Thesis of doctoral (PhD) dissertation

PLANTS TREATED WITH MOLYBDENUM AND ITS TREATMENT'S EFFECT ON THE GROWTH PARAMETERS AND THE UPTAKE OF NUTRIENT ELEMENTS

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1. INTRODUCTIONS AND AIMS

Within the scope of my doctoral work I studied the effect of molybdenum (Mo) treatments of increasing concentration in the nutrient solution-plant and soil-plant system. The supply of plants with appropriate amount of molybdenum is sufficient since Mo is one of the seven nutrients which plays an essential role in the plant metabolism processes.

The object of my research was the analysis of plant and soil samples of hydroponic, rhizobox and pot experiments.

During my soil examination my objective was to determine how much percent of the soil's total molybdenum content can be utilized for plants (soluble element content) and to establish whether the daily watering of the experimental plants (green peas) causes denudation in the soil in various types of soil.

During the examination of plant samples my aim was to answer to the following questions:

- How the molybdenum supply interact with the dry mass product of certain parts of the plant?
- What is the maximum Mo quantity which has a favourable effect on the yield of plants?
- Does molybdenum have a toxic effect in the examined concentration range?
- How the molybdenum supply interact with the intensity of initial root growth?
- What kind of effect do molybdenum treatments have on the molybdenum content of certain parts of the plant and in which part of the plant does molybdenum accumulate the most?
- Is there any difference between the monocotyledon and dicotyledon plants with regard to the Mo uptake?
- How much molybdenum do the experimental plants subtract from the nutrients and soils including molybdenum of increasing concentration and in what proportions is the Mo quantity divided among certain plant parts?
- How do the applied Mo-treatments affect the macroelement and microelement contents of plants?

- Is there a synergistic or antagonistic relationship between the Mo and the examined macro- and microelements?
- How do the Mo-treatments with increasing concentration affect the NO_3-N and NH_4-N concentration of certain parts of the experimental plants?
- Do Mo-treatments contribute to the decrease of the yield's NH_3-N concentration which is a desirable aim from the aspect of human health?

2. MATERIALS AND METHODS

The experiments can be listed into three main groups: 1. hydroponic experiments, 2. rhizobox experiment, 3. pot experiments.

I involved a monocotyledon (maize, *Zea mays* L. cv. Norma SC) and a dicotyledon plant (sunflower, *Helianthus annuus* L. cv Arena PR) in the hydroponic and rhizobox experiments which directly or indirectly play an important role in human analysis while their economic role is also essential. I grew the plants in the Climate Chamber of Department of Agriculture and Botany Plant in the Institute of Plant Sciences under strictly regulated environmental conditions: light intensity: 220 $\mu Em^{-2}s^{-1,}$ periodicity of temperature: 25/20 °C (day/night), relative humidity (RH): 65-75 %, lighting/dark cycle: 16 hours/8 hours.

The nutrient solution used for monocotyledon had the following composition: 2.0 mM $Ca(NO_3)_2$, 0.7 mM K_2SO_4, 0.5 mM $MgSO_4$, 0.1 mM KH_2PO_4, 0.1 mM KCl, 0.1 μM H_3BO_3, 0.5 μM $MnSO_4$, 0.5 μM $ZnSO_4$, 0.2 μM $CuSO_4$. Nutrient solution of the following had to be prepared in order to grow dicotyledon: 2.0 mM $Ca(NO_3)_2$, 0.7 mM K_2SO_4, 0.5 mM $MgSO_4$, 0.1 mM KH_2PO_4, 0.1 mM KCl, 10 μM H_3BO_3, 0.5 μM $MnSO_4$, 0.5 μM $ZnSO_4$, 0.2 μM $CuSO_4$. Iron was supplied in the form of 10^{-4}M Fe-EDTA. Molybdenum was supplemented to the nutrient solution at four different concentrations as follows: 0; 0.07; 0.7 and 7 μM. The experiment ended 9 days after planting.

Experiments in soil were carried out in rhizoboxes, which allowed us to easily monitor many aspects of root development, including overall growth, circadian rhythm of the growth as well as symptoms of phytotoxicity that might have been caused by increased concentrations of molybdenum. The experiments used calcareous chernozem soil obtained from the Látókép Experimental Station of our university. Molybdenum was supplied to the soil as $(NH_4)_6Mo_7O_{24}.4H_2O$ in 3 different concentrations as follow: 30, 90, 270 mg kg^{-1} and control for our reference. The plants were geotropically stimulated to force root growth along the transparent wall of the box, thus allowing convenient monitoring of the roots. The mass of rhizoboxes and the length of the roots were measured daily and water (evaporation, transpiration) was also replenished daily.

I set the pot experiments in the Greenhouse of Institute of Agricultural Chemistry and Soil Science in University of Debrecen, in the spring of 2015. In this experiment I chose green peas (*Pisum sativum* L.) as test plant since its molybdenum need is significant and it is one of the vegetables grown in the largest area in Hungary.

The following types of soil were used during the experiment:

1.) calcareous chernozem soil (pH=6.58) – Faculty of Agricultural and Food Sciences and Environmental Management at University of Debrecen, Látókép Experimental Station of Plant Production

2.) humus sandy soil (pH=7.14) – University of Debrecen, Pallag Experimental Station of Horticulture

3.) humus sandy soil (pH=5.09) – University of Nyíregyháza, Ferenctanya Educational Farm

I summarized the most important parameters of the experimental soils in *Table 1.*

Table 1: *The most important parameters of the experimental soils*

	Látókép	**Pallag**	**Nyíregyháza**
Depth (m)	0-0.3	0-0.3	0-0.3
pH (KCl)	5.71	6.35	3.95
pH (H_2O)	6.58	7.14	5.09
Arany-type plasticity index (K_a)	43	30	-
$CaCO_3$ (%)	0.202	0.5	-
Humus (%)	3.54	1.12	0.99
AL-soluble P_2O_5 (mg kg^{-1})	199	235	21.1
AL-soluble K_2O (mg kg^{-1})	451	287	67.9

We added the molybdenum to the soil in the form sodium molybdate ($Na_2MoO_4.2H_2O$) dissolved in distilled water. In the case of calcareous chernozem soil (Látókép) we applied 0, 3, 30, 90 and 270 mg kg^{-1} molybdenum treatments, in the case of humus sandy soil (Pallag, Nyíregyháza) the applied treatments included the following: 0, 30 and 270 mg kg^{-1}. We did not add molybdenum to the control soil.

The determination of the element content of green peas was carried out in 4 different stages of development which are the following: four-node condition, the beginning of flowering, green ripening, and complete maturity.

During my research work I carried out the element analysis of plant samples with inductively coupled plasma optical emission spectrometry (ICP-OES) and inductively coupled plasma mass spectrometry (ICP-MS). Wet digestion with nitric acid and hydrogen peroxide was applied during sample preparation of these plants. The sample preparation method necessary for the determination of nitrate nitrogen and ammonium nitrogen concentration of the plant samples is different from the method mentioned above. The various nitrogen forms of the certain plant samples were determined by fluid flow (CONTIFLOW) method, using FIAstar Analyzer, after its dissolution in distilled water and ultrasonic shaking.

The elemental analysis of soil samples can be divided to two main components which are the following: 1. The determination of the total element content of the samples with atmospheric wet digestion using concentrated nitric acid and hydrogen peroxide. 2. The determination of the samples' soluble molybdenum content easily available for plants using the extraction tool by Lakanen-Erviö. Afterwards, we measured the element content of the appropriately prepared samples using the abovementioned ICP-OES equipment.

We applied SPSS v.22.0 statistical program to evaluate the results in statistical terms. In order to statistically examine the relationship between the parameters and the certain factors, we used one-factor analysis of variance and Duncan's test regarded $P<0.05$ as significant.

3. RESULTS AND DISCUSSION

3.1. The results of hydroponic experiments

Evaluating the dry mass results of the shoot and root of maize seedling cultivated with nutrients I established that neither the 0.07 μM, nor the 0.7 μM Mo-treatment had a significant effect on the plant's growth. Only in the case of the 7 μM Mo-treatment we could show a significant difference (*Table 2).*

Table 2: *Dry weight (g plant^{-1}) of shoot and root of maize seedling grown in nutrient solution depending on molybdenum treatments (0; 0.07; 0.7; 7 μM)*

Mo-treatment (μM)	Dry weight of maize (g plant^{-1})	
	Shoot	Root
0	0.2785±0.0102^{a}	0.1291±0.0068^{a}
0.07	0.2568±0.0279^{ab}	0.1120±0.0127^{ab}
0.7	0.2429±0.0169^{ab}	0.1238±0.0025^{ab}
7	0.2211±0.0200^{b}	0.1078±0.0096^{b}

The values with different alphabetical index are significantly (P<0.05) different whithin the individual columns. n=3±s.e.

In the case of the sunflower I found that the positive effect of molybdenum on the shoot's mass gain was revealed even in the smallest molybdenum treatment (*Table 3).*

Table 3: *Dry weight (g plant^{-1}) of shoot and root of sunflower seedling grown in nutrient solution depending on molybdenum treatments (0; 0.07; 0.7; 7 μM)*

Mo-treatment (μM)	Dry weight of sunflower (g plant^{-1})	
	Shoot	Root
0	0.2032±0.0011^{a}	0.2097±0.0061^{a}
0.07	0.2621±0.0059^{b}	0.2120±0.0167^{a}
0.7	0.2799±0.0102^{b}	0.2208±0.0025^{a}
7	0.2619±0.0100^{b}	0.1707±0.0218^{b}

The values with different alphabetical index are significantly (P<0.05) different whithin the individual columns. n=3±s.e.

The dry mass of shoot increased by nearly 30% compared to the control. In the case of the sunflower root, however, the 0.07 and 0.7 μM Mo-treatments did not have a significant effect on the dry weight content of the root. Only the largest treatment resulted in significant difference compared to the control.

Analysing the Mo content of the shoot and root of the maize seedling I established that the Mo concentration of maize plants cultivated with nutrients with no molybdenum was relatively low showing the original molybdenum content of seedlings. However, the plant's molybdenum uptake increased due to the Mo treatments, I could only show significant difference in the shoot but not between the control and the 0.07 Mo treatments. The largest Mo accumulation both in the sprout and the root was caused by the 7 μM Mo treatment. I noted a concentration increase of more than eight times in the sprout and more than eleven times in the root compared to the control treatment.

The molybdenum accumulated by the sunflower exceeded the concentration values established in case of the maize in each treatments. For example, in the case of the 7 μM Mo-treatment the Mo concentration measured in the sunflower's shoot and root was more than twice the values measured in the maize.

In the hydroponic experiment the Mo-treatments with increasing concentration primarily influenced the uptake of P and S from among the measured macroelements. Due to the applied molybdenum the phosphorus concentration of maize seedlings slightly increased but only in the root upon the application of 0.7 μM Mo-treatment did I note a significant increase compared to the control. In the case of sunflower seedlings also the 0.7 μM Mo treatment resulted in a statistically demonstrable increase in the P's concentration relative to the control but it is an interesting difference between the two plants of examination that the P concentration of the sunflower shoot decreased during the smallest Mo treatment compared to the control.

Analysing the results of the sulphur content of plant samples I established that the P concentration of the sunflower shoot decreased due to the Mo treatment, but the S content significantly increased in the maize shoot due to the 0.7 and 7 μM Mo treatments.

In addition to the changes in the macroelement content of test plants I also investigated what effects the certain treatments had on the microelement uptake of the experimental plants. I summarized my results in *Tables 4 and 5.*

I established that the Zn, Mn and B concentration of the two experimental plants similarly change as the concentration of these elements due to the treatments increased in the plant's shoot compared to the control.

Table 4: *Microelement content (mg kg^{-1}) of shoot and root of maize seedling grown in nutrient solution depending on molybdenum treatments (0; 0.07; 0.7; 7 μM)*

Mo-treatment (μM)	Fe (mg kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})	Mn (mg kg^{-1})	B (mg kg^{-1})
	Shoot of maize				
0	60.9±6.4^{a}	14.3±0.7^{a}	75.8±1.7^{a}	65.8±3.8^{a}	6.42±0.30^{a}
0.07	57.0±10.4^{a}	13.2±1.2^{a}	88.7±2.5^{b}	66.6±0.1^{a}	8.71±1.70^{b}
0.7	58.3±1.6^{a}	13.2±0.3^{a}	100±8^{c}	70.2±11.5^{a}	8.70±0.07^{b}
7	72.2±25.5^{a}	13.5±0.3^{a}	91.8±1.8^{b}	93.7±3.8^{b}	9.23±0.15^{b}
	Root of maize				
0	167±14^{a}	55.4±10.0^{a}	84.1±6.8^{a}	180±19^{a}	2.85±0.15^{a}
0.07	303±65^{b}	43.0±7.2^{ab}	128±1^{b}	173±18^{a}	4.41±0.58^{b}
0.7	331±38^{b}	41.4±1.1^{b}	127±7^{b}	176±5^{a}	3.96±0.69^{b}
7	187±26^{a}	25.5±5.4^{c}	119±6^{b}	151±28^{a}	5.62±0.59^{c}

The values with different alphabetical index are significantly ($P<0.05$) different whithin the individual columns. n=3±s.e.

Table 5: *Microelement content (mg kg^{-1}) of shoot and root of sunflower seedling grown in nutrient solution depending on molybdenum treatments (0; 0.07; 0.7; 7 μM)*

Mo-treatment (μM)	Fe (mg kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})	Mn (mg kg^{-1})	B (mg kg^{-1})
	Shoot of sunflower				
0	240±16^{a}	18.9±6.8^{a}	48.1±1.6^{a}	36.0±10.6^{a}	15.7±4.2^{a}
0.07	80.1±15.0^{b}	11.9±0.4^{ab}	64.0±0.5^{b}	54.7±6.5^{b}	21.6±1.2^{b}
0.7	79.1±22.0^{b}	9.40±3.50^{b}	70.0±6.6^{b}	60.5±6.5^{b}	22.6±2.7^{b}
7	115±2^{c}	9.00±0.80^{b}	53.9±6.2^{a}	53.5±0.5^{b}	23.2±0.6^{b}
	Root of sunflower				
0	284±76^{ab}	17.3±0.4^{a}	39.6±2.4^{a}	32.3±5.0^{a}	13.4±1.3^{a}
0.07	355±39^{b}	16.0±2.1^{a}	44.8±1.4^{b}	28.4±5.1^{a}	13.1±1.1^{a}
0.7	293±45^{ab}	24.1±0.2^{b}	67.8±0.3^{c}	31.7±16.9^{a}	13.5±0.1^{a}
7	238±14^{a}	19.6±0.9^{c}	55.1±3.7^{d}	22.2±3.0^{a}	12.6±0.2^{a}

The values with different alphabetical index are significantly ($P<0.05$) different whithin the individual columns. n=3±s.e.

However, I noted a difference in the seedlings' change of Fe and Cu content. For example, in case of the maize sprout I found that the nutrient's Mo content had no statistically verifiable effect on the Fe and Cu concentration, while in the case of the sunflower shoot I showed significant decrease in both microelements in relation to the control. In addition, I established that the 0.07 and 0.7 μM Mo-treatments increased the Fe concentration in the root of maize, while they did not cause demonstrable difference in the Fe content of sunflower root. Besides, in the root of maize the 0.7 and 7 μM Mo-treatments reduced, while in the case of sunflower they increased the Cu concentration.

Within the scope of my research work I also investigated how the Mo-treatments with increasing concentration influenced the NO_3-N and NH_4-N concentration of certain plant parts of the experimental plants (*Tables 6-7*).

Table 6: *Nitrate- (NO_3-N) and ammonium-nitrogen (NH_4-N) concentration (mg kg^{-1}) of shoot and root of maize seedling grown in nutrient solution depending on molybdenum treatments (0; 0.07; 0.7; 7 µM)*

Mo-treatment (µM)	**NO_3-N (mg kg^{-1})**	**NH_4-N (mg kg^{-1})**
	Shoot of maize	
0	2153±553^{a}	111^{a}±55
0.07	1730±78^{a}	199^{a}±142
0.7	3939±1427^{b}	160^{a}±39
7	1772±1086^{a}	124^{a}±2
	Root of maize	
0	4407±180^{a}	703±84^{a}
0.07	4611±221^{a}	914±23^{b}
0.7	4934±820^{a}	534±6^{c}
7	5055±1109^{a}	1075±125^{d}

The values with different alphabetical index are significantly ($P<0.05$) different whithin the individual columns. n=3±s.e.

Table 7: *Nitrate- (NO_3-N) and ammonium-nitrogen (NH_4-N) concentration (mg kg^{-1}) of shoot and root of sunflower seedling grown in nutrient solution depending on molybdenum treatments (0; 0.07; 0.7; 7 µM)*

Mo-treatment (µM)	**NO_3-N (mg kg^{-1})**	**NH_4-N (mg kg^{-1})**
	Shoot of sunflower	
0	2146±123^{a}	433±28^{a}
0.07	996±263^{b}	507±37^{a}
0.7	1264±288^{b}	353±220^{a}
7	1324±365^{b}	134±45^{b}
	Root of sunflower	
0	2575±175^{a}	424±117^{a}
0.07	3064±890^{a}	469±24^{a}
0.7	3161±1017^{a}	645±47^{b}
7	2651±874^{a}	42.6±6.7^{c}

The values with different alphabetical index are significantly ($P<0.05$) different whithin the individual columns. n=3±s.e.

As the *Tables 6 and 7* show, no statistically verifiable reduction in NO_3-N concentration could have detected in case of Mo-treatments of maize seedlings compared to the control in case of hydroponic experiment; while 0.07, 0.7 and 7 μM Mo-treatments resulted significantly decrease in NO_3-N content in shoots compared to the control in case of sunflower.

3.2. The results of rhizobox experiments

I summarized the dry mass results of the maize seedlings' shoots and roots treated with molybdenum with increasing concentration in *Table 8.*

Table 8: *Dry weight (g plant^{-1}) of shoot and root of maize seedling grown in rhizoboxes depending on molybdenum treatments (0, 30, 90, 270 mg kg^{-1})*

Mo-treatment (mg kg^{-1})	**Dry weight of maize (g plant^{-1})**	
	Shoot	**Root**
0	0.0238 ± 0.0034^{ab}	0.0400 ± 0.0098^{a}
30	0.0267 ± 0.0046^{bc}	0.0394 ± 0.0103^{a}
90	0.0308 ± 0.0083^{c}	0.0374 ± 0.0120^{a}
270	0.0210 ± 0.0049^{a}	0.0305 ± 0.0069^{b}

The values with different alphabetical index are significantly ($P<0.05$) different whithin the individual columns. n=3±s.e.

It can be well seen based on the results of the table that the 90 mg kg^{-1} Mo-treatment had a favourable effect on the dry matter product of the shoot, but it had no significant effect on the root's dry matter product. However, the largest Mo-treatment hindered the shoot's development. The mass of roots decreased by 24% in relation to the control.
The dry mass results of the sunflower seedlings' shoot and root are included in *Table 9.*

Table 9: *Dry weight (g plant^{-1}) of shoot and root of sunflower seedling grown in rhizoboxes depending on molybdenum treatments (0, 30, 90, 270 mg kg^{-1})*

Mo-treatment (mg kg^{-1})	**Dry weight of sunflower (g plant^{-1})**	
	Shoot	**Root**
0	0.0531 ± 0.0112^{a}	0.0201 ± 0.0069^{a}
30	0.0608 ± 0.0086^{b}	0.0255 ± 0.0053^{b}
90	0.0379 ± 0.0088^{c}	0.0156 ± 0.0046^{c}
270	0.0347 ± 0.0058^{c}	0.0115 ± 0.0028^{d}

The values with different alphabetical index are significantly ($P<0.05$) different whithin the individual columns. n=3±s.e.

I found that the 30 mg kg^{-1} Mo-treatment had a positive effect on the dry matter product of both the shoot and the root. In the case of the shoot, I showed a 14.5%, in the case of the root I showed a 26% increase compared to the control. In contrast, the 90 and 270 mg kg^{-1} treatments prevented the mass growth of the shoot and the root. In the largest treatment I noted a 35% decrease in case of the shoot and 43% decrease in case of the root in relation to the control.

Analysing the Mo concentration results of maize plants I established that due to the Mo-treatments the Mo concentration of shoots and roots significantly increased but I always measured a larger concentration in the root in each treatment. In the case of the 30 and 90 mg kg^{-1} Mo-treatments, the Mo concentration of the root was nearly twice, in the case of the 270 mg kg^{-1} Mo-treatment it was treble of the shoot's Mo concentration. The reaction of the sunflower seedlings to the Mo-treatments was slightly different as that of the maize. The Mo concentration of shoots and roots increased due to the treatments but the measured concentrations considerably exceeded the values measured in maize. In addition, I established that the 270 mg kg^{-1} Mo-treatment slightly prevented its molybdenum uptake.

I summarized the macroelement content of the maize seedlings' shoots and roots in *Table 10.*

Table 10: *Macroelement content (mg kg^{-1}) of shoot and root of maize seedling grown in rhizoboxes depending on molybdenum treatments (0, 30, 90, 270 mg kg^{-1})*

Mo-treatment (mg kg^{-1})	**P (mg kg^{-1})**	**S (mg kg^{-1})**
	Shoot of maize	
0	9684 ± 242^{a}	3567 ± 38^{a}
30	12210 ± 1025^{b}	3426 ± 127^{a}
90	8619 ± 108^{ac}	2830 ± 75^{b}
270	7519 ± 42^{c}	2814 ± 16^{b}
	Root of maize	
0	5543 ± 900^{a}	1521 ± 246^{a}
30	8856 ± 247^{b}	2163 ± 105^{b}
90	6045 ± 451^{a}	2263 ± 52^{b}
270	4341 ± 140^{c}	2025 ± 28^{b}

The values with different alphabetical index are significantly ($P<0.05$) different whithin the individual columns. n=3±s.e.

In the case of maize, I found that the 30 mg kg^{-1} Mo-treatment increased significantly P concentration in shoots and roots but the largest treatment prevented the infiltration of P. Based on *Table 10* it can be established that Mo affected the uptake of S too: due to

the treatment, the shoot's S concentration decreased while in the root I was able to show significant increase in all Mo-treatments compared to the control.
The macroelement content of the sunflower seedlings' shoot and root is shown in *Table 11.*

Table 11: *Macroelement content (mg kg^{-1}) of shoot and root of sunflower seedling grown in rhizoboxes depending on molybdenum treatments (0, 30, 90, 270 mg kg^{-1})*

Mo-treatment (mg kg^{-1})	**P (mg kg^{-1})**	**S (mg kg^{-1})**
	Shoot of sunflower	
0	6862±810^{a}	3708±148^{a}
30	7486±693^{a}	4377±133^{b}
90	9196±302^{b}	4051±81^{ab}
270	8999±96^{b}	2975±88^{c}
	Root of sunflower	
0	5811±101^{a}	2565±25^{a}
30	6023±653^{a}	2532±168^{a}
90	5583±31^{a}	1675±13^{b}
270	1765±282^{b}	1204±14^{c}

The values with different alphabetical index are significantly ($P<0.05$) different whithin the individual columns. n=3±s.e.

Compared to the control the P concentration of shoot is increased, but I saw a regression in the root due to the 270 mg kg^{-1} Mo-treatment in its P concentration which could be verifiable statistically. In the case of sulphur I showed a significant increase in the shoot due to the 30 mg kg^{-1} Mo-treatment but the largest treatment reduced significantly the S content in both parts of the plant.
The microelement content of maize and sunflower seedlings cultivated in rhizobox is included in *Tables 12 and 13.* Based on the tables it can be established that the treatments enhanced the uptake of Fe and Mn, but they a small effect on the Cu and Zn concentration. In addition, it can be seen that the root's B concentration reduced because of the treatments.

Table 12: *Microelement content (mg kg^{-1}) of shoot and root of maize seedling grown in rhizoboxes depending on molybdenum treatments (0, 30, 90, 270 mg kg^{-1})*

Mo-treatment (mg kg^{-1})	Fe (mg kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})	Mn (mg kg^{-1})	B (mg kg^{-1})
			Shoot of maize		
0	66.3±4.3^{a}	5.82±0.33^{a}	78.4±3.5^{a}	47.7±1.7^{a}	11.1±0.6^{a}
30	121±19^{b}	5.93±0.57^{a}	82.7±4.4^{ab}	54.3±0.8^{b}	10.8±0.6^{a}
90	146±43^{bc}	5.33±0.06^{a}	67.3±2.7^{c}	49.4±0.3^{a}	11.2±0.1^{a}
270	179±22^{c}	5.08±0.08^{a}	87.9±4.9^{b}	42.8±0.2^{c}	11.9±0.5^{a}
			Root of maize		
0	1763±53^{a}	4.94±0.54^{a}	24.1±3.9^{a}	41.4±0.3^{a}	6.59±0.43^{a}
30	2143±197^{b}	5.61±0.39^{a}	33.0±1.2^{a}	52.7±0.2^{b}	6.27±1.64^{a}
90	2198±70^{b}	7.27±0.36^{b}	48.9±11.8^{b}	57.3±0.2^{c}	2.33±1.02^{b}
270	1959±146^{ab}	7.36±0.83^{b}	35.3±0.8^{a}	62.7±0.8^{d}	1.57±0.35^{b}

The values with different alphabetical index are significantly ($P<0.05$) different whithin the individual columns. n=3±s.e.

Table 13: *Microelement content (mg kg^{-1}) of shoot and root of sunflower seedling grown in rhizoboxes depending on molybdenum treatments (0, 30, 90, 270 mg kg^{-1})*

Mo-treatment (mg kg^{-1})	Fe (mg kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})	Mn (mg kg^{-1})	B (mg kg^{-1})
			Shoot of sunflower		
0	31.9±1.1^{a}	26.4±1.5^{ab}	109±2^{ab}	94.1±0.8^{a}	23.0±0.2^{a}
30	56.3±0.2^{b}	24.0±1.5^{a}	117±5^{b}	100±3^{b}	20.7±0.8^{a}
90	63.1±8.3^{b}	27.8±1.3^{bc}	99.1±2.7^{a}	98.8±1.7^{b}	19.8±2.1^{a}
270	33.8±7.6^{a}	30.0±0.4^{c}	88.1±6.7^{c}	50.4±1.3^{c}	14.5±2.1^{b}
			Root of sunflower		
0	5672±60^{a}	37.2±1.9^{a}	65.9±3.3^{a}	180±18^{a}	13.7±1.4^{a}
30	4917±26^{a}	37.4±3.4^{a}	57.0±3.0^{ab}	133±8^{b}	15.0±1.0^{a}
90	5351±105^{a}	35.5±1.9^{a}	52.3±0.6^{a}	158±5^{ab}	9.81±2.39^{b}
270	3193±56^{b}	29.1±3.1^{b}	114±9^{c}	83.0±12.0^{c}	10.1±1.0^{b}

The values with different alphabetical index are significantly ($P<0.05$) different whithin the individual columns. n=3±s.e.

I summarized the NO_3-N and NH_4-N concentration results of seedlings in *Table 14-15.* I established that in the case of maize shoots all Mo-treatments, while in the case of root the 30 and 90 mg kg^{-1} Mo-treatments decreased the NO_3-N concentration in a statistically verifiable way and increased the NH_4-N concentration compared to the control, but Mo-treatments resulted no significant decrease in NO_3-N concentration of shoots and roots in case of sunflower.

Table 14: *Nitrate- (NO_3-N) and ammonium-nitrogen (NH_4-N) concentration (mg kg^{-1}) of shoot and root of maize seedling grown in rhizoboxes depending on molybdenum treatments (0, 30, 90, 270 mg kg^{-1})*

Mo-treatment (mg kg^{-1})	**NO_3-N (mg kg^{-1})**	**NH_4-N (mg kg^{-1})**
	Shoot of maize	
0	146 ± 1^{a}	456 ± 2^{a}
30	44.7 ± 1.2^{b}	595 ± 5^{b}
90	74.8 ± 0.8^{c}	490 ± 1^{c}
270	133 ± 2^{d}	539 ± 13^{d}
	Root of maize	
0	163 ± 3^{a}	205 ± 0^{a}
30	41.7 ± 1.2^{b}	213 ± 1^{b}
90	76.6 ± 0.7^{c}	245 ± 1^{c}
270	185 ± 3^{d}	206 ± 4^{a}

The values with different alphabetical index are significantly ($P<0.05$) different whithin the individual columns. n=3±s.e.

Table 15: *Nitrate- (NO_3-N) and ammonium-nitrogen (NH_4-N) concentration (mg kg^{-1}) of shoot and root of sunflower seedling grown in rhizoboxes depending on molybdenum treatments (0, 30, 90, 270 mg kg^{-1})*

Mo-treatment (mg kg^{-1})	**NO_3-N (mg kg^{-1})**	**NH_4-N (mg kg^{-1})**
	Shoot of sunflower	
0	55.1 ± 3.2^{a}	292 ± 1^{a}
30	62.9 ± 0.8^{b}	181 ± 2^{b}
90	104 ± 2^{c}	806 ± 1^{c}
270	106 ± 6^{c}	1262 ± 4^{d}
	Root of sunflower	
0	21.4 ± 1.2^{a}	483 ± 2^{a}
30	20.7 ± 1.7^{a}	402 ± 0^{b}
90	53.8 ± 2.8^{b}	773 ± 3^{c}
270	348 ± 3^{c}	1008 ± 13^{d}

The values with different alphabetical index are significantly ($P<0.05$) different whithin the individual columns. n=3±s.e.

3.3. The results of pot experiment

During my results of soil analysis I established that due to the Mo-treatments with increasing concentration, the total Mo-concentration of soils that can be utilized by the plants showed a significant increase but I found difference in the soluble Mo concentration of different types of soils (*Table 16).*

Table 16: *Total molybdenum and Lakanen-Erviö soluble molybdenum content (mg kg^{-1}) of control and treated soil of Látókép, Pallag and Nyíregyháza*

Mo-treatment (mg kg^{-1})	**Total Mo (mg kg^{-1}) (A)**	**Lakanen-Erviö soluble Mo (mg kg^{-1}) (B)**	**B/A**
		Látókép (pH=6.58)	
0	<LOD	<LOD	-
3	2.96±0.05^a	1.67±0.06^a	0.564
30	27.3±4.2^b	12.1±0.2^b	0.443
90	87.2±2.2^c	43.2±1.0^c	0.495
270	265±5^d	141±12^d	0.532
		Pallag (pH=7.14)	
0	<LOD	<LOD	-
30	27.4±2.5^a	18.4±0.4^b	0.672
270	272±2^b	169±9^c	0.621
		Nyíregyháza (pH=5.09)	
0	<LOD	0<LOD	-
30	30.2±1.0^a	8.74±0.20^b	0.289
270	281±4^b	74.3±2.0^c	0.264

The values with different alphabetical index are significantly ($P<0.05$) different whithin the individual columns. Abbreviations: LOD=limit of detection. n=3±s.e.

In case of the Nyíregyháza soil, 26-29%, in case of the Látókép soil, 44-56% while in case of the Pallag soil, 62-67% of the total molybdenum was available to the plants.

Analysing the molybdenum concentration values of certain layers (1-1 cm) I showed that the periodical watering of plants resulted in Mo denudation in soils from Pallag and Látókép. The Mo concentration of the soil of Pallag was between 22.1 and 31.1 mg kg^{-1}, the Mo concentration of the Látókép soil was between 23.4 and 36.7 mg kg^{-1} in the soil treated with 30 mg kg^{-1} Mo, depending on the soil depth. However, the acidic pH of the Nyíregyháza soil prevented the vertical movement of Mo.

The dry mass results of the pot experiment showed that the growth of the green peas treated with molybdenum is considerably determined by the type, the acidity and other characteristic of the used soil. In case of Látókép and Nyíregyháza soil, the 30 mg kg^{-1} Mo-treatment increased significantly the dry matter product of the plant's vegetative parts in most cases, but the 270 mg kg^{-1} Mo-treatment hindered the growth of peas. However, in the case of green peas cultivated in the soil of Pallag the Mo-treatment did not caused an increase in any dry mass product in any of the phenological phases which as I see it is the consequence of the extra-high molybdenum accumulation arising from the soil's nearly neutral pH value. In addition, I found that the application of the 270 mg kg^{-1} Mo-dose not only hindered the growth of peas but also led to the destruction of plants after the four-node phenological phase.

During my examinations regarding the element analysis I showed that the Mo-treatments with increasing concentration increased the Mo accumulation of peas and the effect of treatment was verifiable in all parts of the peas. We could only show a significant increase in the vegetative organs between the control and the 3 mg kg^{-1} treatments. Comparing the Mo concentration values of plants cultivated in soils from Látókép, Pallag and Nyíregyháza, it can generally be said that the treated plants accumulated the most Mo from the soil of Pallag and the least Mo from the soil of Nyíregyháza, that is, the results show a close conjunction with the Lakanen-Erviö's soluble Mo content values.

Tables 17-19 display the Mo amount of certain parts of the green peas depending on the treatments.

Table 17: *Mo amount (μg $plant^{-1}$) uptake by green pea plants which were in complete maturity, grown in the calcareous chernozem soil of Látókép depending on molybdenum treatments (0, 3, 30, 90, 270 mg kg^{-1})*

	Mo amount (μg $plant^{-1}$) uptake by green pea plants at complete maturity (μg $plant^{-1}$)					
Mo-treatment (mg kg^{-1})	**Green pea plant grown in soil of Látókép**					**Total Mo-amount**
	Leaf	**Stem**	**Root**	**Pod**	**Seed**	
0	1.31 ± 0.05^{a} (25)	1.53 ± 0.16^{a} (30)	0.689 ± 0.059^{a} (13)	0.607 ± 0.033^{a} (12)	1.01 ± 0.11^{a} (20)	5.15
3	3.62 ± 0.87^{a} (25)	4.72 ± 0.03^{a} (33)	0.885 ± 0.023^{a} (6)	3.85 ± 1.00^{b} (27)	1.19 ± 0.08^{a} (8)	14.3
30	94.3 ± 2.4^{b} (33)	140 ± 12^{b} (48)	30.3 ± 3.6^{b} (10)	15.7 ± 1.9^{c} (5)	9.94 ± 0.24^{b} (3)	290
90	251 ± 17^{c} (42)	237 ± 9^{c} (40)	50.0 ± 1.4^{c} (8)	33.5 ± 1.7^{d} (6)	24.9 ± 0.5^{c} (4)	596
270	398 ± 16^{d} (50)	256 ± 1^{d} (32)	71.0 ± 7.1^{d} (9)	39.2 ± 2.1^{e} (5)	34.8 ± 1.0^{d} (4)	799

The values with different alphabetical index are significantly (P<0.05) different whithin the individual columns. The value put in brackets shows percentage of the Mo-amount of the specific plant part and of the whole plant. n=3±s.e.

Table 18: *Mo amount (μg $plant^{-1}$) uptake by green pea plants which were in complete maturity, grown in the carbonate humus sandy soil of Pallag depending on molybdenum treatments (0, 30, 270 mg kg^{-1})*

	Mo amount (μg $plant^{-1}$) uptake by green pea plants at complete maturity (μg $plant^{-1}$)					
Mo-treatment (mg kg^{-1})	**Green pea plant grown in soil of Pallag**					**Total Mo-amount**
	Leaf	**Stem**	**Root**	**Pod**	**Seed**	
0	0.786 ± 0.007^{a} (8)	2.92 ± 0.10^{a} (31)	2.11 ± 0.30^{a} (22)	2.61 ± 0.75^{a} (27)	1.17 ± 0.12^{a} (12)	9.60
30	400 ± 18^{b} (43)	281 ± 14^{b} (30)	138 ± 6^{b} (15)	72.0 ± 1.2^{b} (8)	37.6 ± 0.9^{b} (4)	928
270	-	-	-	-	-	-

The values with different alphabetical index are significantly (P<0.05) different whithin the individual columns. The value put in brackets shows percentage of the Mo-amount of the specific plant part and of the whole plant. n=3±s.e.

Table 19: *Mo amount (µg plant^{-1}) uptake by green pea plants which were in complete maturity, grown in acidic sandy soil of Nyíregyháza depending on molybdenum treatments (0, 30, 270 mg kg^{-1})*

Mo-treatment (mg kg^{-1})	Mo amount (µg plant^{-1}) uptake by green pea plants at complete maturity (µg plant^{-1})					
	Green pea plant grown in soil of Nyíregyháza					Total Mo-amount
	Leaf	Stem	Root	Pod	Seed	
0	0.346±0.007^{a}(11)	0.693±0.085^{a}(22)	0.230±0.024^{a}(7)	0.381±0.036^{a}(12)	1.46±0.22^{a}(47)	3.11
30	14.9±0.3^{b}(21)	24.1±1.4^{b}(34)	17.3±0.1^{b}(24)	6.39±1.51^{b}(9)	8.80±0.04^{b}(12)	71.5
270	118±2^{c}(29)	98.6±4.4^{c}(24)	123±1^{c}(30)	28.9±1.5^{c}(7)	40.6±1.2^{c}(10)	398

The values with different alphabetical index are significantly ($P<0.05$) different whithin the individual columns. The value put in brackets shows percentage of the Mo-amount of the specific plant part and of the whole plant. n=3±s.e.

On the basis of the results I established that the distribution of molybdenum in the plant is considerably determined by the soil's Mo concentration. If the molybdenum is present in the soil in high quantities (30-270 mg kg^{-1} Mo-treatments), Mo accumulate mainly in vegetative parts of green pea plant.

Studying the micro- and macroelement reserves of peas I established that my results sustain the synergistic relationship between Mo and P, and the antagonistic relationship between Mo and S in most cases. However, I found in some cases that as the result of the Mo-treatment, the sulphur content of some plant's parts increased compared to the control. In addition, I showed that due to the Mo loading, the Zn, Mn and B concentration of certain parts of the plant is increased, but I noticed a decrease in the Fe and Cu concentration in most cases compared to the control.

The Mo-treatments had an effect on the different N-forms too. Based on the results of the experiments I found an unequivocal evidence that the high nitrate level of plants with adverse health effects can be decreased with appropriate molybdenum supply. Analysing the NO_3-N concentration values of the vegetative parts I established that in the case of the soil of Látókép the 30 mg kg^{-1} Mo-treatment verifiably decreased the NO_3-N concentration in all parts of the plant, while in the case of the soil of Pallag it decreased it in the leaf and the root. In the case of the soil of Nyíregyháza, however, the 270 mg kg^{-1} treatment resulted in a decrease of NO_3-N concentration in the leaf and the root. Analysing the NO_3-N concentration of the generative parts I showed that the applied Mo-treatments verifiably hindered the NO_3-N accumulation in the pea in the case of the soil of Látókép, Pallag and Nyíregyháza compared to the control. In addition, I established that during the use of the soil of Látókép this favourable effect of the molybdenum could be shown in the smallest, 3 mg kg^{-1} Mo-treatment.

4. NEW AND NOVEL SCIENTIFIC RESULTS

1. It was proved, that according to the dry mass results of the hydroponic experiment, the sunflower as a dicotyledon plant is more responsive to the lack of Mo than the maize (monocotyledon plant). In the case of maize there is no significant difference in the dry mass product of the control plants and plants cultivated with nutrients containing 0.07 μM (physiological Mo-demand) Mo; but in the case of sunflower the dry mass of the plant's shoot cultivated with molybdenum-free nutrients is by 20% less than the plant treated with 0.07 μM molybdenum.

2. The dry mass results of the maize and the sunflower show that the sunflower as a dicotyledon plant is more responsive to the high Mo content. In the case of sunflowers, the 90 mg kg^{-1} Mo-treatment significantly hinder the dry mass growth, but in the case of maize a significant decrease in the dry mass product may only be shown due to the 270 mg kg^{-1} Mo-treatment.

3. It was proved, that there is a considerable difference in the Mo accumulation capability of maize (monocotyledon plant) and that of the sunflower (dicotyledon plant). The molybdenum uptake of the sunflower is almost three times more than that is of the maize in case of same amount of Mo-dose.

4. It was proved, that there is a close connection between the acidity of different types of soil and the Lakanen-Erviö's soluble molybdenum quantity. In the case of the soil of Nyíregyháza (sour humus sand) with the smallest pH value (pH=5.09) 26-29%, in the case of the soil of Látókép (calcareous chernozem) (pH=6.58) 44-56%, while in the case of the soil of Pallag (carbonate humus sand) with the largest pH value (pH=7.14) 62-67% of the total molybdenum was available to the plants.

5. It was stated, that in the case of green peas which were in complete maturity, grown in calcareous chernozem soil, the amount of molybdenum concentration has no significant effect on the dry mass product of the generative organs. In the case of vegetative organs of green pea plants which were in complete maturity, however, the 30 mg kg^{-1} Mo-treatment increases the dry mass growth in a statistically verifiable way.

However, above 30 mg kg^{-1} Mo-treatment there is a decrease in the dry mass of vegetative parts, the values are similar to the control results statistically.

6. The distribution of molybdenum in the plant is considerably determined by the soil's Mo concentration. If the molybdenum is present in the soil in high quantities (30-270 mg kg^{-1} Mo-treatments), Mo accumulate mainly in vegetative parts of green pea plant.

7. It was proved, that the Mo-treatments with increasing concentration verifiably prevent the NO_3-N accumulation in the pea compared to the control treatment. In the case of peas grown in the soil of Pallag I showed a 27%, during the application of Látókép soil I showed a 34-66%, in the case of soil of Nyíregyháza I showed a 75-78% decrease in relation to the control values.

5. SCIENTIFIC RESULTS FOR PRACTICAL APPLICATION

1. It was stated, that from among the examined macroelements the molybdenum can encourage the uptake of phosphor, from among the microelements it encouraged the uptake of zinc, manganese and boron. In the pot experiment the concentration of phosphorus increased by 2-97%, the concentration of zinc increased by 4-95%, the concentration of manganese increased by 9-191%, the concentration of boron increased by 31-364% due to the molybdenum treatments compared to the control. As these elements play an essential role in the plant metabolism processes, their accumulation can be considered favourable.

2. Based on the results of my pot experiments I established that there is a considerable difference in the NO_3-N concentration of the vegetative and generative organs. Major part of NO_3-N accumulated in the vegetative parts of the green peas and they included only a small part of the generative organs which is greatly favourable in respect of human feeding.

3. It was demontsrated, that molybdenum treatment can reduce the nitrate-content in green pea. These results are important with the view of human healthcare, because they show that we are able to ensure the reduced nitrate content in green pea with appropriate molybdenum supply.

4. These results made clear that we have to pay more attention to the Mo-supply in case of sunflower (dicotyledon) than in case of maize (monocotyledon) when cultivating them on acidic soil, because sunflower is more sensitive to lack of Mo. However, when determining the Mo-dose we have to consider that sunflower is more sensitive to the Mo-excess than the maize.

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List of publications related to the dissertation

Hungarian book chapters (6)

1. Várallyay, S., Veres, S., Soós, Á., **Bódi, É.**, Kovács, B.: Arzén kezelés hatása kukorica növény tápanyagfelvételére rhizoboxos nevelési körülmények között.
   In: Georgikon Napok konferenciakötet [elektronikus dokumentum] : 2015-ös előadások, Pannon Egyetem, [Keszthely], 458-464, 2015. ISBN: 9789639639829
2. Kovács, B., Andrási, D., **Bódi, É.**: Molibdén, valamint szelén kezelés hatása búza- és borsócsírák elemtartalmára.
   In: A fenntartható növénytermesztés fejlesztési lehetőségei : Prof. Dr. Sárvári Mihály 70 éves. Szerk.: Pepó Péter, Debreceni Egyetemi Kiadó, Debrecen, 126-137, 2014. ISBN: 9789634737414
3. **Bódi, É.**, Peles, F., Andrási, D., Fekete, I., Kovács, B.: Étkezési csírák beltartalmi értéknek növelése molibdén, illetve szelén dúsítással, valamint mikrobiológiai vizsgálatuk.
   In: Alap és alkalmazott kutatások eredményei a növénytudományokban. Szerk.: Szabó A, [s.n.], [Debrecen], 142-148, 2012. ISBN: 9786155183171
4. **Bódi, É.**, Lévai, L., Tarsoly, M., Nagy, K., Gajdos, É., Bákonyi, N., Győri, Z., Kovács, B.: A molibdénellátás és a nitrátredukció közötti összefüggés vizsgálata tápoldatos és rizoboxos kísérletben.
   In: VI. Kárpát-medencei Környezettudományi Konferencia. Szerk.: Szabó Béla, Tóth Csilla, Bessenyei György Könyvkiadó, Nyíregyháza, 199-204, 2010. ISBN: 9789639909571
5. Tarsoly, M., Lévai, L., **Bódi, É.**, Nagy, K., Andrási, D., Veres, S., Győri, Z., Kovács, B.: Arzén vegyületek hatása a laboratóriumi körülmények között nevelt kukorica és napraforgó növényekre.
   In: VI. Kárpát-medencei Környezettudományi Konferencia. Szerk.: Szabó Béla, Tóth Csilla, Bessenyei György Könyvkiadó, Nyíregyháza, 205-210, 2010. ISBN: 9789639909571

6. Nagy, K., Lévai, L., **Bódi, É.**, Tarsoly, M., Tóth, B., Marozsán, M., Győri, Z., Kovács, B.: Kukorica és napraforgó növények vizsgálata szelénkezelés hatására.
   In: VI. Kárpát-medencei Környezettudományi Konferencia. Szerk.: Szabó Béla, Tóth Csilla, Bessenyei György Könyvkiadó, Nyíregyháza, 211-216, 2010. ISBN: 9789639909571

Foreign language Hungarian book chapters (4)

7. Garousi, F., Veres, S., **Bódi, É.**, Várallyay, S., Kovács, B.: Changes of pH during uptaking of selenate and selenite by sunflower plants growing in nutrient solution.
   In: XXXV. Óvári Tudományos Nap / Nyugat-magyarországi Egyetem, Nyugat-magyarországi Egyetem Kiadó, Mosonmagyaróvár, 327-331, 2014. ISBN: 9789639941940
8. Várallyay, S., Kovács, B., Garousi, F., **Bódi, É.**, Veres, S.: Effect of different arsenic treatments on sunflower and maize plant production.
   In: XXXV. Óvári Tudományos Nap / Nyugat-magyarországi Egyetem, Nyugat-magyarországi Egyetem Kiadó, Mosonmagyaróvár, 415-419, 2014. ISBN: 9789639941940
9. **Bódi, É.**, Veres, S., Garousi, F., Várallyay, S., Kovács, B.: Growth of maize and sunflower seedlings by effect of molybdenum treatments.
   In: XXXV. Óvári Tudományos Nap / Nyugat-magyarországi Egyetem, Nyugat-magyarországi Egyetem Kiadó, Mosonmagyaróvár, 297-302, 2014. ISBN: 9789639941940
10. Kovács, B., Lévai, L., **Bódi, É.**, Puskás-Preszner, A., Hódi, K., Czipa, N., Győri, Z.: Effect of changing of molybdenum content in mineral solution and in rhizobox on element uptake by various plants.
    In: Trace elements in the food chain. Eds.: Szilágyi Mihály, Szentmihályi Klára, HAS, Budapest, 362-366, 2009. ISBN: 9789637067198

Hungarian scientific articles in Hungarian journals (6)

11. Várallyay, S., Veres, S., Garousi, F., **Bódi, É.**, Kovács, B.: Arzénkezelés hatása kukorica és napraforgó csiranövények fiziológiai paramétereire.
    Agrártud. közl. 64, 81-84, 2015. ISSN: 1587-1282.
12. **Bódi, É.**, Veres, S., Andrási, D., Garousi, F., Várallyay, S., Kovács, B.: Molibdénnel kezelt kukorica és napraforgó növények vizsgálata rizoboxos kísérletben.
    Agrártud. közl. 64, 11-14, 2015. ISSN: 1587-1282.
13. **Bódi, É.**, Peles, F., Andrási, D., Fekete, I., Kovács, B.: Funkcionális élelmiszerek előállítása étkezési csírákból molibdénnel, illetve szelén kezeléssel.
    Növénytermelés. 61 (4), 5-34, 2012. ISSN: 0546-8191.
14. **Bódi, É.**, Lévai, L., Huzsvai, L., Kovács, B.: A molibdénellátás hatása kukorica csíranövényekre.
    Növénytermelés. 60 (2), 5-29, 2011. ISSN: 0546-8191.

15. **Bódi, É.**, Peles, F., Kovács, B.: Búza- és borsócsírák molibdénnel, illetve szelénnel történő kezelése, valamint mikrobiológiai vizsgálatuk.
Tudományos Diákköri Közlemények 1, 31-42, 2011.

16. **Bódi, É.**, Lévai, L., Huzsvai, L., Kovács, B.: Növekvő molibdén-koncentráció hatása a különböző nitrogénformákra, valamint a molibdén nitrátasszimilációban betöltött szerepe.
Növénytermelés. 60 (3), 25-50, 2011. ISSN: 0546-8191.

Foreign language scientific articles in international journals (4)

17. Várallyay, S., **Bódi, É.**, Garousi, F., Veres, S., Kovács, B.: Effect of arsenic on dry weight and relative chlorophyll content in greeningmaize and sunflower tissues.
J. Microbiol. Biotech. Food Sci. 4 (3), 167-169, 2015. ISSN: 1338-5178.
DOI: http://dx.doi.org/10.15414/jmbfs.2015.4.special3.167-169

18. Kovács, B., Puskás-Preszner, A., Huzsvai, L., Lévai, L., **Bódi, É.**: Effect of molybdenum treatment on molybdenum concentration and nitrate reduction in maize seedlings.
Plant Physiol. Bioch. 96, 38-44, 2015. ISSN: 0981-9428.
DOI: http://dx.doi.org/10.1016/j.plaphy.2015.07.013
IF: 2.928

19. **Bódi, É.**, Veres, S., Garousi, F., Várallyay, S., Kovács, B.: Effects of molybdenum treatments on maize and sunflower seedlings.
World Academy of Science, Engineering and Technology : International Journal of Biological, Food, Veterinary and Agricultural Engineering. 5 (9), 375-378, 2015. ISSN: 2010-376X.

20. Kovács, B., **Bódi, É.**, Nagy, K., Tóth, B., Fekete, I., Andrási, D.: Effect of selenium and molybdenum content in rhizoboxes on element uptake of maize and sunflower.
Univ. Agron. Sci. Vet. Med. Bucharest Sci. P. Ser. E. Land Reclam. Earth Observ. Surv. Environ. Eng. 2, 23-32, 2013. ISSN: 2285-6064.

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List of other publications

Hungarian books (1)

21. Szerk. **Bódi, É.**, Fekete, I., Kovács, B.: Fiatal kutatók az egészséges élelmiszerért: tudományos ülés : Debrecen, 2013. február 19. DE AGTC MÉKK Hankóczy J. Doktori Isk., Debrecen, [7], 286 p., 2013. ISBN: 9789634736011

Hungarian book chapters (1)

22. Fekete, I., Rakonczás, N., Andrási, D., **Bódi, É.**, Kovács, B.: A különböző szőlőalanyfajták hatása a Cserszegi fűszeres mustjainak makroelem tartalmára.
In: Alap és alkalmazott kutatások eredményei a növénytudományokban. Szerk.: Szabó A, [s.n.], [Debrecen], 165-173, 2012. ISBN: 9786155183171

Foreign language international book chapters (5)

23. Kovács, B., **Bódi, É.**, Soós, Á., Andrási, D.: Application of ICP-MS in various fields of research.
In: 28th Indian Society for Mass Spectrometry Symposium cum Workshop on Mass Spectrometry. Ed.: Suresh K. Aggarwal, P. G. Jaison, Arnab Sarkar, Prudent Arts & FAb Private Limited, Mumbai, 69-80, 2014. ISBN: 9788190444262
24. **Bódi, É.**, Andrási, D., Kovács, B.: Selenium speciation analysis of selenium-enriched wheat sprouts.
In: 28th Indian Society for Mass Spectrometry Symposium cum Workshop on Mass Spectrometry. Ed.: Suresh K. Aggarwal, P. G. Jaison, Arnab Sarkar, Prudent Arts & FAb Private Limited, Mumbai, 220-223, 2014. ISBN: 9788190444262
25. Gajdos, É., Veres, S., Lévai, L., Bákonyi, N., Tóth, B., **Bódi, É.**, Marozsán, M.: Effects of bacteria containing biofertilizer on Cd-tolerance of some crop plants.
In: 18th Symposium of the International Scientific Centre of Fertilizers, More Sustainability In Agriculture: New Fertilizers And Fertilization Management / by P. Sequi, D. Ferri, E. Rea, F. Montemurro, A. V. Vonella, F. Formnaro, Publishing House "Fertilitas Agrorum", Rome, 67-73, 2009, (ISSN 1971-0755)
26. Tóth, B., Bákonyi, N., Gajdos, É., **Bódi, É.**, Marozsán, M., Veres, S., Lévai, L.: Effects of cement and quicklimepowders on the growth of corn and sunflower seedlings.
In: 18th Symposium of the International Scientific Centre of Fertilizers, More Sustainability In Agriculture: New Fertilizers And Fertilization Management / by P. Sequi, D. Ferri, E. Rea, F. Montemurro, A. V. Vonella, F. Formnaro, Publishing House "Fertilitas Agrorum", Rome, 122-126, 2009, (ISSN 1971-0755) ISBN: 19710755

27. Bákonyi, N., Tóth, B., Gajdos, É., **Bódi, É.**, Marozsán, M., Veres, S., Lévai, L.: Role of biofertilizers in plant nutrition.
In: 18th Symposium of the International Scientific Centre of Fertilizers : More Sustainability In Agriculture: New Fertilizers And Fertilization Management / by P Sequi, D. Ferri, E. Rea, F. Montemurro, A. V. Vonella, F. Formnaro, Publishing House "Fertilitas Agrorum", Rome, 17-22, 2009, (ISSN 1971-0755) ISBN: 19710755

Hungarian scientific articles in Hungarian journals (4)

28. **Bódi, É.**, Andrási, D., Kovács, B.: Szelénnel dúsított étkezési csírák szelénspeciációs vizsgálata.
Agrártud. közl. 56, 23-28, 2014. ISSN: 1587-1282.

29. Fekete, I., Rakonczás, N., Andrási, D., **Bódi, É.**, Szilágyi, S., Kovács, B.: A különböző szőlő alanyfajták hatása a szőlőbogyó (must, mag) As, Cu, Co és Zn tartalmára.
Agrártud. közl. 52, 39-44, 2013. ISSN: 1587-1282.

30. **Bódi, É.**, Gálné Remenyik, J., Nemes, A., Homoki, J., Peles, F., Fekete, I., Kovács, B.: Szelénnel dúsított étkezési csírák antioxidáns aktivitásának meghatározása, valamint mikrobiológiai vizsgálatuk.
Agrártud. közl. 52, 25-30, 2013. ISSN: 1587-1282.

31. Fekete, I., Rakonczás, N., Andrási, D., **Bódi, É.**, Kovács, B.: A különböző szőlőalanyfajták hatása a Cserszegi fűszeres mustjainak ásványi anyag tartalmára.
AGTC E-Journal. 1, 1-12, 2012. ISSN: 2063-6423.

Foreign language scientific articles in Hungarian journals (3)

32. Garousi, F., Veres, S., **Bódi, É.**, Várallyay, S., Kovács, B.: Assessment and comparison of selenium-enriched maize with sodium selenite and sodium selenate.
Agrártud. közl. 68, 11-15, 2016. ISSN: 1587-1282.

33. **Bódi, É.**, Fekete, I., Andrási, D., Kovács, B.: The role of selenium-enriched food sprouts with respect to our daily selenium needs.
Eur. chem. bull. 2 (1), 46-48, 2013. ISSN: 2063-5346.

34. Fekete, I., Rakonczás, N., Andrási, D., **Bódi, É.**, Kovács, B.: Effects of various grape rootstocks on macro and microelement uptake of 'Cserszegi Fűszeres' grape cultivar.
Eur. Chem. Bull. 12 (1), 524-527, 2012. ISSN: 2063-5346.

Foreign language scientific articles in international journals (7)

35. Garousi, F., Veres, S., **Bódi, É.**, Várallyay, S., Kovács, B.: Effect of selenite and selenate uptake by maize plants on specific leaf area.
World Academy of Science, Engineering and Technology : International Journal of Biological, Food, Veterinary and Agricultural Engineering. 5 (9), 379-382, 2015. ISSN: 2010-376X.

36. Garousi, F., Kovács, B., **Bódi, É.**, Várallyay, S., Veres, S.: Physiological reactions of sunflower plants to different spices of selenium.
Bull. of Univ. of Agr. Sci. and Vet. Med. 72 (2), 403-408, 2015. ISSN: 1843-5246.

37. Garousi, F., Kovács, B., Várallyay, S., **Bódi, É.**, Veres, S.: Relative chlorophyll content changes during uptaking of selenite and selenate by maize plants grown in nutrient solution.
J. Microbiol. Biotech. Food Sci. 4 (3), 44-47, 2015. ISSN: 1338-5178.
DOI: http://dx.doi.org/10.15414/jmbfs.2015.4.special3.44-47

38. Garousi, F., Veres, S., **Bódi, É.**, Várallyay, S., Kovács, B.: Role of selenite and selenate uptake by maize plants in chlorophyll A and B content.
World Academy of Science, Engineering and Technology : International Journal of Biological, Food, Veterinary and Agricultural Engineering. 9 (6), 549-552, 2015. ISSN: 2010-376X.

39. Fekete, I., Kovács, B., Andrási, D., **Bódi, É.**, Rakonczás, N.: Effect of the different grape rootstocks an berry skin B, Cu, Fe, Mn and Zn contents of' Cserszegi fűszeres cultivar.
Sci. P. Ser. B. Horticult. 57, 55-60, 2013. ISSN: 2285-5653.

40. **Bódi, É.**, Gálné Remenyik, J., Nemes, A., Homoki, J., Peles, F., Fekete, I., Kovács, B.: The determination of antioxidant activity of selenium-enriched wheat and pea sprouts, as well as their microbiological analysis.
Scientific papers. Series A., Agronomy. 56., 196-201, 2013. ISSN: 2285-5785.

41. Burján, Z., **Bódi, É.**, Kovács, B.: The effect of different regions and NPK fertilizer on protein and sulphur content of winter wheat (Triticum aestivum l.) grains.
Scientific papers. Series A., Agronomy. 56, 202-205, 2013. ISSN: 2285-5785.

Hungarian abstracts (9)

42. Várallyay, S., Veres, S., Soós, Á., **Bódi, É.**, Kovács, B.: Arzén kezelés hatása kukorica növény tápanyagfelvételére rhizoboxos nevelési körülmények között.
In: LVII. Georgikon Napok = 57th Georgikon Scientific Conference : Kivonat-kötet : Programfüzet, valamint az elhangzó és poszter előadások rövid kivonatainak gyűjteménye : [agrárgazdaság a növekedéskor után] : [2015. október 1-2., Keszthely]. Szerk.: Nagy Zita Barabara, Pannon Egyetem Georgikon Kar, Keszthely, 123, 2015. ISBN: 9789639639812

43. Várallyay, S., Veres, S., **Bódi, É.**, Garousi, F., Kovács, B.: Hidropónikus körülmények között nevelt napraforgó tápoldatának pH-érték változása különböző arzén kezelések hatására.
In: Tavaszi Szél Absztraktkötet 2015 : Absztraktkötet. Szerk.: Keresztes Gábor, Publio Kiadó, Budapest, 44, 2015. ISBN: 9789633977026

44. **Bódi, É.**, Kovács, B.: Tartamkísérletben alkalmazott molibdén-kezelés hatása a spenót és a sóska molibdén felvételére.
In: XI. Jedlik Ányos Szakmai Napok Konferenciakötet / fel. szerk. Zsirka Balázs, Pannon Egyetem Jedlik Ányos Szakkollégium, Veszprém, 82, 2014.

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45. Fekete, I., Rakonczás, N., Andrási, D., **Bódi, É.**, Kovács, B.: A különböző szőlőalanyfajták hatása a 'Cserszegi Fűszeres' héj és mag makroelem tartalmára.
In: XIX. Ifjúsági Tudományos Fórum / Pannon Egyetem Georgikon Kar, Pannon Egyetem, Keszthely, 1-6, 2013. ISBN: 9789639639515

46. **Bódi, É.**, Gálné Remenyik, J., Nemes, A., Homoki, J., Fekete, I., Kovács, B.: A szelénkezelés és az antioxidáns aktivitás közötti kapcsolat vizsgálata étkezési csírák esetén.
In: XIX. Ifjúsági Tudományos Fórum, [s.n.], [Keszthely], 1-6, 2013.

47. **Bódi, É.**, Andrási, D., Fekete, I., Kovács, B.: Különböző extrakciós módszerek összehasonlítása szelénnel dúsított étkezési csírák esetén.
In: XXXVI. Kémiai Előadói Napok : Program és előadás-összefoglalók. Szerk.: Endrődi Balázs, Laufer Noémi, Szegedi Akadémiai Bizottság Székháza, Szeged, 249, 2013. ISBN: 9789633151457

48. **Bódi, É.**: A molibdénellátás és a nitrátredukció közötti összefüggés vizsgálata.
In: XXX. Jubileumi Országos Tudományos Diákköri Konferencia : Agrártudományi Szekció : Pannon Egyetem Georgikon Kar, Keszthely, 2011. április 6-8. : konferencia-kötet : program és előadás összefoglalók. Szerk.: Pál László, Farkas Róbert, Kodrik László, PE Georgikon Kar, Keszthely, 135, 2011. ISBN: 9789639639416

49. **Bódi, É.**: A molibdénellátás és a nitrátredukció közötti összefüggés vizsgálata.
In: XII. Országos Felsőoktatási Környezettudományi Diákkonferencia Konferencia-kötet. Szerk.: Szarka László, Nyugat-magyarországi Egyetem Kiadó, Sopron, 236-237, 2010. ISBN: 9789639883505

50. **Bódi, É.**: A molibdénellátás és a nitrátredukció közötti összefüggés vizsgálata.
In: XXIX. Országos Tudományos Diákköri Konferencia Agrártudományi Szekció : előadás kivonatok. Szerk.: Falusi Eszter, Staszny-Havas Enikő, Jung Ivett, Bodnár Ákos, Szent István Egyetem Egyetemi Kiadó, Gödöllő, 143, 2009. ISBN: 9789632690957

Foreign language abstracts (22)

51. Várallyay, S., Veres, S., Soós, Á., **Bódi, É.**, Kovács, B.: Effect of Different Arsenic Treatments on The Uptake of Ca, K, S, P And Mg by Maize Seedlings.
In: 1st Meeting of Young Researchers from V4 Countries. Book of Abstract. Ed.: Monika Wesołowska, University of Rzeszow, Rzeszow, 90, 2016.

52. **Bódi, É.**, Várallyay, S., Soós, Á., Kovács, B.: Effect of molybdenum treatment on the element content of maize and green pea in a long-term field experiment.
In: 1st Meeting of Young Researchers from V4 Countries : Book of Abstract. Ed.: Monika Wesołowska, University of Rzeszow, Rzeszow, 17, 2016.

53. Várallyay, S., Veres, S., **Bódi, É.**, Garousi, F., Andrási, D., Kovács, B.: Effect of arsenic treatment on elements contents of sunflower growing on nutrient solution.
World Academy of Science Engineering and Technology. Agricultural and Biosystems Engineering 2 (5), 465, 2015.

54. Várallyay, S., Kovács, B., **Bódi, É.**, Garousi, F., Veres, S.: Effect of different arsenic treatments on root growth of sunflower seedlings in rhizobox experiment.
World Academy of Science, Engineering and Technology. International Journal of Nutrition and Food Engineering 2 (6), 1, 2015.

55. **Bódi, É.**, Veres, S., Garousi, F., Várallyay, S., Kovács, B.: Effects of molybdenum treatments on maize and sunflower seedlings.
World Academy of Science, Engineering and Technology. Agricultural and Biosystems Engineering 2 (5), 516, 2015.

56. Kovács, B., **Bódi, É.**, Garousi, F., Várallyay, S., Soós, Á., Vágó, X., Andrási, D.: Problems and solutions in the application of ICP-MS for analysis of trace elements in various samples.
World Academy of Science, Engineering and Technology. International Journal of Nutrition and Food Engineering 2 (6), 1, 2015.

57. Kovács, B., **Bódi, É.**, Garousi, F., Várallyay, S., Andrási, D.: What are the problems in the case of analysis of selenium by inductively coupled plasma mass spectrometry in food and food raw materials?
World Academy of Science, Engineering and Technology. Agricultural and Biosystems Engineering 2 (5), 1, 2015.

58. Garousi, F., Veres, S., **Bódi, É.**, Várallyay, S., Kovács, B.: Changes of pH during uptaking of selenate and selenite by sunflower plants growing in nutrient solution.
In: XXXV. Óvári Tudományos Nap. A magyar és nemzetközi agrár- és élelmiszer-gazdaság lehetőségei. Szerk.: Schmidt Rezső, Bali Papp Ágnes, Nyugat-magyarországi Egyetem Kiadó, Mosonmagyaróvár, 34, 2014. ISBN: 9789633341933

59. Várallyay, S., Kovács, B., Garousi, F., **Bódi, É.**, Veres, S.: Effect of different arsenic treatments on sunflower and maize plants production.
In: XXXV. Óvári Tudományos Nap. A magyar és nemzetközi agrár- és élelmiszer-gazdaság lehetőségei. Szerk.: Schmidt Rezső, Bali Papp Ágnes, Nyugat-magyarországi Egyetem Kiadó, Mosonmagyaróvár, 21, 2014. ISBN: 9789633341933

60. **Bódi, É.**, Várallyay, S., Garousi, F., Kovács, B.: Effect of molybdenum treatment on the element uptake of spinach and garden sorrel in a long-term field experiment.
In: 14th International Nutrition and Diagnostics Conference : Book of Abstracts / A. Horna, Radanal Ltd., Prága, 167, 2014. ISBN: 9788073957766

61. **Bódi, É.**, Veres, S., Garousi, F., Várallyay, S., Kovács, B.: Growth of maize and sunflower seedlings by effect of molybdenum treatments.
In: XXXV. Óvári Tudományos Nap. A magyar és nemzetközi agrár- és élelmiszer-gazdaság lehetőségei. Szerk.: Schmidt Rezső, Bali Papp Ágnes, Nyugat-magyarországi Egyetem Kiadó, Mosonmagyaróvár, 33, 2014. ISBN: 9789633341933

62. Várallyay, S., **Bódi, É.**, Garousi, F., Kovács, B.: Risk assessment of arsenic contamination.
In: 14th International Nutrition and Diagnostics Conference : Book of Abstracts. / A. Horna, Radanal Ltd., Prága, 166, 2014. ISBN: 9788073957766

63. Kovács, B., **Bódi, É.**, Peles, F., Andrási, D., Fekete, I., Borbélyné Varga, M.: Analyses of element contents and microbiological parameters of wheat- and pea-sprouts treated by molybdenum and selenium.
In: 9th International Symposium on Environmental Geochemistry, AVeiro, Portugal, July 15-21, 2012 : Book of Abstracts. Eds.: Eduardo Ferreira da Silva, Amélia Paula Reis, Carla Patinha, Eduarda Pereira, Sonia Rodrigues, PLM-Plural, S.A, Aveiro, 223, 2012. ISBN: 9789727893652

64. Fekete, I., Rakonczás, N., Andrási, D., Sipos, P., **Bódi, É.**, Kovács, B.: Analyses of potentially toxic elements in the different grape juices (musts) by inductively coupled plasma (ICP) techniques.
In: European Medical Students' Conference Abstract Book, University of Debrecen, Debrecen, 104, 2012.

65. Fekete, I., Rakonczás, N., Andrási, D., Sipos, P., **Bódi, É.**, Kovács, B.: Effects of the different grape rootstocks on the aluminum, copper, iron, manganese and zinc concentrations of the grape musts.
In: SESEH 2012 : 2012 Sino-European Symposium on Environment and Health : Book of Abstracts, Conference Programme / [ed. by National University of Ireland, National University of Ireland, Galway, Ireland, 78, 2012.

66. Fekete, I., Rakonczás, N., Andrási, D., **Bódi, É.**, Kovács, B.: Effects of various grape rootstocks on macro and micro element uptake of 'Cserszegi fűszeres' grape cultivar.
In: 4th International Symposium on Trace Elements in the Food Chain. Friends or Foes? TEFC 2012 15-17 November 2012 Hotel Visegrád, Visegrád, Hungary : Program : Abstracts, Szent István Egyetem, Visegrád, 57, 2012.

67. **Bódi, É.**, Peles, F., Fekete, I., Andrási, D., Kovács, B.: Improvement of nutritional value of food sprouts with enrichment of molybdenum and selenium, as well as their microbiological analysis.
In: SESEH 2012 : 2012 Sino-European Symposium on Environment and Health : Book of Abstracts, Conference Programme / [ed. by National University of Ireland, National University of Ireland, Galway, Ireland, 83, 2012.

68. **Bódi, É.**, Fekete, I., Andrási, D., Kovács, B.: The role of selenium-enriched food sprouts with respect to our daily selenium needs.
In: 4th International Symposium on Trace Elements in the Food Chain. Friends or Foes? TEFC 2012 15-17 November 2012 Hotel Visegrád, Visegrád, Hungary : Program : Abstracts, Szent István Egyetem, Visegrád, 58, 2012.

69. **Bódi, É.**, Peles, F., Fekete, I., Andrási, D., Kovács, B.: Uptake of selenite and selenate during germination of wheat and pea as well as the effect of treatments in their microbiological state.
In: EMESCO Abstract Book / publisher University of Debrecen, University of Debrecen, Debrecen, 78, 2012.

70. Kovács, B., **Bódi, É.**, Peles, F., Puskás-Preszner, A., Andrási, D., Győri, Z.: Effect of molybdenum and selenium treatment on element contents of wheat- and pea-sprouts, as well as their microbiological analyses.
In: 12th International Symposium on Soil and Plant Analysis : Abstract Book. Ed.: Mediterranean Agronomic Institute of Chania, Mediterranean Agronomic Institute of Chania, Crete, Greece, 109, 2011.

71. Kovács, B., Lévai, L., **Bódi, É.**, Puskás-Preszner, A., Hódi, K., Czipa, N., Győri, Z.: Effect of changing of molybdenum content in mineral solution and in rhizobox on element uptake by various plants.
In: Trace elements in the food chain : Deficiency or excess of trace elements in the environment as a risk of health : 3rd International Symposium on Trace Elements in the Food Chain. Eds.: Szilágyi Mihály, Szentmihályi Klára, HAS, Budapest, 56, 2009.

72. Kovács, B., Lévai, L., **Bódi, É.**, Puskás-Preszner, A., Hódi, K., Győri, Z.: Effect of molybdenum and selenium content in mineral solution and soil on element uptake by various plants.
In: 3rd International IUPAC Symposium on Trace Elements in Food : Abstract Book. Eds.: Francesco Cubadda, Federica Aureli, Silvia Ciardullo, Marina Patriarca, Istituto Superiore di Sanitá, Roma, 135, 2009, (ISTISAN Congressi, ISSN 0393-5620 ; 09/C2)

Informational/educational articles (3)

73. **Bódi, É.**, Kovács, B.: Étkezési csírák az egészséges táplálkozásban.
Kulinárium. 11-12, 14-15, 2014. ISSN: 1786-4976.

74. **Bódi, É.**, Peles, F., Kovács, B.: Csírafogyasztás: a legegyszerűbb út az egészséges táplálkozáshoz.
Élelmezés. 3, 16-17, 2012. ISSN: 1785-3184.

75. **Bódi, É.**, Lévai, L., Kovács, B.: Milyen szerepet játszik a molibdén a növényeink nitráttartalmának csökkentésében?
Értékálló aranykorona. 10, 20, 2010. ISSN: 1586-9652.

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