mg kg^{-1})	5.59
Zn (mg kg^{-1})	0.85
Cu (mg kg^{-1})	3.56
B (mg kg^{-1})	0.42

Soil and plant analyses. The innermost mature leaf in the whorl was sampled from the radish plants by selecting one leaf per pot and thus six leaves were taken from each plot and then merged to compose a mixed sample. The soil sampling was conducted by taking cores from each pot with the aid of a soil core sampler. Each sample (one sample per plot) consisted of mixed soil cores. The radish fruits were collected and weighted.

The following parameters were assessed: macronutrients and micronutrient concentration in soil and plants tissues (petioles, blades, fruit skin, fruit skin together with pulp and fruit pulp), fresh weight (FW) and dry weight (DW) of the plant aerial parts, total radish weight, mean weight of radish and dry weight percentage of plant aerial parts. All individual plant parts were washed twice with distilled water, dried in an oven at 75°C for 48 h and then ground to a fine powder. In order to determine the dry weight, the samples were then oven dried at 105°C for 24 h in an air-forced drying oven. Macro-, micro-nutrients and heavy metal content was measured after wet digestion with HNO_3, H_2SO_4, $HClO_4$ by atomic absorption spectroscopy (Perkin-Elmer 2100) using standard methods. Emission technique was used for potassium (K) determination, while phosphorus (P) concentration was measured by the vanado-molybdo-phosphate yellow color method [Page et al. 1982].

Statistical data analysis. Data were subjected to analysis of variance (ANOVA). Comparison of treatments means were determined according to Duncan's Multiple Range test at the P = 0.05 level.

RESULTS AND DISCUSSION

Heavy metal concentration of different organic amendments. In all cases of organic material, Fe had the highest, while Pb had the lowest concentration (Tab. 2). By comparison of all organic amendments with the soil, we concluded that CSO and CLOMP were about 1000-fold more concentrated in Fe than the control soil. Zn concentration in CLOMP was about 500 times higher than in the soil. The commercial fertilizer (CF) had the lowest concentration of heavy metals compared to the other two organic materials. The CLOMP material had the highest concentration of almost all metals. More specifically, CLOMP that was used in the present study, contained 162.75, 488.84, 42.15, 32.69, 18.30 mg kg^{-1} of Cu, Zn, Cr, Ni, Pb, respectively (Tab. 2). All of these heavy metals were below the permissible limits of land application of sewage sludge recommended by the Council of the European Communities (1986) (1000 mg kg^{-1} for Cu, 2500 mg kg^{-1} for Zn, 750 mg kg^{-1} for Cr, 300 mg kg^{-1} for Ni, 750 mg kg^{-1} for Pb). The low concentration of heavy metals even in CLOMP sewage sludge indicates that there is low possibility of plant toxicity due to the accumulation of heavy metals in the soil [McGrath et al. 2000]. Moreover, according to the results obtained at the end of the experiment, all the substrates that were used contained heavy metals at low concentrations (Tab. 5).

Table 2. Element analyses of the amendments used in this study

Materials	Ca	Mg	K	Fe	Mn	Cu	Zn	Cr	Ni	Pb
	% DW			mg kg^{-1} DW						
CSO	0.79	0.21	0.94	1588	72.72	20.15	46.02	34.4	20.07	0.99
CLOMP	0.55	0.30	0.74	1928	69.96	162.75	488.84	42.15	32.69	18.30
CF	0.06	0.03	2.43	58.30	0.19	0.31	10.28	0.14	0.35	0.08

Table 3. Effect of materials application on growth parameters of radish

Materials	Amendment dose m^3 ha^{-1}	Above ground fresh weight g plot^{-1}	Above ground dry weight g plot^{-1}	Leaf dry weight %	Radish weight g plot^{-1}	Mean weight of radish g
CSO	100	1507ab	169a	11.30a	687bcd	38.17bcd
	200	1569ab	147ab	9.41c	789ab	43.81ab
	300	1648a	169a	10.29abc	909a	50.48a
CLOMP	100	1517ab	142ab	9.44c	748bc	41.57bc
	200	1305b	119bc	9.49c	664bcd	36.88bcd
CF	0.05	895c	98c	11.15ab	594cd	33.00cd
CF + NPK		1326ab	137abc	10.53abc	573d	31.81d
Soil	0	1408ab	135abc	9.74bc	630bcd	35.01bcd

Values within a column with the same letters are not significantly different ($P < 0.05$)

Table 4. Mean values of element concentration in various substrates

Materials	Amendment dose m^3 ha^{-1}	% DW		mg kg^{-1} DW						
		Ca	Mg	K	Fe	Mn	Cu	Zn	Ni	Cr
CSO	100	2637a	268a	11ab	0.61ab	5.91a	1.28a	0.8ab	0.83a	0.46a
	200	2682a	273a	11ab	1.08a	5.7a	1.13ab	0.8ab	0.36a	0.32a
	300	2728a	262a	12ab	0.41ab	5.76a	1.18ab	0.8a	0.59a	0.36a
CLOMP	100	2612a	246a	13a	0.15b	5.46a	0.98abc	0.7ab	0.46a	0.41a
	200	2710a	254a	11ab	0.29b	5.63a	1.31a	0.6b	0.69a	0.69a
CF	0.05	2732a	272a	10b	0.05b	5.77a	0.48bc	0.6ab	0.39a	0.90a
CF + NPK		2726a	259a	11ab	0.46ab	5.76a	0.39c	0.6ab	0.55a	0.43a
Soil	0	2675a	270a	10ab	0.67ab	5.98a	0.47bc	0.6ab	0.58a	0.53a

CSO – co-compost of sewage sludge and olive wastes; CLOMP – composted olive leaves, olive tree pruning wastes, olive mill pomace and poultry manure
Values within a column with the same letters are not significantly different ($P < 0.05$)

Effect of various amendments on growth parameters of radish. The effects of organic materials on growth parameters of radish are presented in Table 3. The above ground fresh weight of radish was statistically significantly lower compared to other treatments with the use of CF. This was also apparent for the dry weight of above ground plant part, although statistical significant differences were clearly observed only when compared with CSO treatments. Concerning the percentage of radish leaf dry weight, no significant differences were observed.

Neither the CSO and CLOMP type nor their application rates significantly affected the growth parameters of radish (Tab. 3) as reported by Rathod et al. [2011]. The only exception to the above was CSO 300 that gave the highest yield as well as the biggest radish and was significantly different from other materials and the control. The results also revealed significant differences in the yield (both radish weight and mean weight of radish) between the two highest dose of sewage sludge and the commercial material used with or without inorganic fertilizer. Relative to CLOMP, observed increased trend to yield with regard to both treatments with CF and control although significant differences, was not evident. All the above indicated that mainly sludge, but also compost, can success fully replace inorganic fertilizer needs, that is in line with the research conducted by Samaras et al. [2008] concerning cotton.

In addition, CF + NPK fertilizer gave higher biomass than CF alone (Tab. 4) and it did not increase the heavy metal accumulation in soil (Tab. 5) and in edible part of radish, except from Cu concentration (Tab. 6). CF also resulted in the lowest values in all growth parameters, although statistically significant differences were found only for fresh weight of radish leaves compared with the other treatments. Similar results were obtained for lettuce [Zhao et al. 2012].

Effect of materials on soil heavy metal content. The source and the rate of the organic materials used in the present study did not greatly altered the element content in the substrates over the experimental period (Tab. 4). These outcomes are in accordance with those recorded by Rathod et al. [2011] concerning radish grown in a sandy loam soil. Soil K tend to increase in treatments with organic amendments compared to control but with no significant differences as noticed by Belhaj et al. [2016]. Cu was the only metal that showed the lowest statistically significant concentration in both soil [Belhaj et al. 2016] and CF treatments. The concentrations of all the studied metals were noticeably below threshold values [MEF 2007]. Macro and micro nutrients were not influenced by the source and the rate of all treated materials as reported in a case of a limed mine soil [Rossini-Oliva et al. 2017]. This result was probably due to many factors such as degradability of organic matter, soil type and pH. In the current experiment the alkaline soil pH (pH = 8) possibly prevented the availability of metals [Belhaj et al. 2016].

Heavy metal concentration in various radish tissues. The concentration of various heavy metals was measured in different radish tissues grown in different organic amendments (Tabs. 5 and 6). All heavy metal concentrations in radish tissues were in the normal rate [Jones et al. 1991] and were less than the phytotoxic levels stated by Kabata-Pendias [2011]. This can be

Table 5. Mean values of element concentration in various radish tissues

Plant tissue	% DW				mg kg^{-1} DW						
	Ca	Mg	P	K	Fe	Mn	Cu	Zn	Ni	Pb	Cr
Petiole	1.35a	0.28b	0.3d	3.62e	148bc	24c	10c	58b	11c	19d	13c
Blade	1.42a	0.37a	0.53c	4.24d	173b	112a	17a	64a	33b	43c	35a
Skin	0.79b	0.25c	0.5c	6.3b	416a	28b	13b	48c	42a	52ab	29b
Skin + pulp	0.70b	0.25bc	0.93a	6.9a	196b	13d	10c	63a	44a	56a	26b
Pulp	0.55c	0.21d	0.6b	4.56c	109c	11d	10c	38d	42a	48b	20c

Values within a column with the same letters are not significantly different ($P < 0.05$)

Table 6. Mean element concentration in various radish tissues

	Amendment dose $m^3 ha^{-1}$	(% DW)				(mg kg^{-1} DW)						
		Ca	Mg	P	K	Fe	Mn	Cu	Zn	Ni	Pb	Cr
Petiole												
Soil	0	1.226a	0.240a	0.303a	4.058ab	59f	23.9b	7.9bc	54.1a	14.03ab	23.68ab	4.31bc
CSO	100	1.235a	0.267a	0.303a	3.499bc	229b	24.4b	15.4a	55.3a	5.89d	26.34a	2.30bc
	200	1.347a	0.257a	0.325a	3.638abc	53f	24.7b	11.8ab	59.6a	8.57cd	21.20bc	3.07bc
	300	1.451a	0.325a	0.305a	3.724abc	280a	18.7c	12.8ab	58.7a	11.32bc	15.92d	5.33bc
CLOMP	100	1.501a	0.259a	0.284a	4.177a	162cd	31.3a	10.6ab	58.7a	5.12d	14.02d	10.61a
	200	1.258a	0.248a	0.270a	3.336c	124de	28.1ab	10.3ab	57.1a	10.64bc	15.27d	6.82b
CF	0.05	1.532a	0.348a	0.273a	3.344c	174c	18.6c	9.3abc	63.8a	16.47a	15.36d	4.81bc
CF + NPK		1.258a	0.279a	0.307a	3.155c	101ef	25.2b	3.1c	59.2a	16.36a	17.97cd	0.96c
Blade												
Soil	0	1.323ab	0.336b	0.527ab	4.252c	163bc	99.7c	11.9cd	55.4a	38.54a	45.63ab	24.93bc
CSO	100	1.506ab	0.358b	0.579a	4.528b	169abc	110.6abc	11.9cd	66.1a	35.33a	41.95abc	22.22c
	200	1.449ab	0.515a	0.584a	4.185c	169abc	91.6c	10.9d	67.9a	32.86a	33.50c	20.33c
	300	1.282b	0.323b	0.550a	4.247c	140c	131.6a	17.4b	61.6a	32.86a	40.01bc	23.56bc
CLOMP	100	1.506ab	0.353b	0.480bc	3.897d	188ab	127.4ab	21.9a	67.2a	34.35a	45.59ab	22.88bc
	200	1.516a	0.352b	0.487bc	5.184a	183ab	131.2a	21.3a	64.8a	31.79a	50.18a	33.79a
CF	0.05	1.464ab	0.354b	0.446c	3.752d	199a	97.7c	15.9bc	65.7a	30.15a	43.66ab	33.39a
CF + NPK		1.278b	0.338b	0.585a	3.909d	174ab	103.0bc	23.1a	65.3a	38.26a	36.85bc	29.86ab
Skin												
Soil	0	0.775a	0.245abc	0.474abc	5.910bc	371a	26.9bc	15.3a	46.9b	39.73a	51.78ab	24.57c
CSO	100	0.841a	0.277ab	0.445c	6.554a	460a	26.2bc	12.8abc	50.0ab	39.91a	48.17ab	31.29a
	200	0.782a	0.242abc	0.450bc	6.554a	384a	24.1cd	15.6a	53.4a	43.26a	56.42a	26.10bc
	300	0.730a	0.206c	0.559a	6.556a	425a	20.1d	11.8c	44.6b	37.87a	42.44b	29.32abc
CLOMP	100	0.797a	0.222bc	0.537ab	6.280ab	491a	35.1a	12.2bc	44.8b	46.81a	50.67ab	31.05a
	200	0.806a	0.238abc	0.523abc	6.486a	398a	35.9a	11.2c	50.6ab	44.24a	57.95a	31.13a
CF	0.05	0.762a	0.238abc	0.496abc	5.736c	414a	30.3b	15.0ab	44.4b	43.76a	57.44a	26.32abc
CF + NPK		0.813a	0.291a	0.502abc	6.337ab	386a	29.0bc	12.8abc	49.7ab	39.17a	55.49a	30.75ab
Skin + pulp												
Soil	0	0.721a	0.263a	0.896a	6.766a	336a	8.1c	9.8abcd	62.1c	45.44ab	63.63a	24.11a
CSO	100	0.719a	0.252a	0.998a	6.637ab	210bc	12.4b	9.0bcd	70.5ab	50.11a	51.31a	22.97a
	200	0.722a	0.239a	0.962a	7.032a	171cd	12.2b	8.6cd	71.5a	46.01ab	50.29a	22.89a
	300	0.687a	0.233a	0.920a	6.908a	225b	9.2c	11.3a	63.8bc	48.37ab	57.92a	26.31a
CLOMP	100	0.681a	0.249a	0.978a	7.736a	152d	18.3a	9.6abcd	60.5c	49.20ab	60.52a	28.24a
	200	0.720a	0.267a	0.947a	7.745a	184bcd	14.3b	11.0ab	61.8c	39.21b	59.86a	24.61a
CF	0.05	0.667a	0.246a	0.848a	5.541b	148d	14.3b	10.7abc	57.4c	40.82ab	56.35a	23.23a
CF + NPK		0.715a	0.272a	0.863a	6.839a	145d	13.6b	8.4d	58.2c	44.15ab	56.79a	27.60a
Pulp												
Soil	0	0.572a	0.217a	0.628ab	4.609ab	161a	10.8abcd	7.5c	39.3a	45.70a	55.08a	18.65a
CSO	100	0.516b	0.202a	0.522c	4.416ab	93b	10.5bcd	8.0c	39.2a	37.96a	32.77d	18.03a
	200	0.553ab	0.218a	0.617ab	5.224a	90b	9.5cd	7.1c	37.5a	39.04a	45.96abc	18.52a
	300	0.545ab	0.215a	0.562bc	3.980b	132a	11.9abc	9.3bc	35.3a	37.59a	53.66ab	19.70a
CLOMP	100	0.546ab	0.210a	0.581bc	4.280ab	156a	11.8abc	11.2b	37.2a	45.27a	56.47a	19.51a
	200	0.553ab	0.212a	0.579bc	4.532ab	80b	8.9d	14.2a	43.0a	45.33a	39.93cd	19.57a
CF	0.05	0.536ab	0.209a	0.608ab	4.193ab	86b	12.9ab	9.3bc	39.4a	40.52a	52.29ab	21.67a
CF + NPK		0.579a	0.223a	0.671a	5.262a	71b	13.3a	14.6a	36.8a	45.97a	44.0bc	21.78a

CSO – co-compost of sewage sludge and olive wastes; CLOMP – composted olive leaves, olive tree pruning wastes, olive mill pomace and poultry manure

Values within a column with the same letters are not significantly different ($P < 0.05$)

explained by the low heavy metals concentration in all amendments used. The macro and micro elements showed statistically significant differences among the radish tissues. More specifically, significantly lowest concentration of Ca and Mg was found in the pulp part of radish and the highest in the blade. The highest concentrations of P and K were observed in the skin and pulp and the lowest in petiole (Tab. 5). Fe, Mn, Cu, Zn, and Cr showed the lowest concentration in the pulp. Fe and Mn content in the edible part of radish were statistically significant after increasing doses of sewage sludge application as reported Tamoutsidis et al. [2002].

Statistically significant concentration of Fe, Ni, Pb was found in the skin of the radish, while Mn, Cu, Zn and Cr had the highest concentration in the blade part of the plant compared with the underground plant part (Tabs. 5 and 6). Similar results reported for Cr in radish by Bhat et al. [2011]. The distribution of metals in different plant tissues depends on their form, water transport and plant species [Ouzounidou et al. 1995] therefore, it is difficult to export a general conclusion. In this study, most elemental concentrations were higher in the skin and skin + pulp of radish (Tab. 5). This may be attributed to the fact that the skin and the pulp are the first target parts of the plant that come in contact with heavy metals in the rhizosphere [Punz and Sieghardt 1993]. Moreover, a study that was conducted in plants grown in sewage sludge compared to a reference site found that most of the heavy metal concentration was higher in the root compared to other plant tissues [Eid and Shaltout 2016].

Results of the present study showed no clear trend or effect on micro and macroelements concentration in radish blade as well as in petiole in treatments with organic materials compared to the soil. These findings are in accordance with those of a recent research [Rossini-Oliva et al. 2017], where leaf metals content showed to be diminished or not affected for ryegrass, reduced for tomato and not clearly defined for ahipa. As the above researchers showed, the heavy metals accumulation depends on the plant species as well as the applied amendments.

Concentrations of Fe, Mn, Cu, Zn in petiole and blade of radish had lower values in the control soil than those in the organic materials tested but without definite differences as showed by other authors relative to radish and crops from other families [Belhaj et al. 2016, Golui et al. 2014, Singh and Kumar 2014]. In all the above metal content in radish tissues, but mainly for Fe, there was observed a reduction to their concentration value as the sewage sludge was increased with a sharp increase with the high dose applied. The rest plant Ni, Pb, Cr contents in all the parts measured remained relative influenced by the rates of organic amendments. These no clear results could possibly be explained by the potential antagonism between these metals for uptake by plants and the decreased solubility of metals due to soil alkaline pH hence the corresponding unaffected soil metal content and subsequently plant metal impact [Singh and Kumar 2014]. Moreover, Golui et al. [2014] reported that sewage sludge application in alkaline soils was not so effective to elevate the metals content in spinach.

Table 7. Translocation factor (TF = C_{aerial}/C_{root}) calculated for *Raphanus sativus*

Amendment dose m^3 ha^{-1}		Fe	Mn	Cu	Zn	Ni	Pb	Cr
Soil		0.38	4.05	0.91	1.11	0.60	0.61	0.65
CSO	100	0.78	4.12	1.37	1.14	0.48	0.77	0.51
	200	0.52	3.81	1.09	1.18	0.48	0.54	0.52
	300	0.81	5.47	1.40	1.26	0.54	0.54	0.58
CLOMP	100	0.66	3.65	1.48	1.33	0.42	0.53	1.02
	200	0.70	4.04	1.30	1.18	0.49	0.62	0.81
CF	0.05	0.86	3.03	1.08	1.38	0.56	0.53	0.80
CF + NPK		0.69	3.44	1.10	1.29	0.63	0.53	0.58

Results also revealed that all metal concentrations in radish skin, except Cu, were lower in soil and the same findings occurred for Mn, Zn and Cr content in skin + pulp as well as for Mn, Cu and Cr in pulp part of radish but without a clear trend (Tab. 6). The translocation factor obtained according to Marchiol et al. [2004] and reported in Table 7 was <1 for the elements Fe, Ni, Pb and Cr and >1 for Mn, Cu and Zn meaning that the first four metals were potentially accumulated in roots and on the contrary the rest in shoots of radish. This is mentioned for other plants grown in sewage sludge as a common strategy for plant survival in contaminated environments [Belhaj et al. 2016].

Many factors governed the availability and subsequently the bioaccumulation of heavy metals by the root in the soil environment such as the humic substances, organic chelates, antagonistic presence of other metals and pH. In consequence, the above differences ascertained in the elements accumulation among the various plant tissues elucidate alternative cellular mechanism of their bioaccumulation and translocation.

CONCLUSIONS

The source and the rate of organic materials used in the present study did not markedly change the element content in the substrates and were not so efficient to increase the metals content in plant tissues of radish grown in alkaline soil. A remarkable success of CLOMP, but principally CSO, in replacing the inorganic fertilizer needs of radish crop, was observed. CF should be applied to soils along with chemical fertilizers due to its ineffectiveness to achieve elevated growth parameters, when applied alone.

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