Response of *Jatropha curcas* Plants to Foliar Applied Ascorbic Acid for Decreasing the Harmful Effect of Cadmium Pollution in The Irrigation Water

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ABSTRACT: The present study was carried-out at Antoniades Research Branch, Horticultural Research Institute, A.R.C. Alexandria, Egypt during the two successive seasons of 2014 and 2015. The aim of this study was to evaluate the effects of irrigation water contaminated with cadmium on *Jatropha curcas* plants grown in sandy soil and the possibility of using ascorbic acid spray treatments to overcome the effects of cadmium pollution. Seedlings of *Jatropha curcas* were planted individually in plastic pots (30 cm diameter) filled with 8 kg of sandy soil. The contaminated irrigation water treatments were four concentrations of cadmium 0,100, 200 and 300 mg/l were applied. The plants were also sprayed with ascorbic acid at concentrations of 0, 250 and 500 mg/l by monthly spraying in both seasons.

The results showed that for vegetative growth parameters there was no significant difference in the interaction between cadmium concentrations and foliar spray by ascorbic acid. While a significant reduction was observed in all parameters after irrigation with cadmium contaminated water and a significant increase in vegetative growth parameters was observed after 500 mg/l ascorbic acid application. For chlorophyll and carbohydrate content, the highest significant value was obtained from plants irrigated with tap water and sprayed with 500 mg/l ascorbic acid while the highest significant amount of cadmium content in leaves, stem and roots was obtained from the treatment 300 mg/l cadmium without application of ascorbic acid.
Key wards: *Jatropha curcas*, cadmium, ascorbic acid.

INTRODUCTION

Planting Jatropha in Egypt started in 2004 (SWERI, 2009). It is still in the experimental stage, but it has been proved that the potential to plant this tree is high in the marginal areas and desert. The planting of this tree has succeeded in Upper Egypt. Nevertheless, the growth and blooming periods in this area is shorter than that in other countries; it produces flowers after 18 months while in other countries it needs three years. The industrial effluents often contain large quantity of toxic heavy metals (Ghavri and Singh, 2010). These metals are non bio-degradable and persistent and can be differentially toxic to microbes (Giller *et al*., 2009), plants (Ghavri *et al*., 2010; Sharma *et al*., 2010), animals (Rainbow, 2007) and human being (Lim and Schoenung, 2010). *Jatropha curcas* L. (Family: Euphorbiaceae) is a potential biodiesel plant, which (Gunaseelan, 2009), can survive harsh environments of semi-arid agro-climatic conditions, wastelands (Mangkoedihardjo and Sunahmadia, 2008) and grows fast with little maintenance. It can reach a height of 3-8 m. Genus Jatropha has 172 species having significant economic importance is native to Central America and distributed in Africa and Asia (Cano- Asseleih *et al*., 1989 and Fairless, 2007). Among the various Jatropha species, *J. curcas, J. glandulifera, J. gossypifolia* (Achten *et al*., 2008), identified as the most suitable oil bearing plant, and has been recommended for plantation on waste land. *Jatropha curcas* L., is a perennial crop with potential such as medicinal and biodiesel crop recently and is recognized as potential oil seed (Effendi *et al*., 2010; Rafii *et al*., 2012; Shabanimofrad *et al*., 2011). This plant has a great importance as a medicinal plant in treating tropical diseases of dermatological origin (Igbinosa *et al*., 2009). Also the attention on this crop has increased due to high rate of ozone layer depletion and global warming effect caused by increased usage of fossil fuel resulting in environmental pollution. Renewable biofuel feed stocks are perceived to be essential contributors to the energy supply portfolio as they contribute to the world energy supply security, reducing dependency on fossil fuel resources and provide opportunity for mitigating greenhouse gases (Sudhakar and Nalini, 2011). This newly introduced crop, which grows abundantly in wild and abandoned land, has its seed and oil yield unpredictable especially in tropical climate. Favourable environmental conditions that affect its production are yet to be known (Ovando-Medina *et al*., 2011 and Divakara *et al*., 2010). Ginwal *et al*. (2005) reported that Jatropha has adapted itself to wide range of environmental and ecological conditions which suggests that, there exists considerable amount of genetic diversity yet to be detected for potential realization (Rao *et al*., 2008).

Plants need trace amount of heavy metal but their excessive availability may cause plant toxicity (Sharma *et al*., 2006). Phytotoxic concentration of the heavy metals referred in the literature does not always specify the levels (Wua *et al*., 2010). Cadmium is a toxic heavy metal that has an environmental concern (Mahler *et al.,* 1981). There are many sources of environmental cadmium pollution, including fuel combustion, industrial sludges, phosphate fertilizers, and mine tailings (Unhalekhana and Kositanont, 2008). Cadmium can be absorbed by the human body through respiration and consumption, and cadmium then accumulates in the liver and kidney, causing acute and chronic symptoms such as nausea, abdominal pain, diarrhea, kidney dysfunction, and osteomalacia (Simmons *et al*., 2005).

Ascorbic acid is an essential antioxidant in the ascorbate-glutathione pathway, but it also protects enzymes that have prosthetic transition metal ions. Furthermore, it is a cofactor for many enzymes, including those involved in the cell wall synthesis, most notably in the hydroxylation of proline residues (Ishikawa *et al.* 2006). Moreover, alternative oxidase can be induced by H_2O_2 accumulation and, as ascorbate is involved in controlling the intracellular H_2O_2 level, this might provide the means for a concerted interaction to protect the cell against uncontrolled oxidation (Bartoli *et al.* 2006).

In this study *Jatropha curcas* was selected due to its characteristics as non-edible plant which can grow in tropical areas and its commercial viability for the production of biodiesel, therefore the objective of this study is to determine the potential of *Jatropha curcas* in removing heavy metals from the soil affected contaminated irrigation water and to investigate on the ability of Jatropha in removing heavy metals.

MATERIALS AND METHODS

The present study was carried-out at Antoniades Research Branch, Horticultural Research Institute, A.R.C. Alexandria, Egypt during the two successive seasons of 2014 and 2015. The aim of this study was to evaluate the effects of irrigation water contaminated with cadmium on *Jatropha curcas* plants grown in sandy soil, the possibility of using ascorbic acid spray treatments to overcome the effects of cadmium pollution.

On the 15th of February, 2014 and 2015 (in the first and second seasons, respectively) identical seedlings of *Jatropha curcas* (70-80 cm height and 20-25 leaves per plant in average) were planted individually in plastic pots (30 cm diameter) filled with 8 kg of sandy soil. The chemical constituents of the soil were measured as described by Jackson (1958) in Table (1).

Table (1). Chemical analyses of the used sandy soil for the two successive seasons 2014 and 2015.

Season	pH	EC (dSm^{-1})	Soluble cations (meq/l)				Soluble anions (meq/l)		
			Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_2^{--}
2014	7.94	1.57	3.4	3.4	6.5	1.2	3.6	6.7	2.4
2015	7.91	1.52	3.2	3.0	6.3	1.1	3.3	6.5	2.2

On the 1st of March (in both seasons), the contaminated irrigation water treatments were initiated. Four concentrations of cadmium acetate [$(CH_3COO)_2$ $Cd.2H_2O$] 0,100, 200 and 300 mg/l were applied. The plants were irrigated three times per week; at the end of the experiment every plant received about 250 liters per pot of contaminated water in Table (2). In both seasons, the plants were received by monthly spraying from 15th May till 15th August in both seasons. The plants were also sprayed with ascorbic acid at concentrations of 0, 250 and 500 mg/l. Control plants were sprayed with tap water. On 30th of September in the both seasons, the plants were harvested.

Table (2). Total amount of the water used for each plant (l/pot) in each treatment during the growing two season of 2014 and 2015.

Field Capacity (%)	Months of first and second seasons							
	March	April	May	June	July	August	September	Total
90 %	28.00	30.00	32.00	35.00	40.00	45.00	40.00	**250.00**

In the two seasons, all plants received NPK chemical fertilization using soluble fertilizer (Kristalon 19-19-19) at the rate of 3 g/ pot. Fertilization was repeated every 30 days throughout the growing season (from the 1th of March till the 30th of September). In addition, weeds were removed manually upon emergence.

Data recorded :

(1) Vegetative growth parameters:

Plant height (cm), number of leaves per plant, leaves dry weight per plant (g), leaves area (cm^2) according to Koller (1972), stem diameter (cm), stem dry weight (g), root length (cm) and root dry weight (g).

(2) Chemical analysis determination:

- Total chlorophylls content was determined as a SPAD from the fresh leaves of plants for the different treatments under the experiment at the end of the season using Minolta (chlorophyll meter) SPAD 502 according to Yadava (1986).
- Total carbohydrates percentage in the leaves was determined according to Dubios *et al.*(1956).
- Determination of Cadmium content. Plant samples were divided into leaves stem and roots. They were then dried at 72°C in an oven until completely dried. The dried plant samples were ground to powder. The dried samples were then digested for extraction of cadmium, using the method described by Piper (1947) method and the concentration of heavy metal was determined using an atomic absorption spectrophotometer.
- Available heavy metal, i.e. (Cadmium) in soil samples were extracted by DPTA solution according to Lindsay and Norvell (1978) and determined by Inductively Coupled Plasma Spectrometry.
- Transfer factor (TF) is given by the relation: the ratio of the concentration of metal in the shoots to the concentration of metal in the soil (Chen *et al.*, 2004). The transfer factor is a value used in evaluation studies on the impact of routine or accidental releases of pollutant into the environment.

The layout of the experimental design was split plot design with three replicates. Each replicate contained three plants. The main plots were the contaminated irrigation water levels while the sup plots were the concentrations of ascorbic acid. The means of the individual factors and their interactions were compared by L.S.D test at 5% level of probability according to Snedecor and Cochran (1974).

RESULTS

Vegetative growth:

Plant height (cm)

Data presented in Table (3) Showed that, in both seasons, irrigation water contaminated with cadmium decreased the height of *Jatropha curcas* plants, compared to plants irrigated with tap water (control). Plants irrigated with tap water had the highest mean values of plant height 43.49 and 47.33 cm in the first and second seasons, respectively. Moreover, raising the cadmium concentration caused steady significant reductions in plant height, with the highest concentration (300 mg/l) giving significantly the shortest plants (with mean heights of 33.36 and 36.49 cm in the two seasons, respectively) than those receiving any other cadmium concentration.

Plant height was also significantly affected by spraying the plants with ascorbic acid. In both seasons, plant height increased gradually when the ascorbic acid concentration was raised from 0 mg/l (control) to 500 mg/l. Accordingly, it can be seen from the data in Table (3) that *Jatropha curcas* plants sprayed with 500 mg/l ascorbic acid were significantly taller (with mean plant heights of 39.70 and 42.60 cm in the first and second seasons, respectively) than plants sprayed with any other ascorbic acid concentrations.

Regarding the interaction between the effects of irrigation with contaminated cadmium water and ascorbic acid treatments on growth rate of the plant height of *Jatropha curcas* plants, the results recorded in the two seasons show that, the highest values were obtained in the plants irrigated with tap water and sprayed with ascorbic acid at 500 mg/l (with mean heights of 44.91 and 48.50 cm in the first and second seasons, respectively). On the other hand, the shortest plants (with mean heights of 30.25 and 33.83 cm in the first and second seasons, respectively) were resulted in when the plants were irrigated using the highest cadmium concentration (300 mg/l) without ascorbic acid treatment. It can also been seen from the data presented in Table (3) that in many cases, spraying the plants with ascorbic acid reduced the undesirable effect of contaminated water with cadmium.

Number of leaves per plant

The data presented in Table (3) show the effect of contaminated water with cadmium on number of leaves formed on *Jatropha curcas* plants. In both seasons, plants irrigated with tap water had the highest number of leaves 21.71 and 19.99 leaves per plant in the first and second seasons, respectively. While, the lowest number of leaves (16.83 and 15.27 leaves per plant in the first and second seasons, respectively), was formed by plants that were irrigated using the highest cadmium concentration (300 mg/l).

Concerning the effect of ascorbic acid treatments on the number of leaves, the data recorded in the two seasons (Table 3) show that only one ascorbic acid treatment 500 mg/l caused a significant increase in the number of leaves giving mean values of 19.95 and 17.91 leaves per plant in the first and second seasons, respectively, compared to that of control plants (17.62 and 16.62 leaves per plant in the two seasons, respectively).

Data in Table (3) show that, significant interaction was detected in both seasons between the effects of irrigation with contaminated cadmium water and ascorbic acid treatments on the number of leaves formed by *Jatropha curcas* plants. Combining irrigation using tap water with spraying the plants with ascorbic acid at 500 mg/l gave the highest number of leaves of 22.33 and 20.50 leaves per plant in the first and second seasons, respectively. On the other hand, the lowest number of leaves of 15.33 and 14.33 leaves per plant in the first and second seasons, respectively, were obtained on plants irrigated using the highest cadmium concentration 300 mg/l and sprayed without any ascorbic acid concentration.

Leaves dry weight (g) per plant

The results recorded in the two seasons Table (3) show that the highest dry weight values of leaves (20.22 and 22.00 g in the first and second seasons, respectively), were obtained from plants irrigated with tap water. Moreover, the recorded values were decreased steadily with raising the cadmium concentration. Accordingly, the lowest values 15.50 and 16.96 g per plant in the first and second seasons, respectively, were obtained from plants irrigated with the highest cadmium concentration 300 mg/l.

Data presented In Table (3) also show that spraying *Jatropha curcas* plants with ascorbic acid at 500 mg/l significantly increased the dry weight of leaves giving values of 18.46 and 19.80 g per plant in the first and second seasons, respectively, compared to the control (16.28 and 18.33 g per plant in the first and second seasons, respectively).

Regarding the interaction between the effects of irrigation with contaminated cadmium water and ascorbic acid treatments on the dry weight of leaves of *Jatropha curcas*, the data presented in Table (3) showed that the highest dry weight values of leaves of (20.88 and 22.55 g in the first and second seasons, respectively), were obtained in plants irrigated with tap water and sprayed with ascorbic acid at 500 mg/l, whereas the lowest dry weights of leaves of 14.06 and 15.73 g in the first and second seasons, respectively, were obtained when the plants were irrigated using the highest cadmium concentration 300 mg/l without any ascorbic acid treatment.

Leaves area (cm^2)

The results recorded for both seasons Table (3) show that irrigation with contaminated cadmium water decreased the leaf area of *Jatropha curcas* plants, compared to plants irrigated with tap water (control). In both seasons, plants irrigated with tap water (control) had the largest leaves with mean areas of 1172.80 and 1284.13 cm^2 in the first and second seasons, respectively. The leaf area was decreased steadily with raising the cadmium concentration. Accordingly, the smallest leaves with mean areas of 699.96 and 763.92 cm^2 in the first and second seasons, respectively, were those formed on plants that were irrigated using the highest cadmium concentration 300 mg/l.

Data presented in Table (3) show that, in most cases, the different ascorbic acid treatments had no significant effect on leaf area of *Jatropha curcas* plants. The only exception to this common trend was recorded in the first season, with plants sprayed using ascorbic acid at 500 mg/l forming significantly larger leaves with a mean area of (1021.99 and 1095.17 cm^2 in the first and second seasons, respectively), than those formed by control plants (731.25 and 825.93 cm^2).

Data presented in Table (3) also show that significant interaction was detected between the effects of irrigation with contaminated cadmium water and ascorbic acid treatments on the area of *Jatropha curcas* leaves. The largest leaves with mean areas of 1375.95 and 1499.90 cm2 in the first and second seasons, respectively, was formed by plants irrigated with tap water and sprayed with ascorbic acid at 500 mg/l. On the other hand, the smallest leaves (with areas of 584.20 and 654.73 cm^2 in the first and second seasons, respectively) were obtained on plants irrigated using the highest cadmium concentration 300 mg/l at the lowest concentration 0 mg/l ascorbic acid treatment.

Table (3). Averages of plant height (cm), number of leaves per plant, leaves dry weight (g) and leaves area (cm^2) of *Jatropha curcas* plants as influenced by Cadmium (Cd), Ascorbic acid (AA) and their combinations (Cd× AA) in the two seasons of 2014 and 2015.

Treatments		Plant height (cm)		Number of leaves per plant		Leaves dry weight (g)		Leaves area (cm^2)	
Cd (mg/l)	Ascorbic acid (mg/l)	2014	2015	2014	2015	2014	2015	2014	2015
0	0	42.33	46.50	21.16	19.66	19.68	21.62	941.91	1040.20
	250	43.25	47.00	21.66	19.83	20.10	21.85	1200.54	1312.31
	500	44.91	48.50	22.33	20.50	20.88	22.55	1375.95	1499.90
Average		**43.49**	**47.33**	**21.71**	**19.99**	**20.22**	**22.00**	**1172.80**	**1284.13**
100	0	33.66	40.50	16.83	17.00	15.65	18.83	710.53	859.89
	250	37.16	42.08	18.83	17.50	17.28	19.56	860.86	961.16
	500	39.83	43.83	20.16	18.33	18.52	20.37	994.41	1077.91
Average		**36.88**	**42.13**	**18.60**	**17.61**	**17.15**	**19.58**	**855.26**	**966.32**
200	0	33.91	36.91	17.16	15.50	15.76	17.16	688.38	748.90
	250	36.33	39.75	18.33	16.83	16.89	18.48	803.18	884.10
	500	38.25	40.08	19.33	17.00	17.78	18.63	893.20	932.70
Average		**36.16**	**38.91**	**18.27**	**16.44**	**16.81**	**18.09**	**794.92**	**855.23**
300	0	30.25	33.83	15.33	14.33	14.06	15.73	584.20	654.73
	250	34.00	37.66	17.16	15.66	15.80	17.51	691.30	766.84
	500	35.83	38.00	18.00	15.83	16.66	17.66	824.40	870.20
Average		**33.36**	**36.49**	**16.83**	**15.27**	**15.50**	**16.96**	**699.96**	**763.92**
Mean (AA)	0	35.03	39.43	17.62	16.62	16.28	18.33	731.25	825.93
	250	37.68	41.62	18.99	17.45	17.51	19.35	888.97	981.10
	500	39.70	42.60	19.95	17.91	18.46	19.80	1021.99	1095.17
L.S.D. at 0.05	**Cd**	**1.77**	**1.36**	**0.95**	**1.60**	**0.82**	**0.63**	**44.10**	**36.23**
	AA	**0.81**	**0.86**	**0.41**	**0.45**	**0.37**	**0.40**	**18.25**	**22.40**
	Cd * AA	**1.86**	**1.98**	**0.95**	**1.03**	**0.86**	**0.92**	**42.02**	**51.57**

Stem diameter (cm)

The data recorded for the stem diameter of *Jatropha curcas* plants in the two seasons Table (4) show that irrigation with contaminated cadmium water decreased stem thickness, compared to that of plants irrigated with tap water (control). In both seasons, plants irrigated with tap water had the thickest stems, with mean diameters of 5.28 and 5.75 cm in the first and second seasons, respectively. Raising the cadmium concentration in irrigation water caused a steady reduction in stem diameter. This reduction in stem diameter was significant (compared to the control), even at the lowest cadmium concentration (300 mg/l), which gave stem diameters of 4.05 and 4.43 cm in the first and second seasons, respectively.

In contrast to the effect of cadmium treatments, ascorbic acid treatments improved stem diameter of *Jatropha curcas* plants, compared to the control. Moreover, plants sprayed with 500 mg/l ascorbic acid had significantly thickest stems (with mean diameters of 4.82 and 5.18 cm in the first and second seasons, respectively), compared to the those of control plants, or plants sprayed with any other ascorbic acid concentration.

Regarding the interaction between the effects of irrigation with contaminated cadmium water and ascorbic acid treatments on growth rate of the stem diameter of *Jatropha curcas* plants, the results recorded for the two seasons (Table 4) show that significant differences were detected between the values obtained from plants receiving the different treatment combinations. The highest values (5.46 and 5.90 cm in the first and second seasons, respectively) were obtained in the plants irrigated with tap water and sprayed with ascorbic acid at 500 mg/l. On the other hand, the thinnest stems (with diameters of 3.68 and 4.11 cm in the first and second seasons, respectively) were obtained in the plants irrigated using the highest cadmium concentration 300 mg/l without ascorbic acid treatment. It can also be seen that in some cases, the ascorbic acid treatments helped to overcome the adverse effect of the cadmium treatments on stem thickening.

Stem dry weight (g)

Data presented in Table (4) show that, in both seasons, irrigation using contaminated water with cadmium significantly decreased dry weights of stem of *Jatropha curcas* plants, compared to plants irrigated with tap water (control). Plants irrigated with tap water had the heaviest mean dry weight of stems 37.25 and 41.34 g per plant in the first and second seasons, respectively. The dry weight of stems showed a gradual reduction as the cadmium concentration was increased. Accordingly, the lowest dry weights of stem 30.16 and 33.57 g per plant in the first and second seasons, respectively, were recorded in plants receiving the highest cadmium concentration 300 mg/l.

The results recorded in the two seasons (Table 4) show that, in both seasons, spraying the plants with ascorbic acid increased the dry weight of stem. In both seasons, spraying plants with 500 mg/l ascorbic acid gave the heaviest dry weight of stem 34.09 and 37.47 g per plant in the first and second seasons, respectively. These values were significantly higher than those of control plants, or plants receiving any other ascorbic acid concentration.

Regarding the interaction between the effects of irrigation contaminated water with cadmium and ascorbic acid treatments, the results recorded in the two seasons show that the heaviest stems dry weights of 38.55 and 42.01 g per plant in the first and second seasons, respectively, were those of plants irrigated with tap water and sprayed without ascorbic acid. On the other hand, the lowest stem dry weights (29.28 and 32.52 g per plant in the first and second seasons, respectively) were obtained in plants irrigated using the highest cadmium concentrations 300 mg/l without ascorbic acid treatment.

Root length (cm)

Data presented in Table (4) show that all the tested treatments of irrigation water contaminated with cadmium significantly decreased the root length (cm) of *Jatropha curcas,* compared to that of plants irrigated with tap water (control). In both seasons, plants irrigated with tap water had the highest mean root length 50.02 and 49.60 cm in the first and second seasons, respectively. Raising the cadmium concentration caused a steady reduction in the root length, which reached its lowest values 38.35 and 40.37 cm in the first and second seasons, respectively, in plants irrigated using the highest cadmium concentration 300 mg/l.

The data in Table (4) also indicate that ascorbic acid treatments had a significant effect on the root length. In both seasons, *Jatropha curcas* plants sprayed with ascorbic acid, compared to the control plants. As with the other vegetative growth parameters, spraying the plants with ascorbic acid at 500 mg/l gave the heaviest root length 45.65 and 45.87 cm in the first and second seasons, respectively.

Regarding the interaction between the effects of irrigation using water contaminated with cadmium and ascorbic acid treatments on root length of *Jatropha curcas* plants, the results recorded in the two seasons showed that, the highest values were obtained in plants irrigated with tap water and sprayed with ascorbic acid at 500 mg/l (with mean length of 51.65 and 50.69 cm in the first and second seasons, respectively). On the other hand, the shortest roots (with mean length of 31.78 and 39.57 cm in the first and second seasons, respectively) were those irrigated using the highest cadmium concentration 300 mg/l without ascorbic acid treatment. It can also been seen from the data presented in Table (4) that in many cases, spraying the plants with ascorbic acid reduced the undesirable effect of cadmium.

Root dry weight (g)

Data presented in Table (4) show that irrigation of *Jatropha curcas* plants using water contaminated with cadmium significantly decreased the dry weights of roots, compared to plants irrigated with tap water (control). In both seasons, plants irrigated with tap water had the heaviest dry weight of roots 28.73 and 31.67 g per plant in the first and second seasons, respectively. Steady significant reductions in the dry weight of roots were recorded as the cadmium concentration in the irrigation water was increased, with the highest cadmium concentration 300 mg/l giving the lowest mean values in both seasons 22.83 and 25.26 g per plant in the first and second seasons, respectively.

Regarding the effect of ascorbic acid treatments on the dry weight of roots, data in Table (4) show that spraying *Jatropha curcas* plants with ascorbic acid at 500 mg/l significantly increased the recorded values, compared to the control. The highest weight dry roots 25.59 and 28.13 g per plant in the first and second seasons, respectively, were those of plants sprayed with ascorbic acid at 500 mg/l.

Regarding the interaction between the effects of irrigation using water contaminated with cadmium and ascorbic acid treatments, the data presented in Table (4) show that the highest values (29.71 and 32.28 g per plant in the first and second seasons, respectively) were obtained in plants irrigated with tap water and sprayed without ascorbic acid. On the other hand, the lowest dry weight of roots (21.67 and 24.12 g per plant in the first and second seasons, respectively) were obtained from plants irrigated using the highest cadmium concentration 300 mg/l, with no ascorbic acid treatment.

Table (4). Averages of stem diameter (cm), stem dry weight (g), root length (cm) and root dry weight (g) of *Jatropha curcas* plants as influenced by Cadmium (Cd), Ascorbic acid (AA) and their combinations (Cd × AA) in the two seasons of 2014 and 2015.

reatments		Stem diameter (cm)		Stem dry weight (g)		Root length (cm)		Root dry weight (g)	
Cd (mg/l)	**Ascorbic acid(mg/l)**	**2014**	**2015**	**2014**	**2015**	**2014**	**2015**	**2014**	**2015**
000	0	5.14	5.65	38.55	42.01	48.68	48.77	29.71	32.28
	250	5.26	5.72	36.35	41.08	49.73	49.35	28.23	31.46
	500	5.46	5.90	36.85	40.93	51.65	50.69	28.26	31.27
Average		**5.28**	**5.75**	**37.25**	**41.34**	**50.02**	**49.60**	**28.73**	**31.67**
100	0	4.09	4.92	29.32	32.20	38.71	38.81	23.29	25.88
	250	4.52	5.12	32.10	34.66	42.73	42.73	24.57	27.52
	500	4.84	5.33	33.50	37.27	45.80	44.94	25.31	28.05
Average		**4.48**	**5.12**	**31.64**	**34.71**	**42.41**	**42.16**	**24.39**	**27.15**
200	0	4.12	4.49	26.00	29.30	39.05	35.36	21.89	23.96
	250	4.42	4.83	33.50	35.97	41.77	42.26	25.19	27.21
	500	4.65	4.87	34.77	37.25	43.98	46.09	25.26	27.23
Average		**4.39**	**4.73**	**31.42**	**34.17**	**41.60**	**41.23**	**24.11**	**26.13**
300	0	3.68	4.11	29.28	32.52	34.78	39.57	21.67	24.12
	250	4.13	4.58	29.93	33.75	39.09	39.76	23.29	25.70
	500	4.36	4.62	31.27	34.45	41.20	41.78	23.54	25.98
Average		**4.05**	**4.43**	**30.16**	**33.57**	**38.35**	**40.37**	**22.83**	**25.26**
Mean (AA)	0	4.25	4.79	30.78	34.00	40.30	40.62	24.14	26.56
	250	4.58	5.06	32.97	36.36	43.33	43.52	25.32	27.97
	500	4.82	5.18	34.09	37.47	45.65	45.87	25.59	28.13
L.S.D. at 0.05	**Cd**	**0.21**	**0.16**	**1.45**	**1.61**	**2.05**	**1.56**	**1.10**	**1.08**
	AA	**0.09**	**0.10**	**0.55**	**0.58**	**0.94**	**0.74**	**0.21**	**0.34**
	Cd * AA	**0.21**	**0.23**	**1.28**	**1.34**	**2.17**	**1.72**	**0.50**	**0.78**

Chemical constituents
Total chlorophyll content (SPAD)

The results presented in Table (5) show that the highest content of total chlorophyll was obtained in plant irrigation with tap water 54.52 and 54.73 SPAD in the first and second seasons, respectively. Raising the cadmium concentration in irrigation water resulted in steady significant reductions in the total chlorophyll content, which reached its lowest value 49.46 and 49.89 SPAD in the first and second seasons, respectively, in plants receiving the highest cadmium concentration 300 mg/l.

The results of leaf chemical analysis Table (5) also show that ascorbic acid treatments had clear effect on the total chlorophyll content. The recorded mean values ranged from 53.79 and 53.96 SPAD in the first and second seasons, respectively, in plants sprayed with ascorbic acid at 250 mg/l to 48.92 and 49.43 SPAD in the first and second seasons, respectively, in plants sprayed with ascorbic acid at 0 mg/l.

Regarding to the interaction between the effects of irrigation using water contaminated with cadmium and ascorbic acid treatments, the data presented in Table (5) showed that the highest total chlorophyll contents of 56.19 and 56.29 in the first and second seasons, respectively, were found in leaves of plants irrigated with tap water and sprayed with ascorbic acid at 500 mg/l, the lowest values of 46.37 and 47.13 in the first and second seasons, respectively, were obtained in plants irrigated with cadmium water at 100 mg/l and sprayed with tap water.

Carbohydrates content (%)

Data resulting from chemical analysis Table (5) show that, the total carbohydrates % in the dried leaves of *Jatropha curcas* plants was decreased steadily with raising the cadmium concentration in the irrigation contaminated water with cadmium. The highest mean carbohydrates content 20.28 and 20.27 % in the first and second seasons, respectively, was found in the leaves of control plants, whereas the lowest mean value 18.15 and 18.48 % in the first and second seasons, respectively, was found in plants irrigated with water containing the highest cadmium concentration 300 mg/l.

The results in Table (5) also show that most of the tested ascorbic acid concentrations increased the mean total carbohydrates % in the leaves of *Jatropha curcas* plants, compared to the control. Among the plants receiving the different ascorbic acid treatments, plants sprayed with 250 mg/l ascorbic acid had the highest carbohydrate % in leaves 19.55 and 19.83 % in the first and second seasons, respectively.

Concerning the interaction between the effects of irrigation using water contaminated with cadmium and ascorbic acid treatments on the carbohydrates content % of leaves. The results presented in Table (5) show that the highest mean values of 20.82 and 20.85 % in the first and second seasons, respectively, were obtained in the leaves of plants irrigated with tap water and sprayed with ascorbic acid at 500 mg/l. On the other hand, the lowest carbohydrates content was obtained in the leaves of plants irrigated with cadmium water at 100 mg/l and receiving no ascorbic acid treatment.

Cadmium content in leaves (mg/kg)

The data resulting from leaves chemical analysis Table (5) show that, the cadmium content (mg/kg) in the dried leaves of *Jatropha curcas* plants was raised steadily with raising the cadmium concentration in the irrigation water. The lowest mean cadmium content 0.002 and 0.003 mg/kg in the first and second seasons, respectively, was found in the leaves of control plants, whereas the highest mean value 0.009 and 0.010 mg/kg in the first and second seasons, respectively, was found in plants irrigated with water containing the highest cadmium concentration 300 mg/l.

Concerning the effect of ascorbic acid treatments on the cadmium content in leaves, the data recorded in the two seasons Table (5) show that only one ascorbic acid treatment 500 mg/l caused a significant decrease in the cadmium content in leaves giving mean values of 0.003 and 0.004 mg/kg in the first and second seasons, respectively, compared to that of control plants had the highest cadmium content in leaves 0.008 and 0.009 mg/kg in the first and second seasons, respectively.

Concerning the interaction between the effects of irrigation using water contaminated with cadmium and ascorbic acid treatments on the cadmium content in leaves. The results in Table (5) show that the lowest mean values of 0.002 and 0.002 mg/kg in the first and second seasons, respectively, were obtained in the leaves of plants irrigated with tap water and sprayed with ascorbic acid at 500 mg/l. On the other hand, the highest cadmium content was obtained in the leaves of irrigated with cadmium water at 300 mg/l and receiving no ascorbic acid treatment (0.014 and 0.015 mg/kg in the first and second seasons, respectively).

Cadmium content in stem (mg/kg)

The data resulting from stem chemical analysis Table (5) show that, the cadmium content (mg/kg) in the dried stem of *Jatropha curcas* plants was raised steadily with raising the cadmium concentration in the irrigation water. The lowest mean cadmium content 0.007 and 0.009 mg/kg in the first and second seasons, respectively, was found in the stem of control plants, whereas the highest mean value 0.023 and 0.029 mg/kg in the first and second seasons, respectively, was found in plants irrigated with water containing the highest cadmium concentration 300 mg/l.

Concerning the effect of ascorbic acid treatments on the cadmium content in stem, the data recorded in the two seasons Table (5) show that only one ascorbic acid treatment 500 mg/l caused a significant decrease in the cadmium content in stem giving mean values of 0.011 and 0.012 mg/kg in the first and second seasons, respectively, compared to that of control plants had the highest cadmium content in stem 0.026 and 0.028 mg/kg in the first and second seasons, respectively.

Concerning the interaction between the effects of irrigation using water contaminated with cadmium and ascorbic acid treatments on the cadmium content in stem. The results in Table (5) show that the lowest mean values of 0.005 and 0.006 mg/kg in the first and second seasons, respectively, were obtained in the stem of plants irrigated with tap water and sprayed with ascorbic acid at 500 mg/l. On the other hand, the highest cadmium content was obtained in the stem of irrigated with cadmium water at 300 mg/l and receiving no ascorbic acid treatment (0.041 and 0.045 mg/kg in the first and second seasons, respectively).

Cadmium content in roots (mg/kg)

The data resulting from roots chemical analysis Table (5) show that, the cadmium content (mg/kg) in the dried roots of *Jatropha curcas* plants was raised steadily with raising the cadmium concentration in the irrigation water. The lowest mean cadmium content 0.011 and 0.013 mg/kg in the first and second seasons, respectively, was found in the roots of control plants, whereas the highest mean value 0.039 and 0.042 mg/kg in the first and second seasons, respectively, was found in plants irrigated with water containing the highest cadmium concentration 300 mg/l.

Concerning the effect of ascorbic acid treatments on the cadmium content in roots, the data recorded in the two seasons Table (5) show that only one ascorbic acid treatment 500 mg/l caused a significant decrease in the cadmium content in roots giving mean values of 0.016 and 0.018 mg/kg in the first and second seasons, respectively, compared to that of control plants had the highest cadmium content in roots 0.038 and 0.041 mg/kg in the first and second seasons, respectively.

Concerning the interaction between the effects of irrigation using water contaminated with cadmium and ascorbic acid treatments on the cadmium content in roots. The results in Table (5) show that the lowest mean values of 0.008 and 0.009 mg/kg in the first and second seasons, respectively, were obtained in the roots of plants irrigated with tap water and sprayed with ascorbic acid at 500 mg/l. On the other hand, the highest cadmium content was obtained in the roots of irrigated with cadmium water at 300 mg/l and receiving no ascorbic acid treatment (0.059 and 0.065 mg/kg in the first and second seasons, respectively).

Table (5). Averages of chemical constituents characteristics of *Jatropha curcas* plants as influenced by cadmium (Cd), Ascorbic acid (AA) and their combinations (Cd×AA) in the two seasons of 2014 and 2015.

Treatments		Chlorophyll content (SPAD)		Carbohydrates content (%)		Cadmium content in leaves (mg/kg)		Cadmium content in stem (mg/kg)		Cadmium content in roots (mg/kg)	
Cd (mg/l)	Ascorbic acid (mg/l)	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
000	0	52.87	53.29	19.84	19.75	0.003	0.004	0.010	0.012	0.014	0.017
	250	54.52	54.61	20.20	20.23	0.003	0.003	0.008	0.009	0.012	0.013
	500	56.19	56.29	20.82	20.85	0.002	0.002	0.005	0.006	0.008	0.009
Average		**54.52**	**54.73**	**20.28**	**20.27**	**0.002**	**0.003**	**0.007**	**0.009**	**0.011**	**0.013**
100	0	46.37	47.13	17.18	17.46	0.007	0.007	0.022	0.022	0.032	0.032
	250	55.77	55.86	20.18	20.43	0.007	0.006	0.020	0.020	0.029	0.028
	500	54.00	54.42	19.73	20.14	0.003	0.004	0.010	0.012	0.015	0.017
Average		**52.04**	**52.47**	**19.03**	**19.34**	**0.005**	**0.005**	**0.017**	**0.018**	**0.025**	**0.025**
200	0	49.04	49.13	17.90	18.20	0.011	0.012	0.033	0.035	0.048	0.050
	250	53.36	53.45	19.26	19.45	0.008	0.008	0.024	0.025	0.035	0.036
	500	52.44	52.53	18.67	18.78	0.005	0.006	0.016	0.018	0.023	0.026
Average		**51.61**	**51.70**	**18.61**	**18.81**	**0.008**	**0.008**	**0.024**	**0.026**	**0.035**	**0.037**
300	0	47.42	48.17	17.56	17.84	0.014	0.015	0.041	0.045	0.059	0.065
	250	51.51	51.95	18.57	19.24	0.009	0.010	0.027	0.029	0.038	0.041
	500	49.47	49.57	18.33	18.36	0.005	0.005	0.014	0.015	0.020	0.021
Average		**49.46**	**49.89**	**18.15**	**18.48**	**0.009**	**0.010**	**0.027**	**0.029**	**0.039**	**0.042**
Mean (AA)	0	48.92	49.43	18.12	18.31	0.008	0.009	0.026	0.028	0.038	0.041
	250	53.79	53.96	19.55	19.83	0.006	0.006	0.019	0.020	0.028	0.029
	500	53.02	53.20	19.38	19.53	0.003	0.004	0.011	0.012	0.016	0.018
L.S.D. at 0.05	**Cd**	**0.71**	**0.82**	**0.79**	**0.28**	**0.003**	**0.004**	**0.009**	**0.013**	**0.012**	**0.019**
	AA	**0.84**	**0.81**	**0.43**	**0.35**	**0.002**	**0.003**	**0.005**	**0.008**	**0.007**	**0.012**
	Cd * AA	**1.94**	**1.86**	**0.98**	**0.82**	**0.004**	**0.006**	**0.012**	**0.020**	**0.015**	**0.027**

Transfer factor (TF) of heavy metals

Transfer factor (TF) indicates the efficiency of plants to transfer metals from root to the aerial parts.

Cadmium content in soil samples (mg/kg)

Data in Table (6) showed that the lowest average of cadmium content was observed in soil cultured by untreated plants, while the highest average of cadmium content was observed in soil after the treatment 300 mg/l cadmium and 0 mg/l ascorbic acid.

Table (6). Average of cadmium content in soil samples as influenced by cadmium concentrations in irrigation water and foliar application of citric acid on *Jatropha curcas* leaves at the end of second season (2015).

Treatments		Cadmium content in soil (mg/kg)
Cd (mg/l)	**Ascorbic acid (mg/l)**	
0	0	0.018
	250	0.014
	500	0.011
100	0	0.024
	250	0.022
	500	0.021
200	0	0.050
	250	0.048
	500	0.046
300	0	0.072
	250	0.068
	500	0.065

Transfer factor to leaves (TFL)

From the data presented in Table (7), it can be seen that the transfer factor in the dried leaves of *Jatropha curcas* plants was decreased steadily with raising the cadmium concentration in the irrigation water. Accordingly, the lowest cadmium value (0.143 in the second season) was found in plants irrigated with water containing cadmium concentration 300 mg/l, whereas the highest value (0.251 in the second season) was found in plants irrigated with water containing cadmium concentration 100 mg/l.

The results in Table (7) also show that the transfer factor in the dried leaves was reduced steadily with raising ascorbic acid concentration. Accordingly, the highest cadmium value (0.240 in the second season) was recorded in the leaves of control plants, whereas plants sprayed with the highest ascorbic acid concentration 500 mg/l had the lowest cadmium value (0.144 in the second season).

Regarding the interaction between effect of irrigation using water contaminated with cadmium and ascorbic acid concentrations on the transfer factor in the dried leaves, the data in Table (7) show that the highest mean values 0.291 in the second season, was obtained in plants irrigated with cadmium water at 100 mg/l and sprayed with tap water, while the lowest mean values 0.320 in the second season, was recorded in plants irrigated with cadmium water at 300 mg/l and sprayed with ascorbic acid at 500 mg/l.

Transfer factor to stem (TFS)

From the data presented in Table (7), it can be seen that the transfer factor in the dried stem of *Jatropha curcas* plants was decreased steadily with raising the cadmium concentration in the irrigation water. Accordingly, the lowest cadmium value (0.726 in the second season) was found in plants irrigated with water containing cadmium concentration 300 mg/l, whereas the highest value (0.798 in the second season) was found in plants irrigated with water containing cadmium concentration 100 mg/l.

The results in Table (7) also show that the transfer factor in the dried stem was reduced steadily with raising ascorbic acid concentration. Accordingly, the highest cadmium value (0.726 in the second season) was recorded in the stem of control plants, whereas plants sprayed with the highest ascorbic acid concentration 500 mg/l had the lowest cadmium value (0.434 in the second season).

Regarding the interaction between effect of irrigation using water contaminated with cadmium and ascorbic acid concentrations on the transfer factor in the dried stem, the data in Table (7) show that the highest mean values 0.916 in the first and second season, was obtained in plants irrigated with cadmium water at 100 mg/l and sprayed with tap water, while the lowest mean values 0.230 in the second season, was recorded in plants irrigated with cadmium water at 300 mg/l and sprayed with ascorbic acid at 500 mg/l.

Transfer factor to roots (TFR)

From the data presented in Table (7), it can be seen that the transfer factor in the dried roots of *Jatropha curcas* plants was decreased steadily with raising the cadmium concentration in the irrigation water. Accordingly, the lowest cadmium value (0.609 in the second season) was found in plants irrigated with water containing cadmium concentration 300 mg/l, whereas the highest value (1.137 in the second season) was found in plants irrigated with water containing cadmium concentration 100 mg/l.

The results in Table (7) also show that the transfer factor in the dried roots was reduced steadily with raising ascorbic acid concentration. Accordingly, the highest cadmium value (1.044 in the second season) was recorded in the roots of control plants, whereas plants sprayed with the highest ascorbic acid concentration 500 mg/l had the lowest cadmium value (0.628 in the second season).

Regarding the interaction between effect of irrigation using water contaminated with cadmium and ascorbic acid concentrations on the transfer factor in the dried roots, the data in Table (7) show that the highest mean values 1.333 in the first and second season, was obtained in plants irrigated with cadmium water at 100 mg/l and sprayed with tap water, while the lowest mean values 0.323 in the second season, was recorded in plants irrigated with cadmium water at 300 mg/l and sprayed with ascorbic acid at 500 mg/l.

Table (7). Averages of transfer factor to leaves, stem and roots of *Jatropha curcas* plants as influenced by cadmium (Cd), ascorbic acid (AA) and their combinations (Cd ×AA) in the two seasons of 2014 and 2015.

Treatments		Transfer factor to leaves (TFL)	Transfer factor to stem (TFS)	Transfer factor to roots (TFR)
Cd (mg/l)	**Ascorbic acid (mg/l)**	**2015**	**2015**	**2015**
000	0	0.222	0.666	0.944
	250	0.214	0.642	0.928
	500	0.181	0.545	0.818
Average		**0.205**	**0.617**	**0.896**
100	0	0.291	0.916	1.333
	250	0.272	0.909	1.271
	500	0.190	0.571	0.809
Average		**0.251**	**0.798**	**1.137**
200	0	0.240	0.700	1.000
	250	0.166	0.520	0.750
	500	0.130	0.391	0.565
Average		**0.178**	**0.537**	**0.771**
300	0	0.208	0.625	0.902
	250	0.147	0.426	0.602
	500	0.076	0.230	0.323
Average		**0.143**	**0.427**	**0.609**
Mean (AA)	0	0.240	0.726	1.044
	250	0.199	0.624	0.887
	500	0.144	0.434	0.628
L.S.D. at 0.05	**Cd**	**0.029**	**0.085**	**0.121**
	AA	**0.022**	**0.066**	**0.095**
	Cd * AA	**0.051**	**0.152**	**0.218**

DISCUSSION

This study revealed that at high heavy-metal concentrations, the plant height was significantly reduced, and the biomass was decreased. The root growth was more sensitive than other parameters, as roots rapidly absorbed water and had higher accumulations of heavy metal elements. The results presented by this study were in agreement with earlier reports on other plants, such as aquatic plant *wolffia arrhiza* (Piotrowska *et al.*, 2010), barley *Hordeum vulgare* (Tiryakioglu *et al.*, 2006) and *typha angustifolia* (Bah *et al.*, 2011). Other studies with woody plant reported a higher inhibition of root elongation (Dominguez *et al*., 2009). In particular, Jatropha plants could bioaccumulate and bioconcentrate toxic heavy metals from an aqueous solution (Mohammad *et al*., 2010) and could be used as phytoremediation candidates in some countries (Juwarkar *et al*., 2008; Kumar *et al*., 2008; Jamil *et al*., 2009). Additionally, the plant seedling exhibited a high root/shoot ratio throughout the experiment. An alternative explanation might relate to a strong root system with many roots spread out over the entire soil for survival because root/shoot ratio could reflect plant's response to various environment factors (Otieno *et al.,* 2005; Lukacova Kulikova and Lux, 2010; Li *et al.,* 2010).

The physiological responses, such as the gas exchange rate and photosynthetic function, can be ascribed to the different effects of physico-chemical properties of heavy metals on the integrity and function of the photochemical apparatus of plant seedling fronds, as well as the impact on the chlorophyll concentrations in the leaves. The photosynthesis rate, CO2 assimilation rate, and stomatal conductance in response to cadmium heavy metal have been well documented (Chen *et al*., 2012). The maintenance of an intercellular CO2 concentration is concomitant with the leaf CO2 assimilation rate and reflected photosynthesis function of seedling in the different heavy metal-spiked soils. The chlorophyll and carotenoid contents played a central role in the energy manifestation of green plant. Any significant alteration of their contents possibly resulted in a marked effect on the entire metabolism of the plant (Piotrowska *et al*., 2010). In this study, cadmium resulted in a significant reduction in the chlorophyll contents, possibly due to the inhibition of chlorophyll biosynthesis or a breakdown of pigments and their precursors (Agrawal and Mishra, 2009). cadmium might replace the central Mg from chlorophyll molecules and thereby reduce the photosynthetic light-harvesting ability of plant (Agrawal and Mishra, 2009). In contrast, Car were less sensitive than Chl a and Chl b in response to both cadmium heavy metals, which probably facilitated the maintenance of photosynthetic apparatus against heavy metal stress (Piotrowska *et al.,* 2010). Car stabilized and protected the lipid phase of the thylakoid membrane by serving as the antioxidant to scavenge the free radicals (Polle *et al.,* 1992; Piotrowska *et al*., 2010).

Concerning treatments and the control sample, at a preliminary stage, one should note that the transfer factor of most treatments is lower than one for cadmium; which means that the physiological need of the plant for these elements is rather limited.

Trace elements translocation from roots to shoots via a number of physiological processes, including metal unloading into root xylem cells, long-distance carrying from the xylem to the shoots and metal reabsorption, by leaf mesophyll cells, from the xylem stream. Once the trace metals have been unloaded into the xylem vessels, the metals are carried to the shoots by the transpiration stream (Blaylock and Huang, 2000).

Ascorbic acid is the widely known compound used as an antioxidant and the most effective compound increasing the tolerance of plants to oxidative stresses. Confirmed the role of ascorbic acid in oxidative stress or scavenging freeoxy-radicals (Smith *et al.,* 1989). In addition, ascorbic acid affects the physiological activities of the plants. Also, there is evidence that the tolerance of plants is correlated with the increased amount of ascorbic acid. The antioxidant defense system in the plant cells includes both enzymatic antioxidants such as Superoxide Dismutase, Catalase, Ascorbate Peroxidase and non-enzymatic antioxidants like ascorbic acid, Glutathione and tocopherol. When plants are subjected to environmental stresses, oxidative damage may result because the balance between the production of Reactive Oxygen Substances and their detoxification by the antioxidative system is altered (Gomez *et al.*, 1999). Tolerance to damaging environmental stresses is correlated with an increased capacity to scavenge or detoxify Reactive Oxygen Substances (Foyer *et al.*, 1994). Taking all these observations together, it may be suggested as a hypothetical framework that Cd induces a transient loss in antioxidative capacity perhaps accompanied by a stimulation of oxidant producing enzymes, which results in intrinsic ascorbic acid accumulation. ascorbic acid then would act as a signalling molecule triggering secondary defences.

CONCLUSIONS

The concentrations of heavy metals increase in the environment from year to year**.** Therefore decontamination of heavy metal-contaminated water and soils is very important for maintenance of environmental health and ecological restoration. Phytoremediation is a new cleanup concept that involves the use of plants to clean or stabilize contaminated environments. Phytoremediation of metals is the most effective plant-based method to remove pollutants from contaminated areas. This green technology can be applied to remediate the polluted soils without creating any destructive effect of soil structure. Some specific plants, such as woody species, have been proven to have noticeable potential to absorb toxic heavy metals.

Phytoremediation of contaminated water and soil with heavy metals using non-edible plant like *Jatropha curcas* offers an environmental friendly and cost-effective method for remediating the polluted soil. The *Jatropha curcas* was found to be able to efficiently remove the heavy metals such as cadmium.

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الملخص العربي

إستجابة نباتات الجاتروفا للرش بحمض الأسكوربيك لتخفيض الأثر الضار للتلوث بالكادميوم في ماء الري

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أجريت هذه الدراسة في فرع البحوث بأنطونيادس، معهد بحوث البساتين، مركز البحوث الزراعية – الإسكندرية ، مصر خلال الموسمين المتتاليين ٢٠١٤ و٢٠١٥. وكان الهدف من هذه الدراسة تقييم آثار مياه الري الملوثة بالكادميوم على نباتات الجاتروفا المزروعة في تربة رملية ، كذلك إمكانية استخدام الرش بحمض الاسكوربيك للتغلب على الآثار الضارة للكادميوم. زرعت شتلات الجاتروفا بشكل فردي في أوعية بلاستيكية (قطرها٣٠ سم) مملوءة ٨ كجم من التربة الرملية. وكانت معاملات مياه الري الملوثة بأربعة تراكيزات من الكادميوم وهى صفر ، ١٠٠، ٢٠٠ ، ٣٠٠ مجم/لتر. تم رش النباتات أيضا بحامض الاسكوربيك في ثلاث تركيزات هى صفر،٢٥٠و ٥٠٠ مجم/لتر عن طريق الرش شهريا في كلا الموسمين.

أظهرت النتائج أن هناك اختلاف كبير في التفاعل بين تركيزات الكادميوم ورش النباتات بحامض الاسكوربيك. وقد لوحظ انخفاض كبير في كافة معاملات الري بالماء الملوث بالكادميوم وكذلك لوحظ زيادة كبيرة فى معدلات النموالخضرى بعد الرش ٥٠٠ مجم/لتر حمض الاسكوربيك. تم الحصول على أعلى قيمة من محتوى الكلوروفيل والكربوهيدرات من النباتات المروية بماء الصنبور والرش بتركيز ٥٠٠ مجم/لتر حامض الاسكوربيك في حين أن أعلى كمية كبيرة من محتوى الكادميوم في الأوراق والساق والجذور من خلال الرى بماء ملوث بتركيز ٣٠٠ مجم/لتر الكادميوم دون الرش حمض الاسكوربيك.