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Removal of cadmium (Cd) from low quality water by bentonite applied in the soil

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Abstract

The present study investigated the removal of cadmium from low quality water by bentonite applied in the soil using with the plants test radish, corn and sugar beet. The experiments were carried out in a greenhouse, with a completely randomized design with four replications. The experimental units were plastic pots with a capacity of 5 kg for beets and radish; and for corn in plastic pots with 14 kg. The soil was mixed with increasing doses of bentonite equivalent to 0; 30; 60 and 90 t ha^{-1}. The sowing was done directly on the pot, leaving two plants per pot after thinning. They have been irrigated with poor quality water with a concentration of 0.2 mg L^{-1} Cd. Plants of radish, corn and beet were harvested at 30, 60 and 90 days, respectively, separated in shoot and roots and placed in air circulation oven. The data were submitted to analysis of variance. The present study led to demonstrate that application of bentonite in soil irrigated with poor quality water had a significant positive effect on development of radish, corn and beet crops, ie, influenced at 1% probability the dry biomass of roots of radish, corn and beet and the dry biomass of shoot of the corn. Generally the bentonite promoted the retention of cadmium in the soil, evidenced by the reduction of the concentration and/or accumulation of this metal in the shoot and roots of radish, corn and beet. Bentonite favored the reduction of bioaccumulation and translocation factors of cadmium thereby increasing the concentration of this element in soil in relation to the plants and in shoot in relation to root, except of corn.

Keywords: Bioaccumulation, Translocation, Heavy metals, Clay.
Abbreviations: Cd_cadmium; TI_ translocation index; TF_ translocation factor; BFP_ bioaccumulation factor of cadmium in plant; BFR_ bioaccumulation factor of cadmium in root; KCl_ potassium chloride; P_2O_5_super phosphate.

Introduction

The supply of drinking water is decreasing while demand for water is increasing, so researchers are currently looking for ways to recycle water through the reuse of urban wastewater for irrigation and other purposes (Dantas et al., 2014). In general, wastewater comprises liquid wastes generated by households, industry, commercial sources, as a result of daily usage, production and consumption activities. The wastewater is also a resource that can be applied for productive uses since wastewater contains nutrients that have the potential for use in agriculture, aquaculture and other activities. It is a rich source of nutrients and provides all the moisture necessary for crop growth. However in the composition of wastewater have chemical pollutants, i.e., heavy metals, which, by irrigation may be transported to soils and may affect soil flora and fauna causing crop contamination and consequently, the food chain (Cunha Filho et al., 2014). Some of these heavy metals may bio-accumulate in the soil while others, e.g., Cd and Cu, may be redistributed by soil fauna such as earthworms (Kruse and Barrett, 1985; Maxted et al., 2007). Cadmium (Cd) is a heavy metal naturally present in soil; it is non-essential and highly toxic to most organisms, having toxicity 2 to 20 times higher than many other heavy metals (Vassilev et al., 1998). Plants can extract Cd from the soil and transport it via the xylem into shoots and leaves where easily it accumulates thus can be readily absorbed into the human body throughout the food chain (Zheng et al., 2010). An excessive level of cadmium ions in the water can affect the bio-systems and be a threat to human beings. Hence the removal of cadmium ions from the water and wastewater is highly important. Essential to the reduction of the pollution pressure on arable and other farmland, in situ immobilization technologies have gained prominence and rapid implementation, being generally cost-effective and non-disruptive (Lee et al., 2013). A number of these technologies have been developed by adding various natural or synthetic materials, such as clay minerals (Sun et al., 2013) which inactivate mobile Cd and reduce its labile pool and ecotoxicity. Numerous studies have confirmed that number adsorbents such as clay minerals, for example, bentonite, can effectively immobilize Cd in soils and improve soil properties as pH, fertility, water storage capacity, etc. Adsorption is a traditional method to immobilize Cd from aqueous environment; it is quite popular due to its simplicity and high efficiency. The bentonite is a rock containing clay minerals, predominantly smectite group and quartz impurities. In some varieties are also kaolinite and illite. Due to the large area of surface specific, high cation exchange capacity and low cost, bentonite has a broad application prospect in agriculture and it is probably one of the most promising materials that interact with many heavy metals in contaminated soils and waters. According to Sdiri et al. (2011), this clay can be effectively used for the treatment of contaminated wastewater. This material is found in large quantities in the municipality of Boa Vista, Paraiba State, Brazil.

Knowing, however, that each clay mineral presents greater or lesser adsorption capacity, its efficiency in removing metallic cations of soil / wastewater systems should be assessed in relation to each of these cations, separately. Like cadmium, a heavy metal regarded as an element of high toxicity, not biodegradable, they can be easily accumulated in living tissue and readily absorbed into the human body throughout the food chain. Therefore, the objective of this study was to evaluate the effect of bentonite clay on cadmium adsorption contained in the lower quality water, with the plants test radish, corn and sugar beet.

Results and Discussion

Shoot and root dry of the plants

The reduction in plant growth and, consequently, dry biomass is one of the common symptoms of heavy metal stress on plants with special reference to Cd (Hadi et al., 2014). According to several authors, this may be attributed to the inhibition of chlorophyll synthesis decreasing photosynthetic activity (Chauhan and Joshi, 2010; Nagajyoti et al., 2010).

The present study indicated differences in above-ground shoot and below-ground root dry weight of radish, corn and beet. These results may be attributed to bentonite doses applied in the cultivated soil and irrigated with low quality water containing cadmium. That is, the biomass, generally, increased as a function of increasing amounts of bentonite applied to the soil (Table 1) because, probably by adsorption process. The bentonite in the soil, adsorbing metals, such as cadmium, decreases the deleterious effect of this metal on plants.

According to the analysis of variance the application of increasing doses of bentonite significantly influenced at 1% probability the dry biomass of roots of radish, corn and beet and the dry biomass of shoot of the corn (Table 2).

Dry weight of root radish increased by around 31.38% as a function of treatments ranging from 1,119 g/pot (0 t ha^{-1} bentonite) to 1,469 g/pot (90 t ha^{-1} bentonite) (Figure 2A). The application of bentonite in soil resulted in an increase of dry biomass of shoot and root of corn around 12.21 and 13.93%, respectively (Figure 2B and 2C). The increase in dry biomass of roots of beet was greater than occurred with radish, i.e., it was approximately 53.5%, ranging from 9.10 to 13.97 g/pot according to equation Figure 2D. Increases in dry biomass of shoots and/or roots of radish, corn and beet, indicate that bentonite, probably by adsorption mechanism, reduced the cadmium content available in the soil thus promoting the development of these cultures. As Kabata-Pendias and Pendias (2000), the presence of high concentrations of Cd in the root environment can influence the absorption and metabolism of other nutrients showing stunting due to deficiency of these nutrients such as phosphorous, which has been shown to form insoluble complexes with Cd (Foy et al., 1978) affecting plant growth. For example, Augusto et al. (2014) studied the effect of cadmium used in the development of mustard, observed that 10 mg L^{-1} of Cd in the solution caused a 40% decrease in biomass.

Cadmium concentration in shoot and root

The Cd concentrations in shoots of radish and Cd concentrations in the roots of radish and beet crops were significantly influenced by increasing doses of bentonite (Table 3).

The Cd concentrations in shoots and roots radish ranged from 0.64 to 0.47 mg kg^{-1} and 0.33 to 0.21 mg kg^{-1} promoting a reduction in the order of 26.59 and 35.78%, respectively, when comparing the control with the higher dose (Figure 3A and 3B). It is observed in Table 1 that the Cd concentrations in shoots radish grown in soil without bentonite, and at doses 30 and 60 t ha^{-1} were above or equal to the maximum tolerable value for human consumption of vegetables, roots and tubers and other fresh food which is 0.5 mg kg^{-1} cadmium according to ABIA (1985).

The incorporation of bentonite in the soil influenced the Cd concentration in the root of the beet, reducing by 27.27% in relation to the increasing doses of bentonite (Figure 3C). It is verified that the beet (root) cultivated in the soil without the bentonite had the Cd concentration 0.73 mg kg^{-1}, above the maximum value allowed for vegetables, roots and tubers, that is, unfit for consumption, whereas, beet in the soil with doses of bentonite 30, 60 and 90 t ha^{-1} had the concentration of Cd 0,44, 0,49 and 0,53 mg kg^{-1}, respectively, below or equal to the maximum value allowed, which proves the beneficial effect of the bentonite. It is important to emphasize that this culture was irrigated with water containing cadmium in the maximum concentration allowed to discharge effluents, and even at this limit, it is worrisome the consumption of food irrigated with water of inferior quality, with the presence of this metal because this represents great risk to human health (Kumar et al., 2012; Marin et al., 2010).

Comparing the concentration of Cd in the parts of the plant, it was observed that the highest concentrations of this element occurred in the roots of the corn in relation to the aerial part, corroborating with Wang et al. (2014).

The application of increasing doses of bentonite to the soil generally decreased the concentrations and/or accumulations of cadmium in both the roots and the aerial part of the plants. Perhaps the main reason for this is related to the increase of the specific surface of the soil, increasing the electric charges in the colloids and consequently the cationic exchange capacity. Thus, the adsorption of cadmium in the soil increased, reducing the concentration of the element in the available soil solution to be absorbed by the plants. This positive effect may reflect the increase in plant biomass.

Cadmium accumulated in shoot and root

Increasing doses of bentonite significantly influenced the cumulative amount of Cd in shoot and root of radish and root of corn (Table 4). Except for the cumulative amount of Cd in corn, the best fit was provided by linear regression model (Figure 4). According to Tito et al. (2016), bentonite did not significantly influence the cumulative amount do Cu in the radish, however, was significative about this element in the corn.

The Cd accumulated in shoot and root radish (Figures 4A and 4C) had a reduction of about 39.38 and 20.0%, ranging from 0.0016 to 0.0010 mg / pot and 0.00038 to 0.00032 mg / pot, respectively. This reduction, through the incorporation of bentonite, has been beneficial, since excessive accumulation

Table 1. Dry biomass, cadmium concentration (mg kg^{-1}) and accumulated (g/pot), the translocation index (TI,%), translocation factor (TF), bioaccumulation factor of cadmium in plant (BFP) and root (BFR) of radish, corn and beet plant as a function of increasing doses of bentonite.

Bentonite t ha^{-1}	Dry biomass g		Concentration mg kg^{-1}		Accumulated mg/pot		TI %	TF	BFP	BFR
	Shoot	Root	Shoot	Root	Shoot	Root				
	Radish									
0	2.17	1.18	0.61	0.31	0.0017	0.00038	81.55	1.95	3.52	1.05
30	2.16	1.21	0.65	0.32	0.0014	0.00039	77.77	2.03	3.29	1.08
60	2.31	1.67	0.50	0.24	0.0011	0.00036	75.57	2.09	2.51	0.81
90	2.29	1.41	0.47	0.21	0.0010	0.00029	76.68	2.24	2.20	0.71
	Corn									
0	81.6	13.7	0.054	0.25	0.0044	0.0034	55.68	0.21	0.47	0.85
30	82.9	12.8	0.058	0.19	0.0048	0.0025	65.68	0.32	0.38	0.66
60	81.0	14.7	0.060	0.21	0.0049	0.0031	61.47	0.31	0.41	0.70
90	93.5	15.1	0.042	0.26	0.0039	0.0039	48.95	0.16	0.46	0.88
	Beet									
0	9.10	8.5	1.17	0.74	0.0110	0.0063	61.80	1.55	2.23	2.51
30	7.35	11.1	1.08	0.51	0.0079	0.0056	56.35	2.12	1.86	1.73
60	7.63	13.3	1.08	0.53	0.0083	0.0071	53.84	2.06	1.88	1.80
90	8.28	13.2	0.91	0.52	0.0077	0.0069	51.13	1.75	1.67	1.76

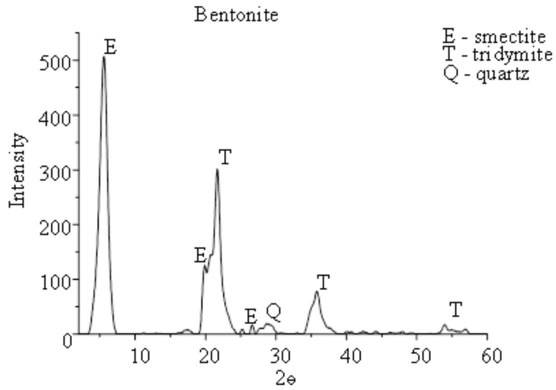

Fig 1. Diffractogram of bentonite obtained by X-ray Diffraction.

Table 2. Summary of the analyses of variance for the dry biomass of the shoot and root of the radish, corn and beets, irrigated with poor quality of water with increasing doses of bentonite.

Source of Variation	DF	Mean Square					
		Radish		Corn		Beets	
		shoot	root	shoot	root	shoot	root
Bentonite	3	0.025ns	0.205**	137.81**	4.317**	2.43ns	20.10**
Linear	1	-	0.266**	226.63**	7.515**	-	52.60**
Quadratic	1	-	0.084*	124.93*	1.756*	-	6.9ns
Error	12	0.168	0.021	14.60	0.252	1.10	2.21
VC (%)		18.34	10.66	4.51	3.56	12.97	12.91
Mean (g)		2.24	1.36	84.79	14.10	8.09	11.53

DF= Degree of Freedom, ^{ns}, * and **, no significant, significant to the 5 and 1% level, respectively. VC = Variation Coefficient.

Table 3. Summary of the analyses of variance for the cadmium concentration in the shoot and root of the radish, corn and beets irrigated with poor quality of water with increasing doses of bentonite.

Source of Variation	DF	Mean Square					
		Radish		Corn		Beets	
		shoot	root	shoot	root^1	shoot^2	root
Bentonite	3	0.029*	0.0114**	0.0002ns	0.005ns	0.019ns	0.048*
Linear	1	0.064*	0.028**	-	-	-	0.081*
Quadratic	1	0.004ns	0.001ns	-	-	-	0.048*
Error	12	0.008	0.0007	0.0001	0.002	0.036	0.01
VC (%)		16.99	10.03	18.94	10.46	19.69	17.79
Mean (mg kg^{-1})		0.56	0.27	0.05	0.48	0.98	0.58

DF= Degree of Freedom, ^{ns}, * and ** no significant, significant to the 5 and 1% level, respectively.VC = Variation Coefficient. ^{1,2} Data transformed in $\sqrt{x}$ and 1/x, respectively.

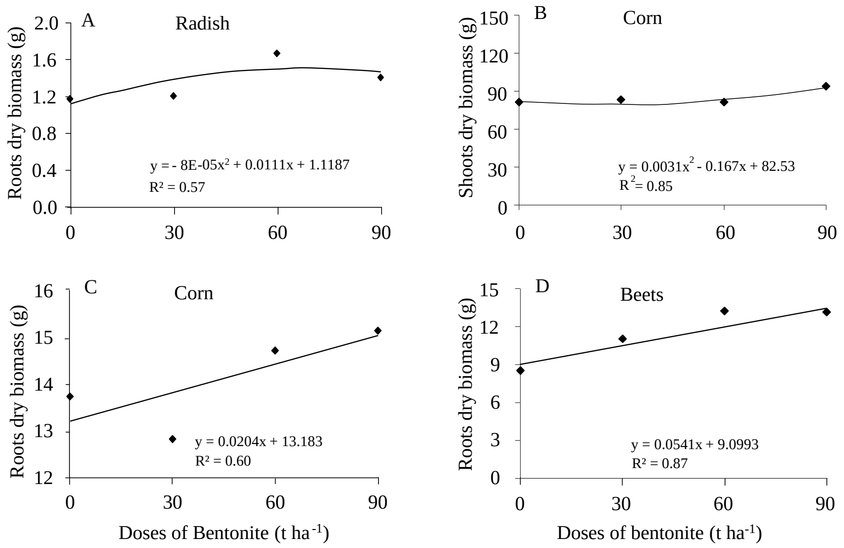

Fig 2. Dry biomass of the radish (A), corn (C) and beet (D) roots, and dry biomass of shoot corn (B) irrigated with lower quality water due to increasing doses of bentonite.

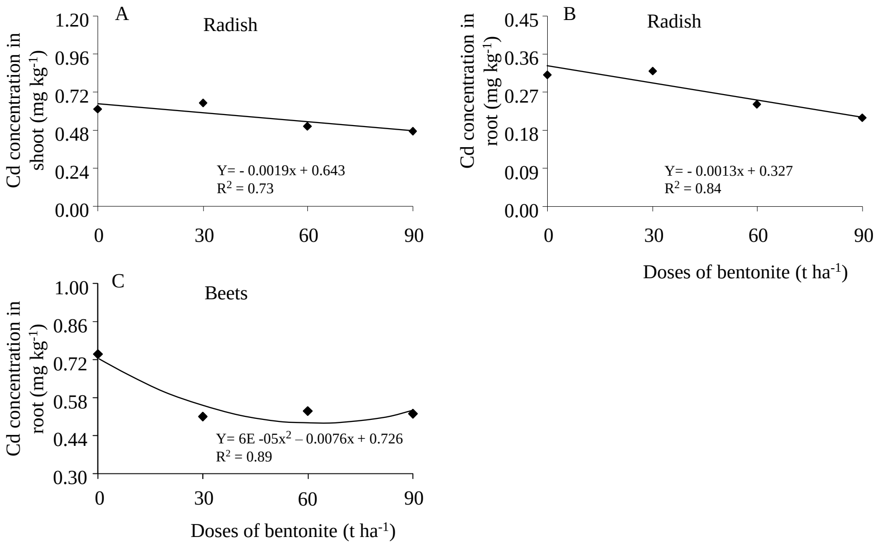

Fig 3. Cadmium concentration in the shoots of radishes (A) and Cd concentration in the root of radish (B) and beet (C), depending on dose increasing bentonite.

Table 4. Summary of the analyses of variance for the accumulated cadmium in the shoot and root of the radish, corn and beets irrigated with poor quality of water with increasing doses of bentonite.

Source of Variation	DF	Mean Square					
		Radish		Corn		Beets	
		shoot	root[1]	shoot	Root[1]	Shoot[2]	root
Bentonite	3	$3.35e^{-7}$ *	$7.17e^{-9}$ *	$7.17e^{-7}$ns	0.00013*	382.07ns	$6e^{-6}$ ns
Linear	1	0.000001**	0.00000**	-	0.00003ns	-	-
Quadratic	1	0.000ns	0.000ns	-	0.0003*	-	-
Error	12	$6.08e^{-8}$	$1.57e^{-9}$	$8.3e^{-7}$	0.00003	979.33	0.000006
VC (%)		18.81	11.13	20.19	11.04	25.34	26.67
Mean (mg)		0.0013	0.0003	0.0045	0.056	123.50	0.009

DF= Degree of Freedom, ns, * and ** no significant, significant to the 5 and 1% level, respectively.VC = Variation Coefficient. [1,2] Data transformed in √x and 1/x, respectively

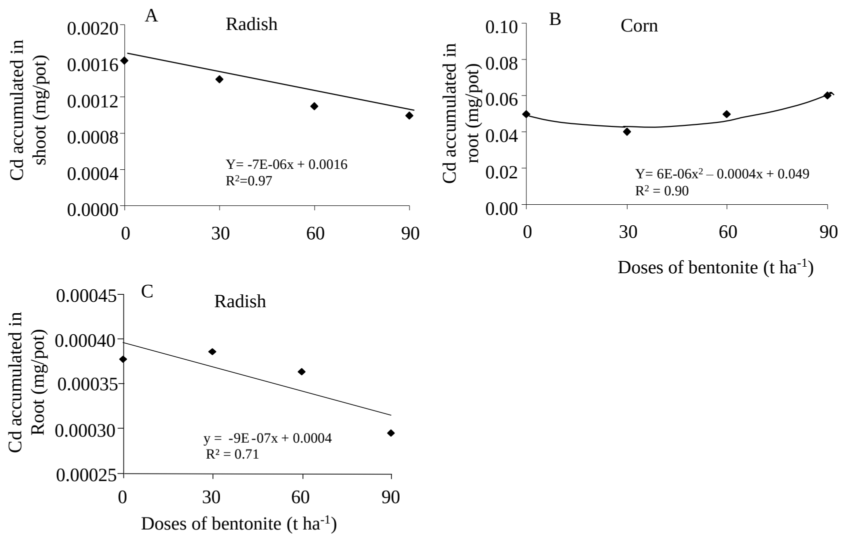

Fig 4. Amount of Cd accumulated in shoots of radishes (A) and amount Cd accumulated in the root of radish (C) and corn (B), depending on dose increasing bentonite.

Table 5. Summary of the analyses of variance for the cadmium translocation index (TI), translocation factor (TF), bioaccumulation factor of cadmium in plant (BFP) and bioaccumulation factor of cadmium in root (BFR) of the radish, corn and beets irrigated with poor quality of water with increasing doses of bentonite.

Source of Variation	DF	Mean Square		
		Radish	Corn	Beets
	translocation index			
Bentonite	3	27.04ns	214.93*	82.65ns
Linear	1	-	83.09 ns	-
Quadratic	1	-	531.88**	-
VC (%)		4.37	11.58	12.87
Mean		77.89	58.56	55.78
	translocation factor			
Bentonite	3	0.061ns	0.024ns	0.286*
Linear	1	-	-	0.064ns
Quadratic	1	-	-	0.765**
VC (%)		12.38	33.09	13.37
Mean		2.08	0.25	1.87
	bioaccumulation factor of cadmium in plant			
Bentonite	3	1.57**	0.007ns	0.218ns
Linear	1	4.50**	-	-
VC (%)		7.97	16.72	19.93
Mean		2.88	0.43	1.91
	bioaccumulation factor of cadmium in root			
Bentonite	3	0.132**	0.049ns	0.559*
Linear	1	0.333**	-	0.94*
VC (%)		10.03	20.12	17.79
Mean		0.91	0.77	1.95

DF= Degree of Freedom, ^{ns}, * and ** no significant, significant to the 5 and 1% level, respectively. VC = Variation Coefficient.

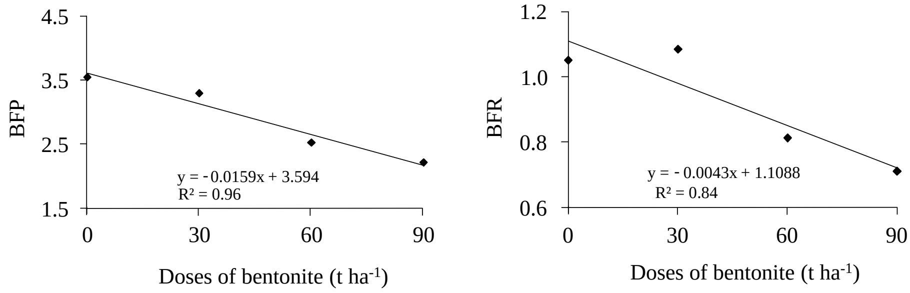

Fig 5. Bioaccumulation factor of cadmium in plant (BFP) and in root (BFR) of radish depending on dose increasing bentonite.

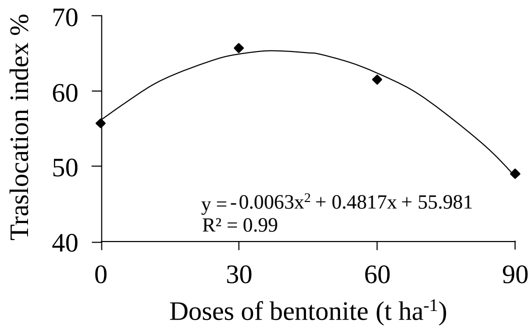

Fig 6. Cadmium translocation index in corn plants according to the increasing doses of bentonite.

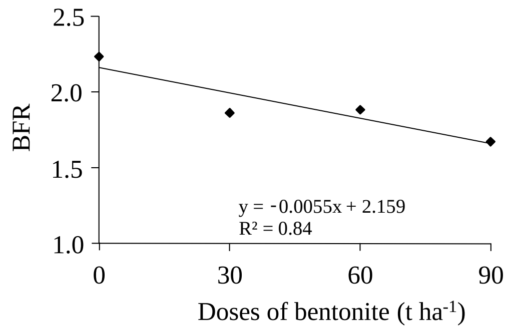

Fig 7. Bioaccumulation factor of cadmium in root (BFR) of beet depending on dose increasing bentonite.

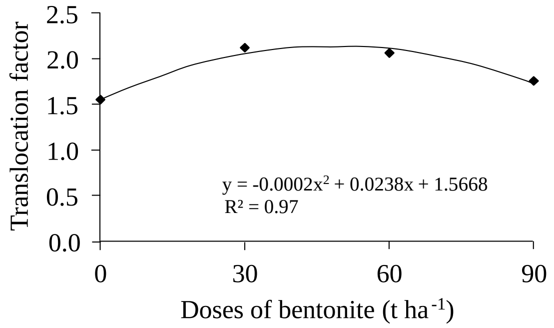

Fig 8. Cadmium translocation factor in beet plants according to the increasing doses of bentonite.

of heavy metals in agricultural soils, such as cadmium, through wastewater irrigation can result in contamination of the soil, and increased absorption of metals heavy by cultures, affecting food quality and safety (Muchuweti et al., 2006).

Only the bentonite dose corresponding to 30 t ha^{-1} promoted the reduction of 14.29% in the Cd accumulation in the corn root while the other doses did not favor the reduction of the Cd accumulation in the root (Figure 4 B) occurring an increase of 26.53% when compared to the control with the highest dose. Probably due to the value of the dry biomass of the root being higher in the doses of 60 and 90 t ha^{-1} of bentonite (Figure 2C). According to Table 4, there was highest accumulation of Cd the corn roots than in the aerial part, corroborating Yu et al. (2016), who observed a greater accumulation of this element of the rice roots. On the contrary, it was observed in the radish and beet, where the highest accumulation of Cd was in the aerial part of the plants.

The irrigation of crops with lower quality water can accumulate heavy metals in soil and/or increase absorption of these metals by plants causing major health risks to consumers (Khan et al., 2008). As discussed in the previous item, the incorporation of bentonite clay in soil was beneficial since it reduced the accumulation of Cd in plants due to loss of soil Cd transfer to plants. This is probably because the adsorption effect of bentonite.

Cadmium translocation index, translocation factor, bioaccumulation factor of cadmium in plant and in root

The ability of a plant to accumulate metals from soils can be estimated using the bioaccumulation potential in plant (BFP) and/or in root (BFR), while its ability to translocate them from the roots to the shoots is measured using the translocation factor (TF). These factors can be used to estimate a plant's potential for phytoremediation purposes.

The values of BFP and BFR of radish decreased significantly as a function of increasing doses of bentonite (Table 5), indicating an increase in the adsorption of cadmium in the soil, decreasing the concentration in the plant parts. This behavior is beneficial since clay minerals such as bentonite have a great potential to adsorb pollutants due to their large specific surface area, the layered structure, and high cation exchange capacity (Bhattacharyya and Gupta, 2008). However, the BFP and BFR (control and dose 30 t ha^{-1}) for cadmium had values more than unity (Table 1), indicating high bioaccumulation potential of radish for this metal. The BFP and BFR of radish ranged from 3.59 to 2.16 and from 1.11 to 0.72 showing a reduction of 39.82% and 34.90 %, respectively, presenting better fit in linear model (Figure 5).

Although the bentonite did not influence the TI and TF of radish (Table 5), the values of this last factor > 1 indicated a very efficient ability to transport cadmium from roots to shoots, most likely due to efficient metal transport systems according to Tito et al. (2016). These authors observed that increasing doses of bentonite promoted copper retention in the soil reducing the translocation of the element to the aerial part of several cultures. It worth noting that radish is a suitable plant for phytoextraction for this metal. This can be confirmed by the concentration data and the amounts of cadmium (Table 1) which were higher in the aerial part than in the roots. This is important because the comestible part of plant is the root. According corn data presented in Table 1, the BFP, BFR and TF values were smaller than unity, indicating low bioaccumulation potential of plant for this metal which is suitable element for phytostabilization. Although there was no significant effect of the increasing doses of bentonite on BFP, BFR and TF factors (Table 5), it can be seen in Table 1 that the application of these doses, mainly 30 and 60 t ha^{-1}, had a tendency to increase the levels of cadmium to the soil in relation to the plant and / or root, thus reducing the values of BFP and BFR. This, probably, because the presence of bentonite causes higher adsorption of cadmium in the soil. According to the values of TI and TF, there was a tendency to increase the cadmium concentration of the aerial part in relation to bentonite doses, however, the large difference between root and shoot concentrations indicates an important restriction of the internal transport of Cd from roots towards shoot, resulting in higher root concentrations rather than translocation to leaves (Table 1). Bentonite applied to the soil had a significant effect on the level of 5% probability in the TI for corn (Table 5), showing a quadratic effect (Figure 6) ranging according to equation from 55.98% to 48.30%, ie, a reduction in the order of 13.64% when compared to control with the higher dose.

As in the radish, the BFR values of beet decreased significantly at 5% of probability as a function of the bentonite doses (Table 5), ranged from 2.159 to 1.664 showing a reduction of 22.93% (Figure 7). However, all the BFR values were above the unit, showing the potential of bioaccumulation in roots, or Cd phytoextraction capacity. The BFP values also decreased in relation to control (without bentonite), however no significantly with bentonite doses (Table 5).The TF value above the unit indicates the predominance of cadmium in the aerial part in relation to the roots as can be confirmed with the concentrations of this element in roots and shoot (Table 1). The variation of these values (from 1.567 to 2.089) according to the doses of bentonite was significantly at 5% of probability increasing 33.32% according to Table 5. The behavior of these values is shown in Figure 8.

Materials and Methods

Plant materials

The cultures used in this experiment were beets (*Beta vulgaris*), radish (*Raphanus sativus*) and corn (*Zea mays* L.).

Soil, bentonite and experimental site

This study was carried out greenhouse conditions, from July 2015 to October 2015 at the Agricultural Engineering Department, Federal University of Campina Grande, Paraiba, Brazil.

The experiments were conducted with on a loamy sand soil classified as a Eutrophic Red Latosol (Embrapa, 2006), collected in Campina Grande region at a 0-20 cm soil depth. After collecting the soil, samples were air-dried, crushed, sieved through a 2 mm sieve and analyzed using the procedures recommended by Embrapa (1997).

The bentonite clay used in this study was collected from a Paraiba State region. The samples were air dried and sieved with 2 mm and 0.074 mm mesh in order to proceed chemical and X-ray diffraction analyzes, respectively.

Composition of soil and bentonite

The following attributes of soil samples were as follows: pH (H_2O) = 6.0; electrical conductivity = 0.16 mmhos cm^{-1}; Ca = 2.10 $cmol_c\ kg^{-1}$; Mg = 2.57 $cmol_c\ kg^{-1}$; Na = 0.06 $cmol_c\ kg^{-1}$; K = 0.14 $cmol_c\ kg^{-1}$; H+ Al = 1.78 $cmol_c\ kg^{-1}$; organic carbon = 5.5 g kg^{-1}; P = 45.0 mg kg^{-1} and Cd = 0.015 mg kg^{-1}.

The X-rays diaphactogram of this bentonite is presented in Figure 1. The diaphactogram picks observed are typical of the smectite (E) clays, and picks of tridymite (T), a silicate mineral and polymorph of high temperature of quartz. Picks of quartz (Q) are observed although in a low quantity.

Treatments and doses

The experiment for each plant consisted of four doses of bentonite: 0.0; 10.7; 21.4 and 32.1 g kg^{-1}, corresponding to 0. 30. 60 and 90 t ha^{-1}, respectively, with 4 repetitions in a completely randomized design totaling 16 experimental units (plastic pots).

Incubation condition and time after treatments

Soil samples mixed with the bentonite dose corresponding to treatment were placed in plastic pots with 5 kg capacity for beets and radish; and for corn in plastic pots with 14 kg. These mixtures were incubated for 20 days with moisture corresponding to field capacity.

Conduct of the study

According to Novais et al. (1991), the radish and beet was fertilized with 1.11 g of urea, 1.25 g of potassium chloride (KCl) and 8.3 g of super phosphate (P_2O_5); corn was fertilized with 3.11 g of urea, 3.5 g of KCl and 23.33 g of P_2O_5.

After the incubation period and NPK fertilization, the seeds of each crop were sown and 8 days after the emergency of seedlings, a thinning was conducted leaving two plants per pot. From this period was initiated irrigation of crops with lower quality water, ie, with water having cadmium (Cd) 0.2 mg L^{-1}. This concentration corresponds to the maximum permissible for effluents, by CONAMA Resolution n°. 20 of June 18, 1996. At the end of each culture cycle, according to the amount of water used in irrigation, the cumulative concentration in soil for cultivation of radish, corn and beet was 0.28; 0.64 and 0.84 mg kg-1 of Cd, respectively.

Harvesting of plant material

At 30; 60 and 90 days of experimental period the plants radish, corn and beet, respectively, were harvested and separated into aerial part and roots, washed with distillated water, and placed in paper bags in order to be dried in forced air stove at 65°C during 48 h. After drying, the plants were triturated and samples were weighed for foliar analyses.

Determination of cadmium in shoot and root of the plants and calculated the factors used

Plant samples were submitted to cadmium determination conducted after nitric-perchloric digestion, according to Embrapa procedures (Embrapa, 1997), using an Inductively Coupled Plasma Optical Emission Spectroscopy (ICP OES), as described by Oliva et al. (2003). The cumulative amount of Cd in dry biomass of the aerial part (shoot) and roots (mg / pot) was calculated by the expression Cd accumulated shoot or Cdaccumulated root = {Dry Biomass of shoot or Dry Biomass of root (g) x element concentration (mg kg^{-1})} / 1000. The translocation index (TI) was determined by using the follow expression (Abichequer and Bohnen, 1998): (Cdaccumulated shoot/ Cdaccumulated in the complete plant) x 100. The translocation factor (TF) gives the leaf/root cadmium concentration and depicts the ability of the plant to translocate the metal species from roots to leaves (shoot) at different concentrations. This index was calculated by the relationship: TF = (cadmium concentration in the aerial part of the plant (mg kg^{-1}) (shoot)/ cadmium concentration in the root (mg kg^{-1})) (Gupta et al., 2008). The bioaccumulation factor (BF), an index of the ability of the plant to accumulate a particular metal with respect to its concentration in the soil substrate (Ghosh and Singh, 2005), was calculated as follows: BFP = cadmium concentration in the complete plant (mg kg^{-1}) / cadmium concentration in the soil (mg kg^{-1}), or, to calculate metal bioaccumulation only in the root was: BFR = cadmium concentration in the plant root (mg kg^{-1}) / cadmium concentration in the soil (mg kg^{-1}).

Statistical analysis

SISVAR statistical program (Ferreira, 2011) was employed to analyze the obtained results, by using the F test and regression polynomials, which were used to adjust the data when significant.

Conclusion

The present study led to demonstrate that application of bentonite in soil irrigated with poor quality water had a significant positive effect on development of radish, corn and beet crops. Generally the bentonite promoted the retention of cadmium in the soil, evidenced by the reduction of the concentration and/or accumulation of this metal in the shoot and roots of radish, corn and beet. Bentonite favored the reduction of bioaccumulation and translocation factors of cadmium thereby increasing the concentration of this element in soil in relation to the plants and in shoot in relation to root, except of corn

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