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# EFFECT OF VANADIUM ON LETTUCE GROWTH, CATIONIC NUTRITION, AND YIELD

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## ABSTRACT

Lettuce plants (*Lactuca sativa* L.) cv. 'grandes lagos' were cultivated in nutrient solutions containing 0 (control), 0.1, 0.2, 0.5 and 1 mg/kg of vanadium. Root and leaf growth (expressed as fresh and dry weights) was inhibited by doses 0.2 to 1 mg/kg V. Yields decreased with increasing rates of vanadium. Toxicity symptoms in the roots consisted of color darkening, club shape of the main roots, reduction of secondary root number and length, and necrosis. Leaves from plants treated with 0.5 and 1.0 mg/kg V also showed turgidity loss.

Vanadium accumulated in the roots and was poorly translocated to the leaves. All the treatments significantly increased vanadium root levels, but it augmented in the leaves

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only at the higher doses. Vanadium affected positively foliar Ca and Fe concentrations, but it depleted K and Mg levels of the roots. 0.1 and 0.5 mg/kg vanadium in the nutrient solution decreased Mn in the roots, whereas the highest dose raised it.

## INTRODUCTION

The biological availability of vanadium by plants is poorly understood and is currently a matter for discussion. Most plants accumulate vanadium from the soil in very small amounts in relation to the total soil content. Vanadium absorption by plants may depend on the soil type. Elevated vanadium concentrations have been reported from plants growing in alluvium, seleniferous, and highly mineralized soils, meanwhile high contents of calcium in the soil limit the vanadium uptake by higher plants (1). Geological deposits of vanadium are not immediate hazards because there is no direct relationship between the vanadium concentrations levels in the deposits and in related soil and plant tissues(2).

Some authors admit that mean content of vanadium in plant tissues is generally lower than 0.5 mg/kg (3, 4), whereas others have referred concentrations ranges from 0.5 to 2 mg/kg (1), from 0.84 to 2.70 mg/kg (5) and up to up to 4.2 mg/kg on dry matter basis (6).

Vanadium is poorly translocated in the plant. Bertrand (6) had already observed that roots accumulate more vanadium than aerial parts of higher plants. In more recent studies, Sziklai et al. (7) have also indicated that vanadium contents in roots of paprika exceeded by far the detected concentration levels from other tissues. The same trend was found by Nowakowski (8) in peas. These observations support also the existence of some mechanisms that favors the vanadium retention by the subterranean organs. Kohno (9) reported levels of vanadium concentration from two cultivars of bush beans which were exposed to different levels of ammonium vanadate. Results from Khono's investigations did not show significant increments of vanadium concentrations in leaves and stems, but did show a significant increase in the roots. Kaplan et al.(10) indicated similar results in beans, and the same pattern have been observed in juniper trees (1).

The role of vanadium in plant nutrition may differ with plant species as well as occurs with other elements. It makes easier the absorption of iron by tomato plants (11), but an opposite pattern have been observed by Kohno (9) in bush beans where an increment of Mn levels occurs in spite of iron. Kaplan et al. (10) did not find any effect of vanadium on Fe or Mn contents in bean plants, but it augmented Ca concentration in the roots producing Ca-K and Ca-Mg antagonisms. On the contrary, vanadium could relieve symptoms of excess Mn in soybean, but caused symptoms of vanadium toxicity (12, 13). In addition, Morrel et al. (14) have suggested that vanadium toxic response could be counteracted by increasing the supply of Fe.

Toxicity symptoms of vanadium in beans consist of darkening of the roots, followed by a reduction of lateral ramifications which take club shape. Leaves become chlorotic, and stems turn red (10). Collard plants exposed to high vanadium concentrations exhibited a light increase of leaf color, a shortening of the principal roots, and less lateral ramifications (15).

Toxicity levels of vanadium depend on plant species. Vanadium concentrations of 2 mg/kg in barley and of 1 mg/kg in cabbage caused 10 % loss in yields of both plants (16), meanwhile sorghum tolerate nearly 10 mg/kg (17).

We have detected high levels of vanadium in wild plants growing in the environs of a fuel-oil power plant located at Tenerife island (Canary Islands) (18). Because of the significance of the agricultural activity within this area, we have carried out this research about the effects of vanadium in cationic nutrition, growth and yield of lettuce plants normally cultivated in the island.

## MATERIALS AND METHODS

Lettuce plants (*Lactuca sativa*, L.) variety 'Capitata' cv. 'grandes lagos' line 118 were germinated in moist vermiculite and cultivated in this medium inside a climate chamber. The seedlings were irrigated once per week with a nutrient solution containing 1/4 the concentration of the one used during the experiment. Two weeks after emergence they were transplanted, one plant per pot, to 2 l pots containing nutrient solution. The experimento was conducted in a greenhouse. The nutrient composition was as described by Huffman and Allaway (19) and Huertas (20), containing macronutrients (224 mg/kg N, 62 mg/kg P, 235 mg/kg K, 160 mg/kg Ca, 24 mg/kg Mg, and 32 mg/kg S) and micronutrientes (2.8 mg/kg Fe, 0.032 mg/kg Cu, 0.7 mg/kg Mn, 0.065 mg/kg Zn, 0.05 mg/kg Mo, 0,54 mg/kg B, and 1.77 mg/kg Cl) as $KNO_3$, $Ca(NO_3)_2.4H_2O$, $NH_4H_2PO_4$, ClK, $MgSO_4.7H_2O$, iron citrate, $Cu(NO_3)_2.3H_2O$, $MnSO_4.H_2O$, $ZnSO_4.7H_2O$, $Na_2MoO_4.2H_2O$, and $H_3BO_3$. The mineral supply and a pH of 4.65 were maintained by replacing the nutrient solution twice during the first 20 days, twice the following two weeks, and every 4 days untill final cropping (45 days in total).

Except for the control, the medium also contained 0.1, 0.2, 0.5 and 1 mg/kg of vanadium (treatments) as $NH_4VO_3$ The experiment was a randomized complete block design (21) with three replications per treatment, eight plants per replication.

Daily and nocturnal temperatures in the greenhouse varied between $34 \pm 3$ °C and $13 \pm 3$ °C, with a relative humidity of 60-70%.

## Plant Sampling

Four plants per treatment and replication were sampled 15 days after transplanting. Two more sampling, 2 plants per treatment and replication, were made 15 and 30 days after the first one. Roots and leaves were prepared separately for evaluating differential content of nutrients, and fresh and dry matter production of each fraction.

## Techniques of Plant Analysis

Leaf and root samples were washed in deionized water, and their fresh weight was measured. Their dry weights were determined after drying in an oven at 80°C until they reached constant weight. Then they were ground to powder. 2 g of each sample were mineralized by wet ashing (22) with a 5:1:2 mixture of concentrated $HNO_3$, concentrated $H_2SO_4$, and 60 % $HClO_4$ acids, respectively. K, Ca, Mg, Fe, Mn, Cu, and Zn, were analyzed by a Perkin-Elmer 2380 atomic absorption spectrophotometer, and V by a Perkin-Elmer HGA-400 Graphite Furnace.

Statistical Analysis

STATGRAPHICS 5.0 statistical program was used for processing data that were subjected to Analysis of Variance (ANOVA), Regression Analysis, and Correlation Analysis.

## RESULTS AND DISCUSSION

Fifteen days after beginning the treatments, the fresh and dry weights of the lettuce's roots that received 0.1 and 0.2 mg/kg of vanadium were similar to those observed from the control (figures 1 and 2). These doses significantly decreased the root fresh weight in the following sampling, but only 0.2 mg/kg V dose affected it negatively at the final one. On the contrary, they did not have any effect on root dry weight. The treatments with 0.5 and 1 mg/kg V always depressed roots growth and reduced their fresh and dry weights. Nowakoski (8) and Kohno (9) reported similar results with pea seedlings and bush beans, respectively, cultivated in nutrient solutions enriched with V.

The leaves of plants that received 0.2 mg/kg of vanadium at the first sampling yielded significantly greater fresh and dry weight than those of the control (figures 3 and 4). These results coincide with the findings of Basiouny (11) with tomato plants exposed to 0.25 mg/kg V, and those of Singh (23) with corn subjected to doses from 0.05 to 0.25 mg/kg of vanadium, even though they did not observed the reduction in dry weight that we detected in our experiment later on. Treating the plants with 0.1 mg/kg V did not practically influence leaf growth, but

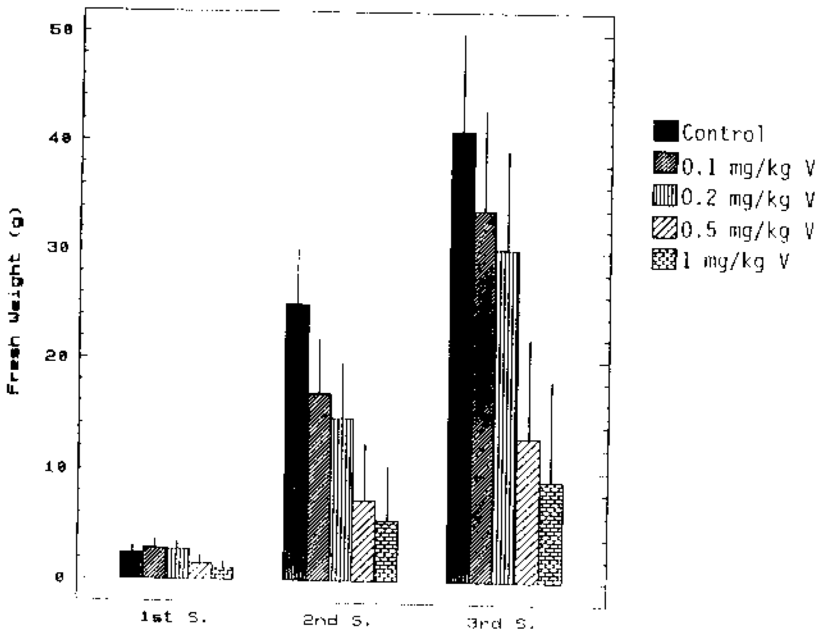


FIG. 1.- Barchart of Fresh Weight of Lettuce Roots. Error Bars = Least Significant Difference at the 0.05 level.
S = Sampling.

the doses of 0.5 and 1 mg/kg V were detrimental. Lettuces exposed to 1 mg/kg V showed a significant decrease of fresh and dry weights of the leaves since the first sampling, meanwhile 0.5 mg/kg in the nutrient solution began to show an adverse effect on both since the second sampling. Nowakowski (8) found also adverse effects of vanadium on shoot fresh and dry weights of pea seedlings.

All the treatments produced vanadium toxicity symptoms in the roots, though they became apparent in the plants that received 0.2 mg/kg V only 25 days after initiating the essay. The lower dose (0.1 mg/kg V) did not generate symptoms until the 35th day.

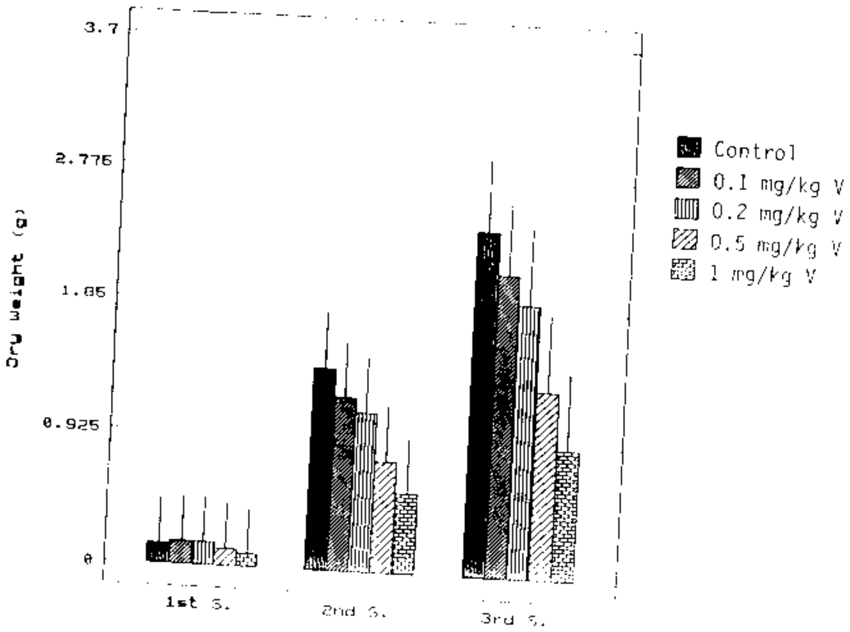


FIG. 2.- Barchart of Dry Weight of Lettuce Roots.
Error Bars = Least Significant Differences at the 0.05 level
S = Sampling.

Seven days after beginning the experiment, the roots of the plants growing in nutrient solution with 1 mg/kg V developed a slightly dark color and were shorter than those from the control. These initial symptoms had been observed by Kohno (9) in bush beans, and by Kaplan et al. (10) in beans, though at higher vanadium concentrations. Afterwards, the main root showed club form, and secondary roots proliferated, but they were grosser and shorter than those from the control. The apex lost its sharpened aspect, and it became bulbous and grey. Kaplan et al. (10, 15) had noticed similar symptoms in beans and collard seedling, but they did not observe any secondary root proliferation. After 10 days, the leaves displayed growth depression and turgidity loss. In the following 5 days, secondary

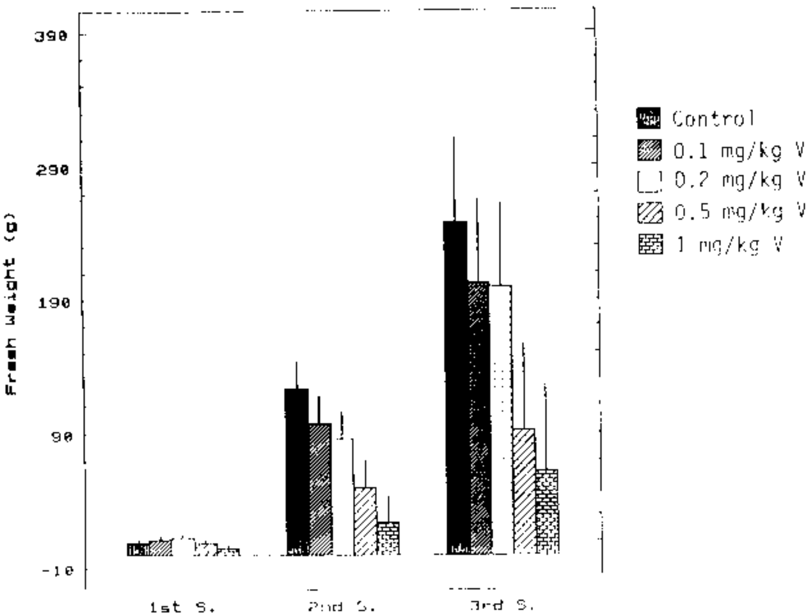


FIG. 3.- Barchart of Fresh Weight of Lettuce Aerial Parts.
Error Bars = Least Significant Difference at the 0.05 level.
S = Sampling.

root formation was constrained and they became short and frail. Later symptoms included necrosis and root death. The plants treated with 0.5 mg/kg V developed the same symptoms, but to a lesser degree.

Unlike the descriptions of Kaplan et al. (10) with beans and Kohno (9) with bush beans, no foliar necrosis or chlorosis were detected, neither leaf reddening nor increase of leaf green color intensity, as opposed to the findings reported by Warrington (17) in sorghum and by Kaplan et al. (10) in beans.

Our results suggest that 0.5 mg/l of vanadium or higher vanadium contents in the nutrient solution lead to a fast disorganization of root cell division, similar to that observed by Hidalgo et al. (24) in onions, who expounded that vanadium

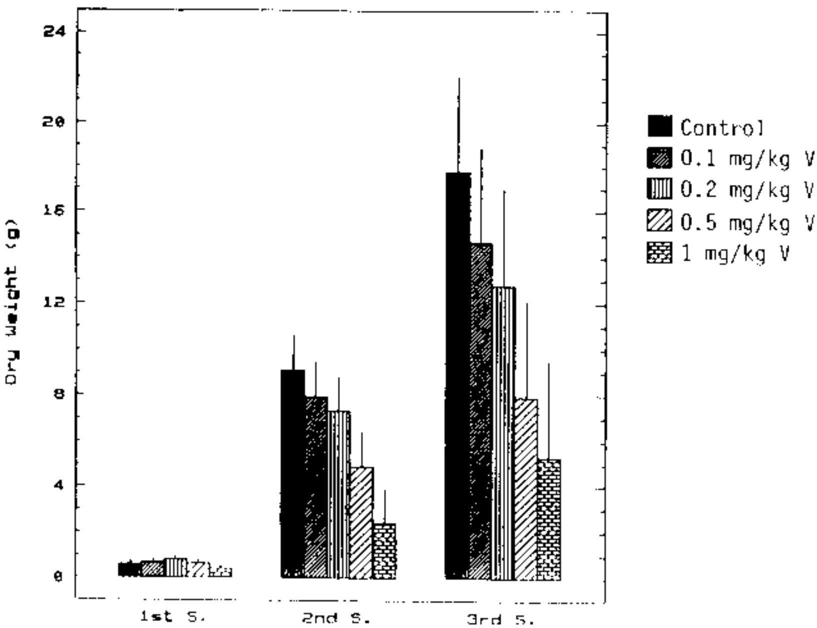


FIG. 4.- Barchart of Dry Weight of Lettuce Aerial Parts.
Error Bars = Least Significant Differences at the 0.05 level
S = Sampling.

diminished the number of mitotic cells and induced chromosome damages. Lux et al. (25) have stated that vanadium disturbs division, elongation, and differentiation of corn root cells.

Vanadium concentration in leaves from the control ranged from 0.22 up to 0.33 mg/kg (figure 5), very close to the vanadium leaf content (0.28 mg/kg) reported by Söremark (26). No significant difference was detected in vanadium concentration of the leaves among the plants from the control and treatments with 0.1 and 0.2 mg/kg V. The plants that received 1 mg/kg V showed significantly higher contents of this metal in the leaves. Similar results were observed in lettuces from the 0.5 mg/kg V treatment, except for the second sampling.

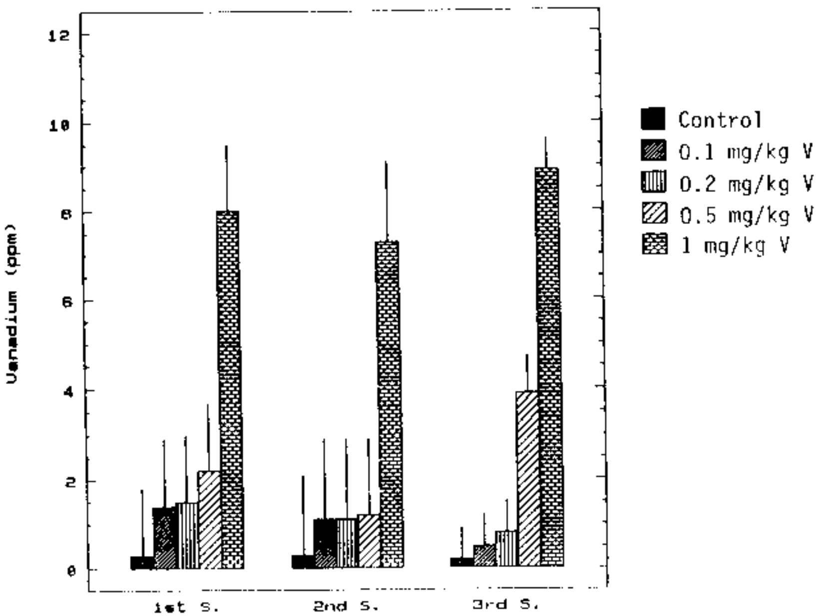


FIG. 5.- Barchart of Vanadium Concentration in Lettuce Aerial Parts.
Error Bars = Least Significant Difference at the 0.05 level.
S = Sampling.

The roots of all the plants accumulated more vanadium than the leaves (figures 5 and 6), corroborating the findings of Basiouny (11) with tomatoes, Sziklai et al. (7) with paprika, and Kohno (9) with bush beans. There were significant differences among the vanadium content of roots from all the treatments and the control, and among the treatments themselves, except for 0.1 mg/kg V and 0.2 mg/kg V. We wish to emphasize that the roots of the plants growing in the nutrient solution with 1 mg/kg V accumulated 73 to 216 times more vanadium than those from the control.

Negative correlations (p= 0.01 or higher) in every sampling were found among vanadium concentration in roots and leaves of lettuces and their

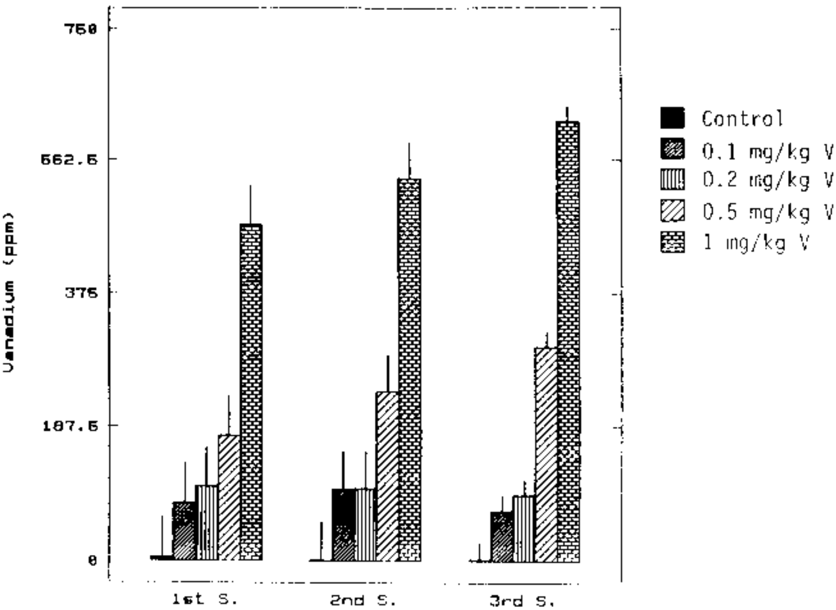


FIG. 6.- Barchart of Vanadium Concentration in Lettuce Roots.
Error Bars = Least Significant Differences at the 0.05 level
S = Sampling.

corresponding fresh and dry weights, which substantiate the results that we have explained above.

Vanadium decreased potassium content of roots and leaves at the first and second samplings (tables 1 and 2), but no effect was observed on the leaves at the third sampling (table 3). 0.2 mg/kg vanadium treatment increased potassium levels of the roots of the final sampling, but the higher doses (0.5 and 1 mg/kg V) depleted their K content. Kaplan et al. (9) detected potassium diminution in roots of 33 days old beans treated with 6 mg/kg V.

The Ca content of the roots remained unaffected by the treatments, whereas leaves from the second and third samplings showed significantly higher Ca

## TABLE 1

Cationic Composition of Lettuce Roots (R) and Leaves (L) 15 Days after Beginning the Treatments with Vanadium.

| | Treatment | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Control | | 0.1 mg/kg V | | 0.2 mg/kg V | | 0.5 mg/kg V | | 1 mg/kg V | |
| NUTRIENT | R | L | R | L | R | L | R | L | R | L |
| K (%) | 6.2 | 5.5 | 6.0 | 4.9 | 5.6 | 4.5* | 3.9* | 4.1* | 3.7* | 3.6* |
| Ca (%) | 0.2 | 1.5 | 0.2 | 1.1 | 0.2 | 1.2 | 0.2 | 0.9 | 0.2 | 0.9 |
| Mg (%) | 0.3 | 0.4 | 0.4 | 0.4 | 0.4 | 0.3* | 0.3 | 0.3* | 0.3 | 0.2* |
| Fe (mg/kg) | 7454 | 462 | 5973 | 202* | 6676 | 243* | 5366 | 232* | 3177* | 396 |
| Cu (mg/kg) | 195 | 20 | 258* | 21 | 216 | 21 | 110* | 20 | 110* | 27* |
| Mn (mg/kg) | 198 | 170 | 311 | 139 | 243 | 131 | 186 | 109 | 230 | 125 |
| Zn (mg/kg) | 122 | 118 | 125 | 106 | 118 | 96* | 107 | 68* | 108 | 79* |

Values [illegible] the same row and plant part followed by (*) are significantly different from the control at the 0.05 level

## TABLE 2

Cationic Composition of Lettuce Roots (R) and Leaves (L) 30 Days after Beginning the Treatments with Vanadium.

| | Treatment | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Control | | 0.1 mg/kg V | | 0.2 mg/kg V | | 0.5 mg/kg V | | 1 mg/kg V | |
| NUTRIENT | R | L | R | L | R | L | R | L | R | L |
| K (%) | 4.7 | 4.7 | 3.9* | 3.5* | 3.9* | 3.2* | 3.3* | 2.8* | 2.8* | 3.0* |
| Ca (%) | 0.5 | 1.3 | 0.5 | 0.8* | 0.3 | 0.8* | 0.2 | 0.7* | 0.3 | 0.7* |
| Mg (%) | 0.4 | 0.3 | 0.3 | 0.2* | 0.4 | 0.2* | 0.3 | 0.2* | 0.3 | 0.2* |
| Fe (mg/kg) | 4540 | 241 | 4466 | 210 | 4513 | 205 | 4540 | 219 | 2880* | 368* |
| Cu (mg/kg) | 53 | 10 | 57 | 10 | 52 | 11 | 50 | 10 | 47 | 11 |
| Mn (mg/kg) | 229 | 90 | 151 | 76 | 113 | 67 | 158 | 65 | 263 | 68 |
| Zn (mg/kg) | 67 | 45 | 64 | 41 | 66 | 38 | 68 | 36 | 59 | 38 |

Values within the same row and plant part followed by (*) are significantly different from the control at the 0.05 level

**TABLE 3**

Cationic Composition of Lettuce Roots (R) and Leaves (L) 45 Days after Beginning the Treatments with Vanadium.

| | Treatment | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Control | | 0.1 mg/kg V | | 0.2 mg/kg V | | 0.5 mg/kg V | | 1 mg/kg V | |
| NUTRIENT | R | L | R | L | R | L | R | L | R | L |
| K (%) | 3.0 | 3.4 | 3.2 | 3.1 | 3.3* | 3.4 | 2.3* | 2.6 | 2.7* | 2.9 |
| Ca (%) | 0.3 | 0.4 | 0.3 | 0.7* | 0.2 | 0.7* | 0.2 | 0.7* | 0.2 | 0.8* |
| Mg (%) | 0.4 | 0.2 | 0.3 | 0.2 | 0.3 | 0.2 | 0.2* | 0.2 | 0.1* | 0.2 |
| Fe (mg/kg) | 4636 | 173 | 3983 | 163 | 4326 | 189 | 3520 | 224* | 3666 | 228* |
| Cu (mg/kg) | 63 | 7 | 63 | 8 | 65 | 8 | 50* | 8 | 69 | 10* |
| Mn (mg/kg) | 187 | 64 | 116* | 54 | 167 | 65 | 100* | 55 | 278* | 80 |
| Zn (mg/kg) | 77 | 40 | 65 | 39 | 73 | 44 | 56* | 35 | 74 | 45 |

Values within the same row and plant part followed by (*) are significantly different from the control at the 0.05 level

concentrations in all the treatments. Singh (19) reported a similar trend in corn plants that received 0.05 mg/kg V.

Magnesium behavior was contradictory. It augmented in the leaves of the treated plants at the first and second samplings, but no effect was observed at the final one. On the contrary, it did not change in the roots till final cropping, where the higher doses of vanadium (0.5 and 1 mg/kg V) decreased it.

The main impact of vanadium on Fe nutrition, specially at 1 mg/kg dose, consisted of raising Fe concentrations in aerial parts, as observed by other authors (9, 10), meanwhile the fluctuations detected in the roots were uneven.

Neither Cu nor Zn changes induced by vanadium followed a clear pattern, though 0.5 mg/kg V in the nutrient solution significantly reduced Cu content of the roots in two of the three samplings. The opposite was observed in the leaves of the plants treated with 1 mg/kg V.

Doses 0.1 and 0.5 mg/kg V decreased Mn concentrations of the roots at the third sampling, whereas 1 mg/kg V significantly raised them. The treatments did not influence Mn content of the leaves, results that coincide with the ones reported by Kaplan (10) in beans.

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