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Effect of vanadium on dry matter and nutrient concentration in sweet basil (*Ocimum basilicum* L.)

Anastasia Akoumianaki-Ioannidou[1], Pantelis E. Barouchas[2], Evridiki Ilia[3], Artemis Kyramariou[3], Nicholas K. Moustakas[3*]

[1]Floriculture and Landscape Architecture Laboratory, Agricultural University of Athens, Greece
[2]Laboratory of Soil Science and Agricultural Chemistry, Technological Educational Institute of Western Greece
[3]Soil Science Laboratory, Agricultural University of Athens, Greece

[*]Corresponding author: nmoustakas@aua.gr

Abstract

An experiment was conducted in pots under glasshouse conditions to study the effects of vanadium (V) on dry matter and on V, Fe, Mn, Pd, Zn, Ca, K and Mg concentrations in leaves, stems and roots of sweet basil (*Ocimum basilicum* L.). A completely randomized block design with five V treatments (0, 5, 10, 20, 40 mg L^{-1}) and six replications per treatment was laid out. Vanadium was applied to the pot medium (peat soil mixture) as NH_4VO_3. No visible toxic or inhibitory symptoms were observed on the plants due to the increasing rates of V. Results indicated that root dry matter increased with increasing rates of V. The V concentration in the leaves and roots increased with V addition but the opposite was observed for the stems. The V concentration in the leaves [*i.e.* 1.84 mg kg^{-1} (DW) at 40 mg L^{-1} added V] was always much lower than in the roots [*i.e.* 11.4 mg kg^{-1} (DW) at 40 mg L^{-1} added V], indicating that V accumulated mainly in the roots and only small quantities were transferred to the leaves. The results indicated that the Ca, Mg, and Mn concentrations in the leaves were not affected by V addition; in contrast, Fe, and Pb concentrations in leaves and roots decreased. A significant negative correlation of concentrations of V with Fe in leaves ($r=-0.41$ at $p\leq0.01$) and in roots ($r=-0.41$ at $p\leq0.01$), as well as between V and Pb in leaves ($r=-0.51$ at $p\leq0.01$) and in roots ($r=-0.74$ at $p\leq0.01$) of sweet basil was detected, indicating an antagonistic effect between V and Fe, and between V and Pb.

Keywords: medicinal herb, culinary herb, vanadium accumulation, nutrient.
Abbreviations: DW_Dry weight; LDM_leaf dry matter; RDM_root dry matter; SDM_stem dry matter; T-U-L_total uptake by leaves; T-U-R_total uptake by roots**;** T-U-S_total uptake by stems.

Introduction

Vanadium (V) is a transition metal and is widely distributed in the earth's crust at an average concentration of 110 mg kg^{-1} (Peterson and Girling 1981). In contrast, vanadium has been found to be the second most abundant transition metal in seawater after molybdenum (10 μg L^{-1}), with a mean concentration of 7 μg L^{-1} (Awofolu 2004). The chemical properties of vanadium are determined by different oxidation states, these being +2, +3, +4 and +5 (Greenwood et al., 1984). The oxidation states of naturally occurring vanadium compounds are only V(IV), as vanadyl (VO^{2+}) and V(V), as vanadate (VO_4^{3-}); V(V) can exist as VO^{2+} in an acid medium, while VO_4^{3-} can exist in an alkaline solution. The coexistence of these two species depends on the pH and redox potential. Both species have different toxic properties, with V(V) compounds being more toxic than V(IV). The concentration of vanadium in soil depends upon the parent material and the pedogenic properties associated with its development, as well as on industrial pollution (WHO et al., 1987). Lener et al. (1998) reported that the V concentration in the surface layer of the soil increased from 18 mg kg^{-1} at 2400 m, from a metallurgical plant producing vanadium pentoxide, to 136 mg kg^{-1} at 600 m. Iron and aluminum (hydr) oxides determine the mobility of V in soils and water (Naeem et al., 2007; Wallstedt et al., 2010) and therefore its fate. Vanadium can form strong complexes with organic matter, and in the presence of organic substances, V(V) may be reduced to V(IV), especially at low pH (Lu et al., 1998). Evidence that V is essential for the growth of higher plants has, however, not yet been conclusively demonstrated since it does not meet the criteria of essentiality set by Arnon and Wessel (1953). The toxicity of V to plants has mainly been studied in nutrient solutions and starts from between 1 mg V L^{-1} and 5 mg V L^{-1} for the most sensitive species (Kaplan et al., 1990). Vanadium toxicity in barley and tomato was found at concentrations ranging from 31 mg to 510 mg added V kg^{-1} in three different soils. There are many examples of the toxic effects of V on plants, and toxicity is associated with V(V) forms in the soil (Hopkins et al., 1977). A possible cause of toxicity is the structural similarity between vanadate ($H_2VO_4^{2-}$) and phosphate ($H_2PO_4^-$) ions (Rehder 1999). Vachirapatama et al. (2005) revealed that some phosphate fertilizers were contaminated with high concentrations of V (90-180 mg kg^{-1}). Thus the use of such fertilizers may cause V to become widely spread in soils, water and vegetables, with possible consequences for human and animal health. Vanadate is absorbed by plant tissues (Bowman 1983; Ullrich-Eberius et al., 1989) and can inhibit plasma membrane hydrogen (H^+)-translocating ATPase (Vara and Serrano 1982), which is known to play an important role in nutrient element uptake by plant cells.

Vanadium is toxic to humans at high concentrations and can cause irritation of the respiratory tract, although it has not been possible to determine the level of exposure that provokes such effects (Costigan et al., 2001).

Sweet basil (*Ocimum basilicum* L.) is a medicinal and culinary herb, used very widely in Mediterranean cooking. There is currently little information on the absorption and translocation of metals by plants and the response of plants such as sweet basil to an increasing concentration of V in the soil. Given the increasing use of such plants, more information on the level of V in plant tissues that are consumed by livestock and humans, and its effect on plant growth and nutrient content is required. Therefore the objectives of this research were to examine the effect of V on dry matter (DM) and V concentration in different parts of sweet basil, as well as the effects of V on the concentration of a number of other metals (Ca, K, Mg, Fe, Mn, Zn, Pb, Cr and Cd).

Results and Discussion

Plant DM (leaves, stems, roots) as affected by V

During the experiment no toxic symptoms or inhibitory effects on sweet basil plants due to increasing application rates of V were observed. Leaf dry matter (LDM) and stem dry matter (SDM) were not affected by V addition (Tables 1 and 2), in contrast, root dry matter (RDM) linearly increased with increasing V addition (Table 3) as presented in Fig. 1. Singh (1971) detected an increase in dry matter when corn was subjected to doses of V from 0.05 to 0.25 mg L^{-1}. Basiouny (1984) found that the dry matter of tomato plants increased when they were exposed to 0.2 mg V L^{-1}. Vachirapatame et al. (2011) found that the growth of Chinese green mustard and tomato plants was retarded by nutrient solutions containing at least 40 mg V L^{-1}.

Elemental concentrations in different parts of sweet basil
Leaves

Vanadium concentration in the leaves of sweet basil increased with increasing V application (Table 1), reaching a maximum of 1.8 μg g^{-1} (DW) with application of 40 mg V L^{-1} (Fig. 2). The concentration of V in leaves at the application of 40 mg V L^{-1} increased by 78% compared to the control. The Fe concentration in the leaves from the control ranged from 43.5 to 30.2 μg g^{-1} (DW) and linearly decreased significantly with increasing dose of V (Table 1), reaching a minimum of 30.2 μg g^{-1} (DW) with the 40 mg V L^{-1} applied dose (Fig. 3). In contrast, Kohno (1986) for bush beans and Kaplan et al. (1990) for beans reported that the Fe content in the aerial plant parts increased with increasing rates of V. The leaf concentration of Fe at the application of 40 mg V L^{-1} was reduced by 44% compared to the control. Vanadium reduced Fe absorption and subsequent translocation by plants as has been reported for other metals (*i.e.* Cd, Co, Cu, Ni, and Zn) (Foy et al. 1978). However, the leaves of sweet basil in our study did not show symptoms of Fe deficiency, suggesting that Fe levels in the leaves were adequate for plant growth, despite the 44% reduction. The Pb concentration in leaves of sweet basil decreased with increasing doses of V (Table 1), reaching a minimum of 0.8 μg g^{-1} (DW) with the 40 mg V L^{-1} applied dose, a decrease of 97% compared to the control (Fig. 4).

These reductions in Fe and Pb in the leaves of sweet basil with increasing rates of V, in conjunction with the significant negative correlation of V with Fe ($r = -0.52$ at $p \leq 0.05$) and with Pb ($r = -0.74$ at $p \leq 0.05$) concentrations, possibly indicate an antagonistic effect of V on Fe and Pb.

There was no effect of V additions on the concentrations of Mn, Zn, Ca, K, and Mg in the leaves of sweet basil (Table 1).

Stems

The application of V reduced the concentration of V in the stems of sweet basil (Table 2), reaching a minimum of 0.02 μg g^{-1} (DW) of V with application of 40 mg V L^{-1} (Fig. 2). The root concentration of V at application of 40 mg V L^{-1} decreased by 5% compared to the control. The Pb concentration of the stems ranged between 1.2 and 0.7 μg g^{-1} (DW) in the control and at 40 mg V L^{-1} dose, respectively (Table 2). Increasing V doses linearly reduced the Pb concentration in the stems (Fig. 4). Iron, Mn, Zn, Ca, K, and Mg concentrations in the stems were not affected by V treatments (Table 2).

Roots

Increasing V application linearly increased the concentration of V in the roots of sweet basil (Table 3), reaching a maximum of 11.4 μg g^{-1} (DW) with application of 40 mg V L^{-1} (Fig. 2), an increase of 98% compared to the control.

We wish to emphasize that the plants grown in pots with 40 mg L^{-1} V accumulated 47 times more V in the roots than those of the control and four times more than in the control. The plants grown with 40 mg V L^{-1} also accumulated seven times more V in the roots than in the leaves. Gil et al. (1995) reported that the roots of lettuce growing in a nutrient solution with 1 mg V kg^{-1} accumulated 73 to 216 times more V than those of the control. Many researchers observed that V accumulated mainly in roots i.e. Kohno (1986) reported that the V concentration in the roots, of two cultivars of *Phaseolus vulgaris* grown in nutrient solution containing 0.05–2 mg L^{-1} of V as NH_4VO_3, increased exponentially with increasing V concentration in the solution. Nowakowski (1993), who studied V bioaccumulation in seedlings of three cultivars of *Pisum sativum* grown in Petri dishes in distilled water and in NH_4VO_3 solutions (0, 5, 10, 20, 30 mg kg^{-1}), concluded that there was a low translocation rate of V from roots to shoots. Wallace et al. (1977) reported that in beans cultivated in a culture solution with 10^{-4} M NH_4VO_3 the concentration of V in leaves, stems and roots were 13, 8 and 881 mg kg^{-1} (DW), respectively. Yang et al. (2011) reported that the roots of alfalfa grown in soil contaminated by V-Cd in a pot experiment had higher contents and better absorption of V than did aerial parts. More recently, Saco et al. (2013) studied the response of *P. vulgaris* L. (cv. Contender) grown hydroponically in different vanadyl sulphate concentrations and concluded that V accumulated in the roots and only small quantities were transferred to the leaves. Our study shows that V accumulated primarily in roots, which places V among the group of metals (Ag, Al, Au, Hg, Pb, Sn, and Ti) that are generally considered immobile in plants (Logan and Chaney 1983). The observation that V accumulated in great amounts in the roots supports the existence of a mechanism that favors V retention by the roots, but this has not yet been identified. Cannon (1963), Wallace et al. (1977), and Peterson and Girling (1981) reported that V precipitated in the roots as calcium vanadate, whereas Morrell et al. (1986) concluded that V accumulated in the roots due to the reduction of V(V) to V(IV) during root uptake, which further reduced translocation within the plant. However, Kaplan et al. (1990) considered that V accumulated as a result of the formation of

Table 1. Effects of V treatment on leaf dry matter (LDM) and on V, Fe, Mn, Pb, Zn, Ca, K, and Mg concentrations in the leaves of sweet basil.

V added	LDM	V	Fe	Mn	Pb	Zn	Ca	K	Mg
mg L^{-1}	g $plant^{-1}$	µg g^{-1}					%		
0	0.96	0.40a	43.5a	16.1	1.3a	13.6	1.0	1.04	0.3
5	0.80	0.49a	41.3ab	17	1.1a	12.9	0.9	0.89	0.3
10	1.00	0.72a	34.8bc	19.1	1. 4a	12.9	1.1	0.85	0.3
20	1.18	0.83a	33.2c	17.5	1.2a	12.3	1.0	0.86	0.3
40	1.10	1.84b	30.2c	16.5	0.8b	10.6	1.0	0.78	0.3
F-test	2.2	12.8**	4.5**	0.9	5.1**	1.7	1.2	2.2	1.5

Column means followed by the same letter are not significantly different, according to Duncan's multiple range test, at p≤0.05; column means without letters indicate no significance by Duncan's test at p≤0.05; **p≤0.05.

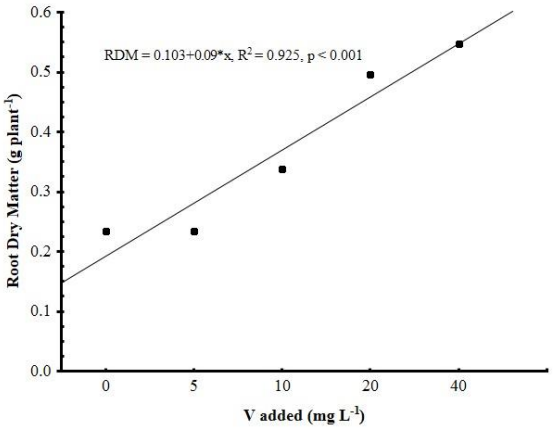

Fig 1. Root dry matter of sweet basil as affected by V treatments.

Table 2. Effects of V treatment on stem dry matter (SDM) and on V, Fe, Mn, Pb, Zn, Ca, K, and Mg concentrations in the stems of sweet basil.

V added	SDM	V	Fe	Mn	Pb	Zn	Ca	K	Mg
mg L^{-1}	g $plant^{-1}$	µg g^{-1}					%		
0	0.89	0.41a	22.5	5.6	1.2b	9.6	0.3	0.8	0.1
5	0.88	0.30b	25.0	4.1	1.1ab	9.2	0.3	0.8	0.1
10	0.93	0.15c	26.0	5.1	1.1ab	9	0.3	0.8	0.1
20	1.16	0.04d	22.6	4.3	0.9ab	8.4	0.3	0.8	0.1
40	0.98	0.02d	28.0	4.5	0.7c	8.9	0.3	0.8	0.2
F-test	1.62	50.7**	0.20	0.54	3.12**	0.18	0.51	0.21	1.88

Column means followed by the same letter are not significantly different, according to Duncan's multiple range test, at p≤0.05; column means without letters indicate no significance by Duncan's test at p≤0.05; **p≤0.05.

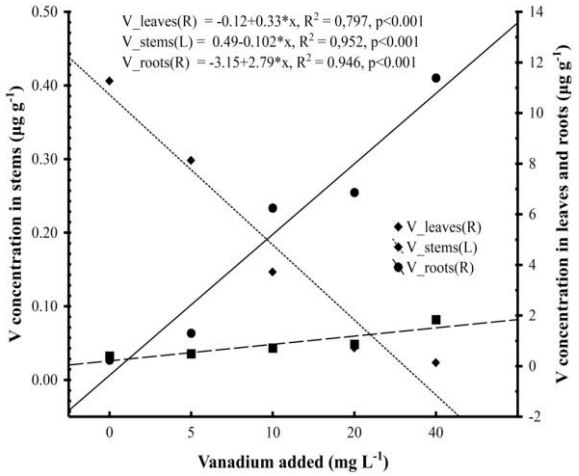

Fig 2. V concentration in leaves, stems, and roots of sweet basil treated with different levels of V.

Table 3. Effects of V treatment on root dry matter (RDM) and on V, Fe, Mn, Pb, Zn, Ca, K, and Mg concentrations in the roots of sweet basil.

V added	RDM	V	Fe	Mn	Pb	Zn	Ca	K	Mg
mg L^{-1}	g $plant^{-1}$	μg g^{-1}					%		
0	0.23a	0.24a	65.8a	5,3	1.9a	13.6ab	0.4b	0.07	0.06a
5	0.23a	1.30a	64.9a	4.7	2.0a	14.3b	0.3a	0.05	0.05ab
10	0.34a	6.25b	62.2a	4.5	1.4ab	10.5bc	0.3a	0.04	0.04ab
20	0.50b	6.86b	49.3ab	3.9	0.8b	9.4c	0.2a	0.04	0.03b
40	0.55b	11.4c	39.8b	3.5	0.18c	8.7c	0.2a	0.03	0.03b
F-test	8.84**	29.96**	3.32**	2.24	12.82**	4.78**	4.12**	2.29	3.64**

Column means followed by the same letter are not significantly different, according to Duncan's multiple range test, at p≤0.05; column means without letters indicate no significance by Duncan's test at p≤0.05; **p≤0.05.

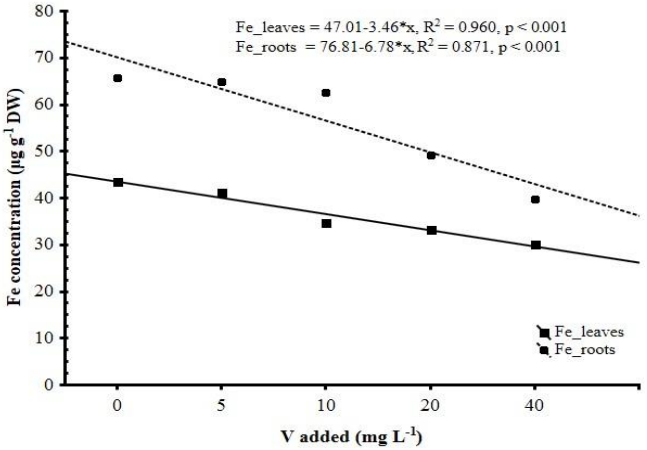

Fig 3. Fe concentration in leaves, and roots of sweet basil treated with different levels of V.

Table 4. Correlation coefficients between V and Ca, Fe, K, Mg, Mn, Pb, V, and Zn concentrations in the roots of sweet basil grown under different levels of V.

	Ca	Fe	K	Mg	Mn	Pb	Zn
V	−0.45*	−0.52*	−0.52*	−0.55*	−0.37	−0.74**	−0.57**

Correlation is significant at *p≤ 0.05, **p≤ 0.01.

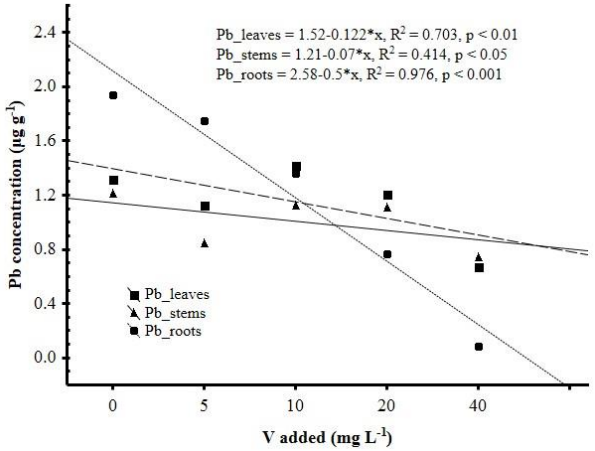

Fig 4. Pb concentration in leaves, stems, and roots of sweet basil treated with different levels of V.

its complexes with organic compounds, such as organic acids and amino acids. Immobilization of V in the roots is presumed to be the primary mechanism by which plants tolerate large quantities of V in the soil. The linear increase of V concentration in leaves and roots with addition of V (Fig. 2) indicates that indeed this may one mechanism of tolerance (Rascio and Navari-Izzo 2011). Fe concentration in the roots was significantly reduced by increasing V additions (Table 3), reaching a minimum of 3.32 μg Fe g^{-1} V at 40 mg V L^{-1} (Fig. 3). In contrast, Gil et al. (1995), Kohno (1986), and Kaplan et al. (1990) detected increasing Fe concentration in aerial parts of lettuce, bush beans, and beans, respectively, with increasing rates of V. The Pb content of the roots of sweet basil ranged between 1.9 and 0.2 μg g^{-1} (DW) (Table 3) and decreased with increasing rates of V (Fig. 4). The significant negative correlation of Pb with V concentrations in the roots (Table 4) indicates the possibility of an antagonistic effect between these two metals.

Table 5. Effects of V treatment on V, Fe, Mn, Pb, Zn, Ca, K, and Mg uptake by different plant parts of sweet basil.

Leaf uptake								
V added	V	Fe	Mn	Pb	Zn	Ca	K	Mg
(mg L^{-1})	µg $plant^{-1}$					mg $plant^{-1}$		
0	0.4a	42.0	15.5	1.2ac	13.0	0.99	1.00	0.25
5	0.4a	34.0	13.6	0.9bc	10.4	0.74	0.71	0.22
10	0.8ab	35.3	19.4	1.4a	13.2	1.09	0.86	0.34
20	1.1b	39.5	20.2	1.4a	14.3	1.20	1.00	0.32
40	2.1c	34.1	18.8	0.7b	12.0	1.08	0.87	0.34
F-test	15.1**	0.43	1.17	3.76**	0.72	1.77	1.21	1.29
Stem uptake								
V added	V	Fe	Mn	Pb	Zn	Ca	K	Mg
(mg L^{-1})	µg $plant^{-1}$					mg $plant^{-1}$		
0	0.4d	19.8	5.0	1.1ab	8.4	0.29	0.72	0.10
5	0.3c	21.4	3.6	0.7a	7.9	0.26	0.71	0.11
10	0.1b	25.4	4.9	1.1ab	8.6	0.29	0.72	0.13
20	0.1a	26.2	4.9	1.3b	9.6	0.39	0.92	0.16
40	0.0a	26.4	4.4	0.7a	8.7	0.31	0.74	0.14
F-test	41.6**	0.30	0.40	13.8**	0.33	3.20	1.09	3.02
Root uptake								
V added	V	Fe	Mn	Pb	Zn	Ca	K	Mg
(mg L^{-1})	µg $plant^{-1}$					mg $plant^{-1}$		
0	0.06a	15.43	1.36	0.48a	3.31	0.091	0.016	0.014
5	0.33a	15.78	1.11	0.35a	3.14	0.061	0.012	0.011
10	2.22b	20.92	1.52	0.44a	3.62	0.095	0.015	0.014
20	3.34b	25.22	1.94	0.36a	4.75	0.099	0.019	0.018
40	6.21c	21.32	1.87	0.05b	4.86	0.101	0.018	0.016
F-test	24.22**	0.99	1.30	4.04**	1.01	0.80	0.39	0.74

Column means followed by the same letter are not significantly different, according to Duncan's multiple range test, at $p \leq 0.05$; column means without letters indicate no significance by Duncan's test at $p \leq 0.05$; **$p \leq 0.05$.

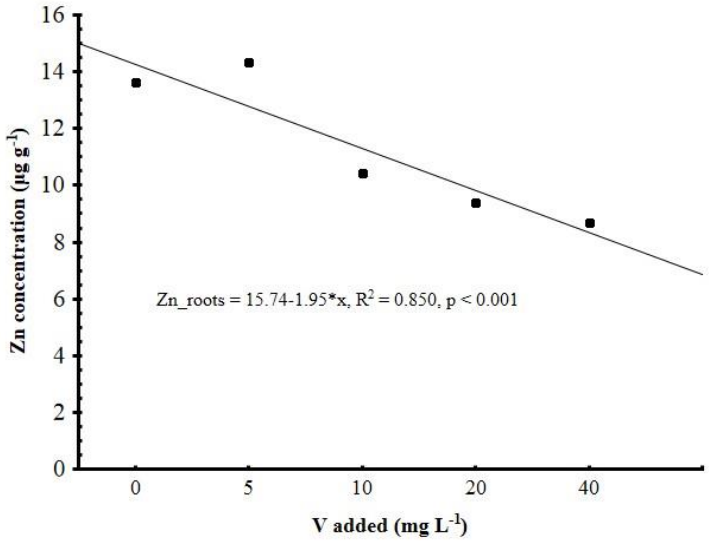

Fig 5. Zn concentration in roots of sweet basil treated with different levels of V.

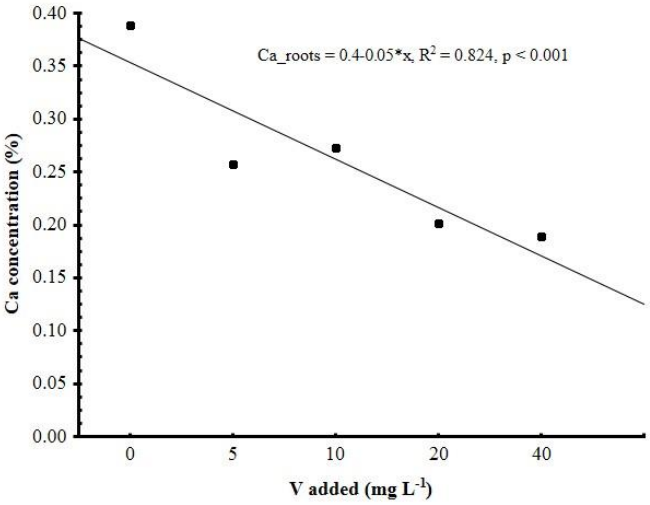

Fig 6. Ca concentration in roots of sweet basil treated with different levels of V.

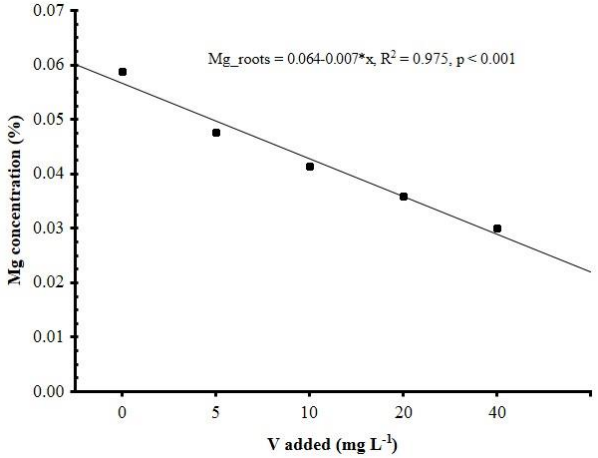

Fig 7. Mg concentration in roots of sweet basil treated with different levels of V.

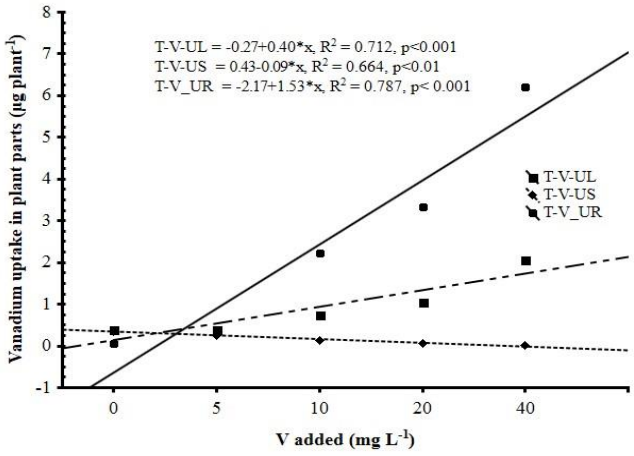

Fig 8. V uptake in plant parts of sweet basil treated with different levels of V (T-V-UL=total V uptake by leaves; T-V-US= total V uptake by stems; T-V-UR= total V uptake by roots).

Zinc concentration in the roots ranged from 13.6 to 8.7 µg g^{-1} (DW) and decreased with increasing rates of V, as presented in Fig. 5. The significant negative correlation of Zn with V concentration in the roots (Table 4) indicates possible antagonistic effects between the two metals, although the decreasing concentration of Zn in roots exposed to increasing V rates may be due to cellular incorporation of V (Okeson et al. 2004). Manganese and K concentrations in roots of sweet basil were not affected by V (Table 3). Calcium and Mg concentrations in roots of sweet basil linearly decreased with increasing rates of added V as presented in Fig. 6 and Fig. 7, respectively.

Vanadium uptake and distribution in different parts of sweet basil

The uptake of V, Fe, Mn, Pb, Zn, Ca, K, and Mg on a per-plant basis are presented in Table 5. Increasing V doses led to a linear increase in V uptake by leaves of sweet basil (Fig. 8). Welch and Huffman (1973) concluded that barley roots passively take up V and the uptake is a linear function of V addition. The relative distribution of V content among plant parts (leaves, stems, roots) increased in roots and decreased in leaves and stems with increasing doses of V. The relative distribution of V in our experiment was 75% in roots, 25% in leaves and 0.3% in stems at the dose of 40 mg V L^{-1} (Fig. 9). Basiouny (1984) reported that in tomato plants growing in nutrient solution spiked with ^{48}V, the distribution of V in the roots, stems, and leaves was 96.4, 0.7 and 2.9%, respectively, of the absorbed radioactivity after 24-h exposure. Kaplan et al. (1990) studied the effect of V on soybean (*Glycine max* L.) in a hydroponic experiment concluded that the relative distribution of V among plant parts was 92.7% in roots, 5.4% in lower leaves and 1.9% in upper leaves, at doses of 3 and 6 mg V L^{-1}. Cannon (1963), in a study of 30 shrubs growing in areas that were naturally enriched with V, observed that roots clearly contained the highest concentration of V, older leaves contained twice as much as younger leaves, and stems lacked any measurable amount of this metal. Vachirapatama et al. (2011) analyzed the V levels in dry leaf, stem and root of Chinese green mustard plants and in the dry root and fruit of the tomato plants that were cultured in nutrient solutions containing 0, 1, 10, 20, 40 and 80 mg L^{-1} NH_4VO_3. They found that the accumulation of vanadium was higher in the root compared with other parts of Chinese green mustard and tomato plants. Our results indicate that 75% of the total V uptake of sweet basil is distributed to the roots.

Materials and Methods

Pot experiments

Pot experiments were conducted under glasshouse conditions for a period of four months at the Agricultural University of Athens to study the effect of different V applications on sweet basil. Seeds of sweet basil were sown in a peat and perlite medium (1:1 v/v) contained in palettes, each with 20 individual cells. After four weeks, the plants were transplanted to 1 L black plastic pots filled with a substrate of 50% peat and 50% perlite by volume (1:1), with pH 5.6, an organic matter content of 90-95% and electrical conductivity of 0.3 S m^{-1}. Each pot contained one plant. The pots were arranged in a completely randomized block design with five treatments and six replicates for each treatment. Vanadium was applied two or three times per week as ammonium metavanadate (NH_4VO_3) at concentrations of 0 (control), 5,

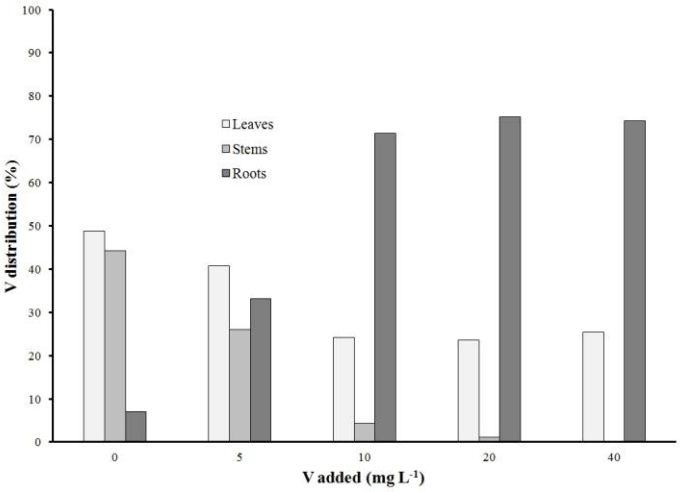

Fig 9. V distribution in different plant parts of sweet basil treated with different levels of V.

10, 20 and 40 mg L^{-1}. The volume of each application was 50 mL per pot and the duration of the experiment was six weeks, i.e. a total of 500 mL per pot for each treatment, corresponding to 2.5, 5, 10 and 20 mg V for the levels of 5, 10, 20 and 40 mg V L^{-1}, respectively. Fertilization of the pots was performed approximately every two weeks, using a commercial fertilizer (Nutrileaf-60) with 2 mg N, 2 mg P_2O_5, and 2 mg K_2O for each pot (the content of V in the fertilizer was negligible).

Plant material analysis

At the end of the experiment, approximately three months after transplanting, leaves, stems and roots were harvested. All the plant parts were oven-dried at 50°C to constant weight, ground in a stainless steel Wiley mill and passed through a 250 μm plastic sieve. 0.5 g samples of the ground material from each pot were placed in beakers and ashed at 450°C. The residue was dissolved in 5 ml of 6N HCl. The clear solutions were analyzed by ICP-OES (Thermo Scientific iCAP 6000). The operating conditions were: nebulizer gas flow rates: 0.5 L^{-1}; auxiliary gas flow: 0.5 L min^{-1}; plasma gas flow: 15 L^{-1}; pump rate: 45 rpm; ICP RF power: 1100 W. Aliquots of an ICP multi-element standard solution (100 mg L^{-1}; Merck) containing the analyzed elements were used for the preparation of a calibration solution. Working standard solutions were prepared by dilution of the stock standard solution to the desired concentration in 1% HNO_3. The ranges of the calibration curves (6 points) were selected to match the expected concentrations for all the elements of the sample studied by ICP-OES. The correlation coefficient r^2 obtained for all cases was 0.9999. The detection limits (LOD) were calculated as the concentrations of an element that gave the standard deviation of a series of 10 consecutive measurements of blank solutions.

Statistical analysis

The experiment was conducted using the completely randomized design with five treatments and six replications. Analysis of variance (ANOVA) was used to determine the statistical significance of the difference between treatment means for all the parameters studied. ANOVAs were calculated using STATISTICA™ Ver. 8.0 (StatSoft 2008). Where a significant difference was found, the Duncan's Multiple Range Test at the 5% level of probability was used to compare individual treatment means. Data were also subjected to regression and correlation analysis.

Conclusions

Vanadium did not retard the growth of sweet basil until 40 mg V L^{-1} was added. Root dry matter increased linearly with increasing addition of V. Vanadium concentration increased linearly in leaves and roots and decreased in stems with application of increasing rates of V. Increasing V addition led to a linear decrease in Fe concentration in leaves and roots. Lead concentration decreased with increasing rates of V in all studied plant parts of sweet basil. Zinc, Ca and Mg concentration in the roots of sweet basil decreased linearly with increasing rates of V. Finally, our study indicates that 75% of the total V uptake by plant parts of sweet basil was distributed to the roots. Vanadium negatively impacts the nutritional quality of sweet basil regarding Fe content. However, its antagonist effect on Pb uptake could be especially relevant where sweet basil is grown on soils contaminated with such metals.

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References

Arnon DI, Wessel G (1953) Vanadium as essential element for green plants. Nature. 172:1039-1040.

Awofolu OR (2004) Determination of vanadium in foods by atomic absorption spectrometry. Afr J of Sci and Tech. 5:15−21.

Basiouny FM (1984) Distribution of vanadium and its influence on chlorophyll formation and iron metabolism in tomato plants. J Plant Nutr. 7:1059-1073.

Bertrand D (1950) The biochemistry of vanadium. In: Survey of Contemporary Knowledge of Biochemistry. American Museum of Natural History, Bulletin 94, Article 7:403-456.

Bowman BJ (1983) Vanadate uptake in *Neurospora crassa* occurs *via* phosphate transport system II. J of Bacteriol. 153:286-291.

Cannon HL (1963) The Biogeochemistry of Vanadium. Soil Sci. 96:196-204.

Costigan M, Cary R, Dobson S (2001) Vanadium pentoxide and other inorganic vanadium compounds. In Concise International Chemical Assessment Document 29.

Foy CD, Chaney RL, White MC (1978) The physiology of metal toxicity in plants. Ann Rev Plant Physiol. 29:511566.

Greenwood NN, Earnshaw A (1984) Chemistry of Elements. Pergamon Press, Oxford.

Gil J, Alvarez CE, Martinez MC, Pérez N (1995) Effect of vanadium on lettuce growth, cationic nutrition, and yield. J of Environ Sci and Health. 30(1):73-87

Hopkins LL, Cannon HL, Miesch AT, Welch RM, Nielsen FH (1977) Vanadium: Geochemistry and the environment. National Academy of Sciences, Washington DC.

Kaplan DI, Adriano DC, Carlson CL, Sajwan KS (1990) Vanadium toxicity and accumulation by beans. Water Air Soil Poll. 49:81-91.

Kohno Y (1986) Vanadium induced manganese toxicity in bush bean plants grown in solution culture. J Plant Nutr. 1:1261-1272.

Lener J, Kucera J, Kodl M, Skokanova V (1998) Health effects of environmental exposure to vanadium. In: Nriagu J (ed) Vanadium in the environment. Wiley and Sons, New York.

Logan TJ, Chancy RL (1983) Utilization of Municipal Wastewater and Sludge on Land – Metals. In: Page AL, Gleason TL III, Smith JE Jr, Iskandar IK, Sommers LE (eds.) Proceedings of the 1983. Workshop on Utilization of Municipal Wastewater and Sludge on Land, Univ. of California, Riverside, CA, p. 480.

Lu XQ, Johnson WD, Hook J (1998) Reaction of vanadate with aquatic humic substances: An ESR and V-51 NMR study. Environ Sci Technol. 32:2257–2263.

Morrell BG, Lepp NW, Phips DA (1986) Vanadium uptake by higher plants: some recent development. Environ Geochem Helth. 8:14-48.

Naeem A, Westerhoff P, Mustafa S (2007) Vanadium removal by metal (hydr)oxide adsorbents. Water Res. 41:1596–1602.

Nowakowski W (1993) Vanadium Bioaccumulation in *Pisum sativum* seedlings. Biol Plant. 35:461-465.

Okeson LD, Riley M, Riley-Saxton E (2004) In vitro alveolar cytotoxicity of soluble components of airborne particulate matter: effects of serum on toxicity of transition metals. Toxicol in Vitro. 18:673-680.

Peterson PJ, Girling CA (1981) Vanadium. In: Lepp NW(ed) Effect of Heavy Metal Pollution on Plants. Applied Science Publishers, London, New Jersey.

Rascio N, Navari-Izzo F (2011) Heavy metal hyperaccumulating plants: how and why do they do it? And what makes them so interesting? Plant Sci. 180:169-181.

Rehder D (1999)The coordination chemistry of vanadium as related to its biological functions. Coord Chem Rev. 182:297-322.

Saco D, Martin S, San Jose P (2013) Vanadium distribution in roots and leaves of *Phaseolus vulgaris*: morphological and ultra structural effects. Biol Plant. 57:128-132.

Singh BB (1971) Effect of vanadium on the growth, yieldand chemical composition of maize (*Zea mays* L.). Plant Soil. 34:209-212.

StatSoft Inc (1998) STATISTICA for Windows. Tulsa, OK; StatSoft Inc.

Ullrich-Eberius CI, Sanz A, Novacky AJ (1989) Evaluation of arsenate and vanadate associated changes of electrical membrane potential and phosphate trans- port in *Lemma Gibba*. J of Exp Bot. 40:119-128.

Vachirapatama N, Jirakiattikul Y, Dicinoski G, Townsend AT, Haddad PR (2005) On-line preconcentration and sample clean-up system of vanadium as 4-(2- pyridylazo) resorcinol (PAR) and hydrogen peroxide ternary complex in plant tissues by ion interaction HPLC. Anal Chim Acta. 543:70-76.

Vara F, Serrano R (1982) Partial purification and properties of the proton translocating ATPase of plant plasma membranes. J of Biol Chem. 257:12826-12830.

Wallace A, Alexander GV, Chaudry FM (1977) Phytotoxicity of Cobalt, Vanadium, Titanium, Silver, and Chromium. Comm Soil Sci Plant Anal. 8:751-756.

Wallstedt T, Bjorkvald L, Gustafsson JP (2010) Increasing concentrations of arsenic and vanadium in (southern) Swedish streams. Appl Geochem. 25:1162–1175.

Welch RM, Huffman EWD (1973) Vanadium and plant nutrition. Plant Physiol. 52:183-185.

WHO (1987) Air quality guidelines for Europe. Copenhagen. World Health Organization. Regional Office for Europe**:** 426.

Yang J, Teng Y, Wang J, Li J (2011) Vanadium uptake by alfalfa grown in V–Cd-contaminated soil by pot experiment. Biol Trace Elem Res. 142:787–795.