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RESEARCH ARTICLE

Calcium, Magnesium and Micronutrient Uptake in Watercress (*Nasturtium officinale*) under Arsenic and Salinity Stress Conditions

Jafar Sufian[1]*, Ahmad Golchin[2] and Arman Avanes[3]

[1]PhD student, Department of Soil Sciences, Zanjan University, Zanjan, I. R. Iran
[2]Professor, Department of Soil Sciences, Zanjan University, Zanjan, I. R. Iran
[3]Assistant Professor, Department of Chemistry, Maragheh University, Maragheh, I. R. Iran

ABSTRACT

Heavy metals are elements that mainly have a 5-22 gr.cm^{-3} specific gravity. Some of these metals are essential micronutrients for plant growth (Such as Zinc (Zn), Copper (Cu), Manganese (Mn), Nickel (Ni) and Cobalt (Co)). Some other heavy metals, have a high toxicity properties such as Lead (Pb), Cadmium (Cd) and Mercury (Hg). In order to investigate the potential of watercress (*Nasturtium officinale*) in the uptake of elements from nutrient solutions with different salinities, a factorial experiment was conducted in a completely randomized design with three replications in the greenhouse. In this experiment, different levels of arsenic were zero, 5, 10, 20, 40, 40, 80 and 160 mg.L^{-1}, which were obtained from sodium arsenate source and added to Epstein's nutrient solution to obtain the mentioned concentrations. The salt concentration of the nutrient solution was 0, 10, 20, 40 and 80 mM which was prepared from sodium chloride source and added to Epstein solution. After making nutrient solutions with different salinity and concentrations, watercress was cultivated. The ANOVA results showed that the interaction of salinity and arsenic levels on the calcium, magnesium, iron, manganese, zinc and copper concentrations in watercress was significant at the level of one percent probability. The highest concentrations of these elements were obtained in the levels without salinity and arsenic and the lowest values were obtained in the 80 mM salinity levels and 160 mg.l^{-1} arsenic.

INTRODUCTION

Watercress (*Nasturtium officinale*) is a member of the Brassicaceae family and it is one of the oldest vegetables consumed by humans. It has been used in salads, spices, herbs, and herbs [1]. This plant is very rich in ingredients including beta-carotene (Vitamin A), aspartic acid (Vitamin C), calcium, folic acid, iron, iodine and iron, also contains arginine, lysine, tryptophan and antioxidant [2]. It is a perennial and aquatic plant that often walks along streams and waterways and sometimes in swamps. It has creeping stems that grow small, white roots from different parts of it.

The use of heavy metals and their compounds in various industrial processes has led to the accumulation of these metals in landfills and effluents, pesticides and sewage [3]. With the growth of population and the development of industries, this practice is growing and naturally the environment will be more affected by pollutants, especially heavy metals. All heavy metals are very toxic and biodegradable in the environment and if their compounds are soluble in water, they cause contamination of water sources and eventually soil. In addition to the

*Corresponding author

Jafar Sufian, PhD student, Department of Soil Sciences, Zanjan University, Zanjan, I. R. Iran

E-mail: tapo.89@gmail.com

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toxicity of these metals, their accumulation in the body of living organisms has increased their health importance [4].

Arsenic is a metallic element found in soil, surface and groundwater, air and some foods [5]. Arsenic enters the environment through geological processes, human activities such as burning fossil fuels and mining, the use of arsenic-containing chemicals in agriculture [6]. Environmental pollution to arsenic has attracted much attention due to its very high toxicity to plants, animals and humans. One of the ways arsenic enters the human body is through drinking water. Arsenic can cause malignant tumors in the skin, lungs and disorders of the human nervous system [7].

The increase in world population is associated with increasing demand for water, and the world's water resources are declining due to phenomena such as global warming, drought and various other reasons [8]. As a result it leads to global water scarcity, environmental pollution and increasing salinity of land and water resources are prominent features to affect both plants and animals in the 21st century [9-12]. On the other hand, about 10 million hectares of the world's agricultural lands are removed from the production cycle due to irrigation salinity. Salinity stress has three significant effects on plants: 1- Reduction of water potential 2- Causes ion imbalance or disruption of ion homeostasis, and 3- toxicity. This mode significantly changes access to water. It therefore reduces plant growth, thus limiting production [13]. Salinity affects the physiology of organisms in general and growth rate and absorption capacity of the metal in particular in plants and animals [10-12]. Findings of Leblebtect, et al. [14] on the effect of salinity on growth and accumulation capacity of heavy metals in Spirodela polyrrhiza (Lamnase) showed that at high salinity levels (100 and 200 mM) decreased the relative growth rate and came down the accumulation of cadmium and nickel by plant.

MATERIALS AND METHODS

In order to evaluate the potential of watercress to absorb nutrient from contaminated nutrient solutions containing different concentrations of NaCl, factorial experiment with completely randomized design and three replications were conducted in the greenhouse of Soil Science Department, Zanjan University. In these experiments, arsenic was used at the levels of 0, 5, 10, 20, 40, 80 and 160 mg.L^{-1} (Because this concentration range includes a large part of the possible pollution in the environment) using Epestin nutrient solution. The concentrations of NaCl in Epestin nutrient solutions were 0, 10, 20, 40 and 80 mM. Nutrient solutions with different concentration of arsenic and NaCl were used to grew watercress for a period of 30 days. After transferring the watercress into planting containers, a certain volume of nutrient solutions containing arsenic and salt were added to the containers and once every four days, the water of the culture medium was changed and the distilled water and fresh nutrient solution were changed. Containing different concentrations of arsenic and cadmium were added to containers containing watercress for 30 days. After 30 days, the plants were removed from each container and after washing with distilled water and taking their free water, the final weight of the plants was measured and then dried in an oven at 55° C for 72 hours. Then, plant samples prepared from the mill and after their digestion in the laboratory, the amount of their elements were measured. Calcium, magnesium and micronutrient including zinc, iron, manganese and copper as well as arsenic were measured using Atomic Absorption Spectrometry (AA 20, Varian Australia). The data were statistically processed by analysis of variance according to a randomized complete block design and means with standard errors were calculated using the program Statistical Analysis System, version 9.1 (SAS Institute, Cary, NC, USA). Differences between the treatments were determined using Duncan's test.

RESULTS AND DISCUSSION

According to the comparison mean of the data (Table 1), the control treatment had the highest plant calcium concentration with an average of 3.08%. The lowest plant calcium concentration with an average of 1.18% belonged to 160 mg arsenic per liter and 80 mM salinity. Calcium is of fundamental importance for maintaining membrane permeability and cell integrity. Due to relative immobility in plants, long distance transportation and distribution of Ca in the plant primarily rely on both the transpiration rates (E.g., size of the plant) and duration of transpiration (E.g., age of the tissue) [15]. Arsenic accumulation negatively influenced Ca accumulation by watercress, especially at high As levels. In a study of As effects on nutrition of *S. alterniflora* grown in hydroponic conditions, Carbonell, et al. [16] obtained similar results showing that Ca concentrations in the shoots are positively correlated with dry biomass. The fact that Ca concentrations in the watercress decreased may suggest that Ca had a limited role in the defense of watercress against arsenic toxicity.

Magnesium mainly serves as the central atom of the chlorophyll molecule and a co-factor in many enzymes activating phosphorylation processes. Like Ca, the accumulation and distribution of Mg in the plant mainly depends on plant transpiration when the Mg supply is adequate.

The presence of salinity and arsenic in the nutrient solution reduces the uptake of magnesium by the plant. The highest magnesium concentration of the plant was related to the control treatment with an average of 0.7%. Increasing the concentration of salinity and arsenic in the nutrient solution decreased the magnesium concentration of the plant. The lowest magnesium concentration of the plant was related to 80 mg arsenic per liter and 80 mM salinity treatment with an average of 0.4%. Magnesium in the watercress was

Table 1: Ca and Mg uptake (%) in *Nasturtium officinale* at Arsenic treatments,salinity treatments.

Arsenic Levels (mg.l^{-1})	Salinity (mMNaCl)	Ca uptake	Mg uptake
0	0	3.0877a	0.69972a*
	10	2.8211a-d	0.66085b
	20	2.7989a-d	0.55533e-j
	40	2.6267b-d	0.51646j-n
	80	2.4657d-f	0.49425n-p
5	0	2.9877ab	0.66085b
	10	2.9599ab	0.59976cd
	20	2.4379d-g	0.54423g-l
	40	2.4712d-f	0.52757i-n
	80	2.1325e-i	0.44427qr
10	0	2.0103g-i	0.63308bc
	10	2.9655ab	0.57199d-h
	20	2.8155a-d	0.54423g-l
	40	2.7156a-d	0.51091k-o
	80	2.549b-e	0.46648pq
20	0	2.9322a-c	0.59421c-e
	10	2.4157d-h	0.56644d-i
	20	1.9825hi	0.53867g-m
	40	1.9603i	0.50535l-p
	80	1.9437i	0.47203o-q
40	0	2.499c-e	0.59976cd
	10	2.1769e-i	0.57755d-g
	20	2.1214e-i	0.54423g-l
	40	2.0381f-i	0.51091k-o
	80	1.3328k	0.43871qr
80	0	1.9548i	0.58865d-f
	10	1.8604ij	0.54978f-k
	20	1.8826ij	0.52201j-n
	40	1.927i	0.4998m-p
	80	2.1158e-i	0.40539r
160	0	1.505jk	0.56644d-i
	10	1.3883k	0.54978f-k
	20	1.3328k	0.53312h-n
	40	1.3217k	0.51646j-n
	80	1.1829k	0.43316qr

*Values followed by the same small or capital letter are not significantly different within rows or columns at Duncan test $p \leq 0.05$.

reduced by As addition. Carbonell Barrachina, et al. [17] have shown similar result in stems of bean plants at harvesting stage when sodium arsenite was applied at 5 mg As/l. Rio, et al. [18] reported that the relationship between As and Mg in root of red Amaranthus was found negative. Shaibur, et al. [19] found a significant negative effect on the concentration of Mg both in shoots and roots of barley plants due to As treatments. Similar results were observed by Carbonell, et al. [16] and Tu and Ma [20].

The concentrations of Fe in the watercress ranged from 219 to 663 mg.kg^{-1} (Table 2). Arsenic addition reduced Fe concentrations in all levels. The Fe concentrations had significant negative relationship with As.

Comparison of means showed that As_0S_0 treatment (Treatment without salinity and arsenic) with an average of 663.9 mg.kg^{-1} had the highest iron concentration. With increasing salinity and arsenic in the nutrient solution, the concentration of iron in plant tissues decreased. The lowest plant iron content in As_5S_4 (80 mg arsenic per liter and 80 mM salinity), As_6S_3 (160 mg arsenic per liter and 40 mM salinity) and As_6S_4 (160 mg arsenic per liter and 80 mM salinity) treatments.

Zinc concentrations in the watercress, ranging from 183 to 827 mg.kg^{-1}, were significantly affected by As rates. watercress Zn decreased linearly by As addition (Table 2).

Watercress Mn concentrations, varying from 152 to 282 mg kg^{-1}, were significantly affected by As additions. The interaction of salinity and arsenic levels reduced the plant manganese concentration. The highest concentration of plant manganese was measured in As_0S_0 treatment (control) with an average of 282.6 mg.kg^{-1}. The lowest level was observed in As_6S_4 treatment (160 mg arsenic per liter and 80 mM salinity) with an average of 152.16 mg.kg^{-1} (46% decrease compared to the control).

The range of Cu concentrations in the watercress was 8 to 43 mg.kg^{-1}, with a mean of 18 mg kg^{-1}. Similar to Fe, Zn and Mn, the Cu concentrations had significant negative relationship with As. According to the comparison of the mean data, the highest copper concentration with an average of 43.3 mg.kg^{-1} was related to the control treatment (As_0S_0). The lowest copper concentration with plant was 80% lower than the control with an average concentration of 8.3 mg.kg^{-1} in As_6S_4 treatment (160 mg arsenic per liter and 80 mM salinity).

Arsenic-induced reduction in micronutrients in the watercress was probably due to As phytotoxicity.

Abdel-Sabour, et al. [21] stated that heavy metals caused problems in the transfer of zinc and other trace elements in the plant. In cases where the plant was exposed to cadmium poisoning, the concentration and absorption of trace elements of the plant was reduced. A study showed that arsenic reduced the absorption of all macro and

Table 2: Micronutrient uptake (ppm) in *Nasturtium officinale* at Arsenic treatments, salinity treatments.

Arsenic Levels (mg.l^{-1})	Salinity (mMNaCl)	Fe	Zn	Mn	Cu
0	0	663.9a	827.45a	282.667a	43.316a*
	10	563.94b	749.7b	271.562ab	37.207b
	20	493.41de	538.67cd	259.901b-d	26.656d
	40	450.38e-h	416.5e-h	248.793d-f	21.658e-g
	80	404.28h-j	410.95e-h	232.135gh	13.328m-p
5	0	646.69a	605.31c	270.447ab	29.988c
	10	560.89bc	583.1cd	251.011c-e	23.879de
	20	515.07cd	527.57d	237.13fg	20.547f-h
	40	424.83f-i	444.27ef	222.689h-j	16.66i-m
	80	364.02j-k	433.16e-g	206.029k-o	14.439k-n
10	0	564.22b	455.37e	263.783bc	21.658e-g
	10	486.47de	399.84e-h	249.9d-f	18.937g-i
	20	462.04e-g	394.29e-h	228.797g-i	17.771h-k
	40	416.78g-i	349.86h-k	213.803j-m	16.66i-m
	80	324.31k-m	305.43i-m	202.697m-p	14.994j-n
20	0	541.73bc	405.39e-h	260.451b-d	22.769ef
	10	486.19de	372.07f-i	238.793e-g	18.881g-i
	20	402.62h-j	355.41g-j	216.58i-l	18.326h-i
	40	383.46ij	294.33i-m	208.805j-n	15.549i-m
	80	316.54k-m	288.77j-m	201.586m-p	10.551pq
40	0	472.03d-f	405.39e-h	230.463gh	18.326h-j
	10	427.88f-i	316.54i-l	218.801h-k	16.993i-l
	20	391.79ij	272.11k-n	213.803j-m	16.66i-m
	40	358.19jk	261.01l-o	199.365n-p	16.105i-m
	80	299.32mn	227.69m-o	181.594qr	12.217n-p
80	0	450.65e-h	305.43i-m	218.801h-k	18.881g-i
	10	402.89h-j	299.88i-m	211.027j-n	17.215i-l
	20	354.03j-l	283.22j-m	204.363l-p	15.549i-m
	40	301.82mn	255.45l-o	194.922op	13.883l-o
	80	243.51o	249.9l-o	165.489s	11.107o-q
160	0	356.25jk	266.56l-n	222.694h-j	17.771h-k
	10	307.38l-n	255.45l-o	211.14j-n	16.105i-m
	20	264.34no	238.79l-o	191.035pq	13.328m-p
	40	249.62o	194.37no	174.375rs	10.551pq
	80	219.91o	183.26o	152.161t	8.33q

*Values followed by the same small or capital letter are not significantly different within rows or columns at Duncan test $p \leq 0.05$.

micronutrients in tomatoes in hydroponic environments [16].

CONCLUSION

The presence of salt and arsenic reduced growth and in high concentrations caused plant death. Increasing the concentration of arsenic and salt at the solution media, decreased the concentrations of calcium, magnesium, iron, manganese, zinc, and copper in the watercress. In my opinion, if the increase in salinity is due to the competition that sodium creates with cationic elements, it will reduce the absorption of trace elements by regulation. Also, the presence of large amounts of sodium ions leads to disturbance of the balance of nutrients in the nutrient solution and ultimately disrupts the absorption and transfer of other essential elements such as calcium, potassium and magnesium from the soil to the plant.

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