Effect of Marine Algae on Bio-accumulation of Heavy Metals from Polluted Soil by some Leafy Vegetables

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Abstract: A pot experiment was carried out to evaluate the effect of two marine algae (*Ulva lactuca* L. and *Pterocladia capillacea* (G.) B. et T.) on bio-accumulation of some heavy metals (Pb, Zn and Mn) from polluted soil by some leafy vegetables (Crisp head lettuce, *Lactuca sativa var. capitata* L. and Red cabbage, *Brassica oleraceae var. capitata* Form *rubra* L.). Surface soil samples (0-30cm) were collected from El-Gable El-Asfer farm located 25km northeast Cairo, Egypt. For both crops the experiment involved 48 pots comprised 8 treatments with 3 replicates in a completely randomized design. The two types of marine algae were mixed with (1:1, w/w) then added to soil at different rates 10.0, 20.0 and 30.0 g/ pot (5.0 kg) before planting. In this study, a program of observations and measurements was developed to evaluate the growth and head characteristics for both crops. The head characteristics of each crop were increased with marine algae treatment application to clean and polluted soils. Also, the available amounts of Pb, Zn and Mn were reduced in polluted soil with increasing addition rates of mixed marine algae to soil compared to control. In general the bioaccumulation of heavy metals was decreased in the following order Mn> Zn> Pb. Moreover, highest bio-accumulation of Mn was found in lettuce tissues compared to red cabbage tissues, while the highest bio-accumulation of Zn was recorded in red cabbage tissues compared to lettuce tissues.

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1. Introduction

Vegetables provide the human body with the essential bioavailable trace elements and a constant supply of these various elements is necessary for healthy daily life. However, high levels of these elements in soil and crop can have detrimental effects on soil fertility as well as crop yield and its consumers (**Ibrahim *et al.,* 2014).**

Heavy metal pollution represents an important environmental problem due to its toxic effects and accumulation throughout the food chain and hence in the human body, (**El-Sikaily, 2007**).Release of heavy metals into the environment is a potential threat to water and soil quality as well as to plant, animal and human health (**Usman *et al.*, 2006**).

Metal absorption and accumulation in plant depend on a many soil factors, such as: pH, EC, clay content, organic matter content, cationic exchange capacity, nutrient balance, other trace elements concentration in soil, physical and mechanical characteristics of soil, etc. The metals availability for plants is different, depending on plant species and their adaptation to environmental conditions. Herbs absorb less metal than fast growing plants such as lettuce, spinach, carrot and tobacco, (**Oros, 2001**).

Plants take heavy metals from soils through different reactions such as: absorption, ionic exchange, redox reactions, precipitation – dissolution, etc. As an extension to these reactions, it can be said that the solubility of trace elements depends on minerals in soil (carbonates, oxide, hydroxide…etc.), soil organic matter (humic acids, fulvic acids, polysaccharides and organic acids), soil pH, redox potential, soil temperature and humidity (**Tarradellas *et al.*, 1996**).

Ion exchange, chemical and microbiological precipitation methods among others have been developed to remove heavy metals from water, but their use is limited because they are capital, labor and energy intensive. In the recent year's bio-sorption have emerged as an economical and environmental friendly method for the decontamination of polluted water (**Abdel-Ghani and El-Chaghaby, 2014).** The use of plant in environmental clean-up of such toxic metals can guarantee a greener and cleaner planet for all of us at a cheaper cost (**Ilya *et al.*, 2001)**.

The adsorption is the one of the important procedure for the removal of the traces heavy metals from the environment. The main properties of the adsorbents for heavy metal removal are strong affinity and high loading capacity. Natural adsorbents have generally these properties (**Barbier *et al.*, 2000**).

Some practical aspects of the application of algal biomass for the bio-sorption of heavy metals from wastewater (**Allam and Abdel-Kareem, 2001**

and Brinza *et al.*, 2007) suggested the use of algal biomass as a potential alternative to the existing technologies for the removal and/or recovery of toxic precious metals. This alternative is advantageous, appropriate, economically feasible (**Feng and Aldrich, 2004 and Vilar *et al*., 2007**) and suitable for developing new by-products from wastewater treatment plants(**Sandau *et al*., 1996**).Seaweeds are also excellent agents of filtering the metals like Zn, Cd, Cu, Ni and Fe, from seawater. They remove the toxic materials from the environment which accumulate in the body cell **(Rodriguez *et al.*, 2001).**

The present investigation have been carried out to evaluate the effect of heavy metals bio-accumulation on growth and quality of some leafy vegetables, also to study the efficiency of marine algae on bio-accumulation of heavy metals from polluted soil by the studied crops.

2. Material and Methods

A pot experiment was carried out at the experimental farm of Environment and Bio-Agriculture Department, Faculty of Agriculture, Al-Azhar University, Nasr City, Cairo, Egypt during the winter season of 2014, to evaluate the effect of two marine algae (*Ulva lactuca* L. and *Pterocladia capillacea* (G.) B. et T.) on bio-accumulation of heavy metals (Pb, Zn and Mn) from polluted soil by some leafy vegetables (Crisp head lettuce, *Lactuca sativa L.* and Red cabbage, *Brassica oleraceae var. capitata* Form *rubra L.*).The used cultivars were Great lakes and Ruby perfection F_1hybrid for lettuce and red cabbage, respectively.

2.1 Soil samples:

Surface soil samples (0-30cm) were collected from El-Gable El-Asfer farm located at 25km northeast Cairo, Egypt, this soil is irrigated continuously with sewage effluent for about 80 years. Soil sample was air dried and then ground to pass through a 2mm sieve. The characteristics of the investigated soil (particle size distribution), was determined according to **Klute (1986**) while the chemical properties e.g. EC, pH, organic matter, soluble cations, and anions were determined according to **Page *et al.*(1982**). The available Pb, Zn and Mn were determined in the experimental soil using ammonium bicarbonate-DTPA extractable according to **Soltanpour and Schwab (1977**) and their contents in the obtained extract were measured by atomic absorption spectrophotometer. The results of soil analysis before the treatment are presented in Tables (1-3).

Table 1: Mechanical analysis of clean and polluted soil samples

Soil type	Particle size distribution (%)				Textural class
	Coarse sand	Fine sand	Silt	Clay	
Clean	53.91	22.80	11.20	12.09	Sand loamy
Polluted	54.21	20.43	11.67	13.69	Sand loamy

Table 2: Chemical analysis of clean and polluted soil samples

Soil types	OM %	pH (1:2)	EC dsm^{-1}	Cations (me qL^{-1})				Anions (me qL^{-1})			
				Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{--}	HCO_3^{-}	SO_4^{--}	Cl^{-}
Clean	2.11	7.33	0.36	1.22	0.23	1.45	0.28	ND	1.80	0.16	1.40
polluted	2.51	7.73	1.29	5.62	3.80	4.11	2.13	ND	3.74	7.32	4.61

Table 3: Heavy metals contents of clean and polluted soil samples

Heavy metals (mg kg^{-1})			
Elements	**Clean soil**	**Polluted soil**	**Critical limits of heavy metals in soil ***
Pb	0.251	26.170	0.50<
Zn	0.480	91.840	<1.50
Mn	0.581	21.651	1.80<

*** Hammissa *et al.* (1993).**

2.2Marine algae

Two types of marine algae (*Ulva lactuca* and *Pterocladia capillacea*) were collected from Abo-Qir Bay, Alexandria, Egypt and washed with sea water, tap water, and then distilled water several time, to remove extraneous and salt, then dried in an oven at 50 °C until complete dryness. The dried algae biomass was chopped, sieved and kept under dry conditions until needed. The moisture percentage, the ash and nitrogen content were determined according to **AOAC (2006**). A factor of 6.25 was used to convert N to protein, also pH and heavy metals (Pb, Zn and Mn) were estimated according to **Page *et al.* (1982**), as shown in Tables (4-5).

Table 4: Chemical analysis of marine algae

Types	pH (1:2)	Ash (% dry weight)	Moisture %	Protein (% dry weight)	Fat (% dry weight)	Carbohydrates (% dry weight)
Ulva lactuca	6.61	29.1	90.40	17.11	2.27	51.52
Pterocladia capillacea	6.83	18.7	89.60	20.41	1.40	59.49

Table 5: Contents of marine algae from heavy metals

Types	Heavy metals (mg kg^{-1})		
	Pb	**Zn**	**Mn**
Ulva lactuca	0.08	0.39	0.46
Pterocladia capillacea	0.14	1.20	0.66

2.3 Experimental treatments:

For both crops the experiment involved 48 pots comprised 8 treatments in three replicates in a completely randomized design. The two types of marine algae (*Ulva lactuca.* and *Pterocladia capillacea*) were mixed (1:1, w/w) and added to soil at different rates 10.0, 20.0 and 30.0 g/pot (5.0 kg, 20 cm diameter and 25 cm depth) before transplanting, then transplants of the studied crops were set up into the experimental pots, the treatments of this study were as follows;

1. Clean soil (Control 1)
2. Clean soil + marine algae with rate 10.0 g/ pot
3. Clean soil + marine algae with rate 20.0 g/ pot
4. Clean soil + marine algae with rate 30.0 g/ pot
5. Polluted soil (Control 2)
6. Polluted soil + marine algae with rate 10.0 g/ pot
7. Polluted soil + marine algae with rate 20.0 g/ pot
8. Polluted soil + marine algae with rate 30.0 g/ pot

The seeds of both cultivars were sown in seed trays, and after 30 days form seeds sowing, the transplants of the studied crops were selected for uniformity and set up into the experimental pots. The conventional agricultural practices, especially the fertilization with the recommended doses were applied. In this experiment a program of observations and measurements was developed, concerning growth and head characteristics. However, the produced crops were harvested after 60.0 days (for lettuce) and 90.0 days (for Red cabbage) from the transplanting date. Plant organs were rinsed in distilled water, dried at 70°Cuntil complete dryness, and then dry weights were recorded. The plant samples were ground and wet digested with acid mixture (HNO_3 and $HC1O_4$) according to **Jackson (1973)**. Heavy metals under investigation (Pb, Zn and Mn) in clear digested solutions were determined using Perkin Elmer Inductively Coupled Spectrophotometer Plasma 400 (ICP).

2.4 Statistical analysis:

Mathematical statistical producers were used to process the obtained experimental data. Testing of the significance of determined differences between calculated means values was done using "SPSS software ver. 20" following the methods of **(Steel and Torrie, 1980)**. All evaluations of significance were carried out based on F-test and Duncan-test for threshold of significance of 5%.

3. Results and Discussion

3.1Effect of marine algae on head characteristics of the studied crops grown in clean and polluted soils

Data in Tables (6 and 7) showed that the head characteristics of lettuce and red cabbage after harvesting in the clean and polluted soil samples were significantly affected by mixing the marine algae with soil samples. The relative head fresh weight, head size, head diameter and head dry weight in both crops were significantly increased with the increase of the rate of mixed marine algae compared to control (1 and 2). Meanwhile the outer leaves number in lettuce and unfolded leaves number in red cabbage were decreased as the application rate of mixed marine algae increased. These results could be attributed to the role of marine algae in chemical and nutrient elements behavior in both clean and polluted soil, which increase the availability of micro and macronutrients to bio-absorption by the studied crops (act as bio-fertilizers) and in-turn increasing the biomass production of the cultivated crop when applied to the soils before transplanting (**Rodney *et al.*, 2004 and Xiao *et al.*, 2008**).

The dry weight of roots and leaves of both crops reflect the high bio-accumulation and uptake of heavy metals found at treatment of 30g/pot followed by using rates of 20g/pot and 10g/pot, respectively. **Abd-Elhady and El-Zabalawy (2014)** recorded the change of chemical behavior of the metal ions, due to addition of marine algae from cation to anion as well as the release of organic acids which slightly decrease the soil reaction (pH). These results elucidate the important role of marine algae application for improving soil polluted with heavy metals and the higher uptake of heavy metals by the studied crops cultivated in polluted soils than control (control 2).

Table 6: Effect of marine algae on head characteristics of lettuce grown in heavy metals polluted soil

Experimental Treatments	Plant and head characteristics				
	OLN*	HFW** (g)	Head size (cm^3)	Head diameters (cm)	HDW*** (g)
T_1 = Clean soil (Control 1)	13.1^{a} ±0.9	332.6^{h} ±3.5	548.3^{h} ±2.2	10.2^{e} ±0.4	12.7^{e} ±0.4
T_2 = Clean soil + 10.0 g marine algae	11.8^{b} ±0.9	346.7^{g} ±1.4	568.5^{g} ±1.2	10.7^{de} ±0.3	13.3^{d} ±0.3
T_3 = Clean soil + 20.0 g marine algae	10.7^{c} ±0.3	357.2^{f} ±3.2	589.4^{f} ±2.2	11.1^{d} ±0.2	13.9^{d} ±0.3
T_4 = Clean soil + 30.0 g marine algae	10.1^{d} ±0.7	362.9^{e} ±1.1	601.6^{e} ±2.5	11.4^{c} ±0.4	14.2^{c} ±0.4
T_5 = Polluted soil (Control 2)	9.9^{e} ±2.0	375.5^{d} ±2.3	626.6^{d} ±4.5	11.8^{cb} ±0.2	14.6^{c} ±0.4
T_6 = Polluted soil + 10.0 g marine algae	8.6^{f} ±1.2	392.4^{c} ±1.5	654.8^{c} ±3.3	12.4^{b} ±0.4	15.5^{b} ±0.5
T_7 = Polluted soil + 20.0 g marine algae	8.1^{fg} ±0.4	420.1^{b} ±3.2	711.0^{b} ±8.5	13.3^{a} ±0.4	16.7^{a} ±0.2
T_8 = Polluted soil + 30.0 g marine algae	7.8^{g} ±0.9	432.5^{a} ±1.5	731.7^{a} ±4.4	13.6^{a} ±0.6	16.9^{a} ±0.3

* = Outer leaves number; ** Head Fresh Weight; *** = Head Dry Weight

Table 7: Effect of marine algae on head characteristics of red cabbage grown in heavy metals polluted soil

Experimental Treatments	Plant and head characteristics				
	ULN*	HFW** (g)	Head size (cm^3)	Head diameters (cm)	HDW*** (g)
T_1 = Clean soil (Control 1)	19.7^{a} ±0.8	675.3^{h} ±7.5	811.3^{h} ±5.3	14.8^{e} ±0.6	55.2^{f} ±6.1
T_2 = Clean soil + 10.0 g marine algae	18.2^{b} ±0.3	721.6^{g} ±6.5	854.1^{g} ±1.9	16.2^{d} ±0.4	55.6^{ef} ±1.0
T_3 = Clean soil + 20.0 g marine algae	16.3^{d} ±0.6	752.1^{f} ±7.5	887.9^{f} ±2.0	16.4^{d} ±0.5	56.7^{e} ±0.3
T_4 = Clean soil + 30.0 g marine algae	14.7^{f} ±0.4	789.9^{e} ±5.0	930.6^{e} ±11.4	16.8^{c} ±0.7	58.4^{d} ±0.7
T_5 = Polluted soil (Control 2)	17.4^{c} ±0.5	861.0^{d} ±3.6	1001.0^{d} ±8.7	17.0^{c} ±1.0	60.2^{c} ±1.0
T_6 = Polluted soil + 10.0 g marine algae	15.8^{e} ±0.8	879.8^{c} ±2.6	1031.2^{c} ±6.0	17.5^{b} ±1.4	61.9^{b} ±0.9
T_7 = Polluted soil + 20.0 g marine algae	14.6^{f} ±0.4	896.4^{b} ±1.3	1042.1^{b} ±5.0	17.7^{b} ±0.6	62.1^{b} ±0.8
T_8 = Polluted soil + 30.0 g marine algae	12.3^{g} ±0.3	945.7^{a} ±14.6	1098.1^{a} ±2.9	18.1^{a} ±0.6	64.4^{a} ±0.7

* = Unfolded leaves number; ** Head Fresh Weight; *** = Head Dry Weight

3.2 Effect of marine algae on bioremediation of heavy metals polluted soil

Table (8) represents the available Pb, Zn and Mn as affected by different levels of mixed marine algae. It was shown that the available amounts of Pb, Zn and Mn were significantly reduced as affected by increasing rates of mixed marine algae compared to control. However the lower values of available Pb, Zn and Mn in polluted soil were obtained as a result of application of mixed marine algae at 30 g/pot after harvesting. These results reflect the effective role of marine algae in the chemical behavior of heavy metals in soil. This role could be summarized in the capability of mixed marine algae to retain heavy metals in soils as unavailable form. At the same time, the decomposition of organic matter is followed by formation of active groups which have the ability to retain the metal in the complex and chelated form. These findings are in agreement with those obtained by (**Sarl and Tuzen, 2007)** who found that the ability of marine algae to immobilize heavy metals under consideration in polluted soil thought to have high metal binding capacities due to the presence of polysaccharides, proteins, amino, hydroxyl, carboxyl and sulphate groups, which can act as binding sites for metals. The green alga *Ulva lactuca* is particularly useful in these respects because of its wide distribution and relatively simple structure.

On the other hand, the improvement of head characteristics of both crops may be also attributed to the increasing availability of micro and macro-nutrients to bio-absorption by the studied crops due to the effect of mixed marine algae. These results are in a harmony with those obtained by **Rodney *et al.* (2004) and Xiao *et al*. (2008**) who reported that the addition of algae to soil reduced the pH from 9.5 to 7.6, while the exchangeable calcium increased from 20 to 30%. This remark insured the role of application's amount to increase solubility and concentration of heavy metals, which could led to high plant uptake of heavy metals in polluted soils. These results confirm the role of marine algae in improving soil polluted with heavy metals and interpret the higher uptake of these metals by the studied crops cultivated in polluted soils than control.

3.3 Effect of marine algae on bio-accumulation of heavy metals from polluted soil to the tissues of the studied crops

Table 8: Effect of marine algae on bioremediation of polluted soil after the end of experiment

Experimental treatments	**Contents of soil from available heavy metals (mg.Kg^{-1})**					
	Pb		**ZN**		**Mn**	
	lettuce	**cabbage**	**lettuce**	**cabbage**	**lettuce**	**cabbage**
T_1 = Clean soil (Control 1)	0.58^e ±0.02	0.58^e ±0.03	0.48^e ±0.02	0.46^e ±0.04	0.25^e ±0.02	0.23^e ±0.02
T_2 = Clean soil + 10.0 g marine algae	0.51^f ±0.02	0.50^f ±0.03	0.44^f ±0.02	0.42^f ±0.03	0.21^f ±0.02	0.21^f ±0.03
T_3 = Clean soil + 20.0 g marine algae	0.43^g ±0.03	0.42^g ±0.02	0.39^g ±0.04	0.38^g ±0.01	0.17^g ±0.02	0.16^g ±0.04
T_4 = Clean soil + 30.0 g marine algae	0.36^h ±0.04	0.34^h ±0.05	0.35^h ±0.03	0.34^h ±0.02	0.14^h ±0.02	0.14^h ±0.02
T_5 = Polluted soil (Control 2)	21.65^a ±1.2	21.64^a ±2.0	91.80^a ±2.2	91.66^a ±2.4	26.13^a ±1.8	25.98^a ±2.3
T_6 = Polluted soil + 10.0 g marine algae	19.81^b ±1.8	19.75^b ±1.6	77.22^b ±2.0	76.98^b ±1.9	20.98^b ±2.2	20.82^b ±1.7
T_7 = Polluted soil + 20.0 g marine algae	17.70^c ±2.0	17.69^c ±1.9	63.31^c ±1.7	63.12^c ±2.1	14.98^c ±1.8	14.78^c ±1.5
T_8 = Polluted soil + 30.0 g marine algae	15.34^d ±1.4	15.29^d ±1.2	48.31^d ±2.7	47.96^d ±1.6	10.23^d ±1.3	9.94^d ±0.9

Table 9: Effect of marine algae on bio-accumulation of **Pb** in the studied crops

Experimental Treatments	**Concentration of Pb (mg. kg^{-1})**			
	Lettuce		**Red cabbage**	
	Roots	**leaves**	**Roots**	**Leaves**
T_1 = Clean soil (Control 1)	0.13^f±0.02	0.09^f±0.01	0.12^f±0.01	0.07^f±0.01
T_2 = Clean soil + 10.0 g marine algae	0.13^f±0.02	0.11^f±0.02	0.13^f±0.02	0.09^f±0.02
T_3 = Clean soil + 20.0 g marine algae	0.16^{ef}±0.03	0.13^{ef}±0.02	0.15^{ef}±0.02	0.12^{ef}±0.02
T_4 = Clean soil + 30.0 g marine algae	0.17^e±0.03	0.15^e±0.02	0.16^e±0.02	0.14^e±0.01
T_5 = Polluted soil (Control 2)	0.39^d±0.04	0.34^d±0.03	0.42^d±0.03	0.33^d±0.02
T_6 = Polluted soil + 10.0 g marine algae	0.54^c±0.04	0.45^c±0.04	0.51^c±0.04	0.43^c±0.03
T_7 = Polluted soil + 20.0 g marine algae	0.61^b±0.05	0.53^b±0.04	0.59^b±0.03	0.52^b±0.03
T_8 = Polluted soil + 30.0 g marine algae	0.76^a±0.03	0.66^a±0.03	0.75^a±0.04	0.64^a±0.03

Tables (9-11) show positive effects of marine algae in increasing the bio-accumulation and uptake of Pb, Zn and Mn by the studied crop. In general, the bio-accumulation and uptake of Pb, Zn and Mn was significantly increased by increasing the rate of mixed marine algae to both soils compared to control. It is noteworthy to mention that the bioaccumulation of heavy metals was decreased in the following order Mn> Zn> Pb. These results agreed with those of **Intawongse*et al.* (2006)** who reported that soil to plant transfer factor values decreased from Mn > Zn > Pb. The highest Pb bio-accumulation and uptake was achieved by roots of both crops (table 9). At the same time lettuce tissue accumulated higher values than red cabbage and the accumulation was directly proportional to the applied dose of marine algae.

Tables 10 and 11 illustrate the bio-accumulation of Zn and Mn respectively by the two studied crops. The bio-accumulation of both metals showed the same trend as that of Pb, but cabbage showed more Zn accumulation than lettuce. These results coincide with that of **Boamponsem *et al.*, (2012)** who observed that the highest concentration of Mn was found in the stem of lettuce and the highest concentration of Zn was found in the roots of cabbage. Also are in a harmony with those obtained by (**Oros, 2001**) who found that metal absorption and accumulation in plant depend on a few soil factors, such as: pH, EC, clay content, organic matter content, cationic exchange capacity, nutrient balance. The metals availability for plants is different, depending on plant species and their adaptation to the environment conditions. These results could be attributed to the role of marine algae to increased availability of macro and micro-nutrients to absorption by plants under this study. The results are in agreement with those obtained by **Abd-Elhady and El-Zabalawy (2014)** who found that the increase of seaweeds treatments gave higher percentage values of micronutrients (content and uptake) in root and shoots of rid radish compared to control.

Table 10: Effect of marine algae on bio-accumulation of **Zn** in the studied crops

Experimental Treatments	**Concentration of Zn (mg. kg^{-1})**			
	Lettuce		**Red cabbage**	
	Roots	**leaves**	**Roots**	**Leaves**
T_1 = Clean soil (Control 1)	1.34^g ±0.03	1.00^h ±0.02	1.71^g ±0.02	1.21^g ±0.01
T_2 = Clean soil + 10.0 g marine algae	1.44^f ±0.02	1.13^g ±0.02	1.80^f ±0.02	1.32^f ±0.02
T_3 = Clean soil + 20.0 g marine algae	1.48^{ef} ±0.01	1.20^f ±0.02	1.87^{ef} ±0.02	1.39^{ef} ±0.02
T_4 = Clean soil + 30.0 g marine algae	1.51^e ±0.01	1.27^e ±0.02	1.92^e ±0.02	1.41^e ±0.02
T_5 = Polluted soil (Control 2)	7.74^d ±0.3	5.62^d ±0.4	9.86^d ±0.3	6.72^d ±0.5
T_6 = Polluted soil + 10.0 g marine algae	8.99^c ±0.6	6.81^c ±0.5	10.60^c ±0.4	7.98^c ±0.4
T_7 = Polluted soil + 20.0 g marine algae	10.17^b ±0.5	8.27^b ±0.6	12.23^b ±0.5	9.12^b ±0.3
T_8 = Polluted soil + 30.0 g marine algae	11.63^a ±0.4	9.33^a ±0.5	14.82^a ±0.4	10.55^a ±0.4

Table 11: Effect of marine algae on bio-accumulation of **Mn** in the studied crops

Experimental Treatments	**Concentration of Mn (mg. kg^{-1})**			
	Lettuce		**Red cabbage**	
	Roots	**leaves**	**Roots**	**Leaves**
T_1 = Clean soil (Control 1)	1.14^g ±0.01	1.46^g ±0.02	1.06^g ±0.01	1.32^f ±0.02
T_2 = Clean soil + 10.0 g marine algae	1.23^f ±0.02	1.52^f ±0.02	1.19^f ±0.01	1.38^f ±0.02
T_3 = Clean soil + 20.0 g marine algae	1.30^{ef} ±0.02	1.57^{ef} ±0.02	1.26^{ef} ±0.02	1.42^{ef} ±0.02
T_4 = Clean soil + 30.0 g marine algae	1.36^e ±0.02	1.62^e ±0.02	1.31^e ±0.02	1.47^e ±0.02
T_5 = Polluted soil (Control 2)	7.02^d ±0.3	8.85^d ±0.4	7.12^d ±0.2	7.84^d ±0.3
T_6 = Polluted soil + 10.0 g marine algae	7.83^c ±0.5	9.68^c ±0.3	7.63^c ±0.3	8.81^c ±0.4
T_7 = Polluted soil + 20.0 g marine algae	8.35^b ±0.4	10.66^b ±0.5	8.16^b ±0.3	9.37^b ±0.2
T_8 = Polluted soil + 30.0 g marine algae	9.98^a ±0.3	11.90^a ±0.3	8.88^a ±0.4	10.59^a ±0.5

4. Conclusion

This study clarify the important role of marine algae in monitoring polluted soil by reducing the amount of heavy metals available in the soil through adsorption of large portion of these metals. At the same time, the mixing of marine algae stimulated the roots of the studied crops to increase the absorption of salts, minerals, which in turn increases the concentrations of heavy metals in the roots and leaves. The increased values of heavy metals in lettuce and red cabbage impose the prohibition from eating vegetable products obtained from this polluted soil, especially if fertilized by marine algae and also suggest the increased risk of contamination implied by consuming such products. Consequently, we recommend the using of marine algae as bio-fertilizers for the cultivation of non-edible crops in contaminated soils.

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