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PHYTOEXTRACTION OF CADMIUM AND LEAD BY SELECTED CULTIVARS OF *Tagetes erecta* L. PART I. EFFECT OF Cd AND Pb ON YIELDING

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Abstract. The objective of the presented studies carried out in the Department of Horticultural Plant Fertilization, University of Life Sciences in Poznań was the investigation of the influence of the introduced doses of cadmium and lead (soil pollution) on the yield of the particular organs of selected cultivars of Marigold (*Tagetes erecta* L.) and to check whether these plants are suitable to be planted on soils polluted with the mentioned metals. Plants used in the experiment were planted in individual outflowless containers in plastic tunnel. The studied cultivars of Marigold were planted in a substrate artificially polluted with cadmium and lead. The two heavy metals were introduced in the following doses: Cd – 0 (control); 1; 5; 10 mg dm^{-3}, Pb – 0 (control); 100; 500; 1000 mg dm^{-3}. Statistical analyses carried out in the present paper refer to the analysis of variance for leaf, stalk and inflorescence matters and the number of inflorescences. Analysis of the mean total yield of the particular cultivars grown in all substrates has shown that the highest total yield was reached by 'Titania' cultivar, in the second place was 'Hawaii' and the smallest yield was obtained from 'Mann im Mond'. The smallest amounts of cadmium and lead, regardless of the applied dose, remained in the substrate in which 'Hawaii' cultivar was grown.

Key words: phytoextraction, cadmium, lead, *Tagetes erecta* L.

INTRODUCTION

Recultivation of polluted soils includes the removal of organic contaminations contained in the soil and particularly of materials derived from crude oil, as well as the immobilization or removal of heavy metals [Wójcik 2000]. One of the methods of soil purification from heavy metals is phytoextraction. It is a method friendly to the environment and it does not evoke any social controversions since it does not disturb the biological life of soils and it does not cause any side-effects in the form of deposited

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substances which had been used for soil purification [Ciura et al. 2001]. Obvious merits of this method are its low costs. The removal of heavy metals by traditional methods is twice or even four times more expensive so, their application on big areas is not payable from the economic point of view [Glass 1997]. However, the problem lies in the fact that there is no information available which species of the higher plants are suitable for phytoextraction purposes in our moderate climate and which plant species are fitted to be grown on soils contaminated with heavy metals. This fact gave the incentive to perform studies aiming at the determination what effect do cadmium and lead doses introduced to the soil (contaminating the soil) exert on the particular organs of selected cultivars of *Tagetes erecta* L. and whether these plants are suitable for cultivation on soils contaminated by the mentioned heavy metals. A successive publication will present results referring to phytoextraction of these metals by selected cultivars of *Tagetes erecta* L.: 'Mann im Mond', 'Hawaii', 'Titania'.

Tagetes erecta L. belongs to *Asteraceae* family. It originates from Mexico where it reaches the height of 70 cm. Its stalks are thick, strongly branched and with abundant leafage. The leaves are aromatic, pinnated. Flower heads are big, individually set on shoot apices and their diameters range from 5 to 10 cm. They flower abundantly during the whole summer until autumn. Achenes are flat, elongated, brown, provided with a volatile apparatus. Only full-blossomed cultivars are cultivated, they differ by plant height, structure and by the degree of coloring and the size of inflorescences. Marigold are suitable for flower-beds, borders, for the creation of garden groups and for growing in containers, in balcony boxes, as well as for cut flowers. Marigold can be planted on each soil, but in infertile and dry localities, they grow poorly and their flowers are less abundant. They like insolated localities, but they can be also grown in semi-shadow. They are resistant to diseases and pests.

MATERIAL AND METHODS

Experiment was carried out in the Department of Horticultural Plant Fertilization, University of Life Sciences in Poznań. In the initial stage, for 3 weeks after seeding, the experiment was carried out in an unheated greenhouse. Subsequently, the plants were planted into individual containers and they were transferred to an unheated tunnel. The experiment included the following cultivars of *Tagetes erecta* L. cultivar: 'Mann im Mond', 'Hawaii' and 'Titania'.

In order to estimate the usefulness of *Tagetes erecta* L. for phytoremediation, the plants were planted in a substrate artificially contaminated with cadmium and lead.

Plants used in the experiment were planted in individual outflowless containers of one dm^3 capacity, in a completely random design. Experimental factors included: three cultivars of *Tagetes erecta* L., two heavy metals cadmium and lead, increasing doses.

Each cultivar represented one part of the experiment consisting of eight combinations, while each combination consisted of five replications. One replication was represented by one plant grown in a separate container of 1 dm^3 capacity.

The substrate used in the experiment consisted of highmoor peat from Harmann Company. The weight of 1 dm^3 of peat was 470 g. In order to obtain an adequate pH

value for the growing of Marigold, a neutralization curve for the substrate was plotted. On this basis, the dose of $CaCO_3$ was determined and it was: 7.5 g $CaCO_3$ dm^{-3} of peat. in order to maintain the pH value within the interval of 6.5–7.0.

In the first stage of substrate preparation for plant cultivation, the peat was mixed with calcium carbonate and it was placed in the outflowless containers. In the next stage, cadmium and lead, in the form of chemically pure agents, were introduced to each container. The doses of cadmium and lead applied in the experiment represented different degrees of contamination. The doses of 1 mg Cd dm^{-3} and 100 mg Pb dm^{-3} show increased values, while the doses: 5 mg Cd dm^{-3} and 500 mg Pb dm^{-3} show a small contamination. Doses of 10 mg Cd dm^{-3} and 1000 mg Pb dm^{-3} polluted soil in a medium degree. Cadmium was introduced in the form of cadmium sulphate $3CdSO_4$ $8H_2O$, while lead was in the form of lead acetate $(CH_3COO)_2$ Pb $3H_2O$. In order to obtain a well done mixture , the highmoor peat was mixed with an adequate amount of cadmium or lead and with a multicomponent fertilizer Azofoska in the amount of 3 g dm^{-3}. After an exact mixing, the substrate was transferred to the experimental containers. The multicomponent fertilizer Azofoska was applied in order to introduce nutritive components into the substrate (1 g Azofoska = 136 mg N, 64 mg P_2O_5, 191 mg K_2O, 45 mg MgO, 1.7 mg Fe, 0.45 mg Zn, 1.8 mg Cu, 2.7 mg Mn, 0.45 mg B, 0.90 Mo).

In the experiment, seeding material was used which originated from the Horticultural Seed Production and Nursery Enterprise in Ożarów. In the first half of April, seeds of three Marigold cultivars: 'Mann im Mond', 'Hawaii' and 'Titania' were sown in spaces into multipallets and they were covered with a layer of sand, in order to limit moisture losses. The substrate consisted of highmoor peat with an addition of multicomponent fertilizer Azofoska in the amount of 1.5 g dm^{-3} and 5 g $CaCO_3$ dm^{-3}.

After the preparation of the substrates, plants were planted into the experimental containers. In each container, one plant was planted. Then, the containers were transferred from the greenhouse to an unheated tunnel and they were placed in a random order where they remained until the end of experiment.

Three months after plantation into the containers filled with the artificially contaminated substrate, in the phase of full blooming, samples of plants material and substrate were taken. Before the liquidation, the containers with substrate and plants were irrigated to a constant weight. Subsequently, plants were cut down. Each plant was weighed separately and the masses of stalks, leaves and inflorescences were weighed separately as well. The number of flowers was counted from each plant separately. After the termination of the experiment, soluble forms of cadmium and lead contained in the substrate were determined in Lindsey's extract.

Statistical analyses carried out in this experiment included the analysis of variance referring to leaves, stalks and inflorescences masses and to the number of inflorescences. The statistical analyses were carried out in Statobl univariate analysis of variance for factorial orthogonal experiments. Differences between mean values were determined at the significance level of $\alpha = 0.05$.

RESULTS AND DISCUSSION

Total yield. Table 1 of the here presented studies shows the total yield of the particular cultivars grown in this experiment. The total yield included the yield of the particular plant organs, i.e. the masses of inflorescences, leaves and stalks.

Table 1. The total yield of the particular cultivars (g plant^{-1} fresh mass)
Tabela 1. Plon ogólny badanych odmian (g · roślina^{-1} św.m.)

Cultivar Odmiana	Metal	I*	II	III	IV	Mean Średnia A/B	Mean Średnia A
'Mann im Mond'	Cd	135.75	147.25	138.25	136.50	139.44	133.50
	Pb	135.75	143.25	124.00	107.25	127.56	
Mean – Średnia A/C		135.75	145.25	131.13	121.88		
'Hawaii'	Cd	136.75	142.50	143.75	133.75	139.19	134.69
	Pb	136.75	135.00	136.25	112.75	130.19	
Mean – Średnia A/C		136.75	138.75	140.00	123.25		
'Titania'	Cd	154.50	162.75	150.00	155.25	155.63	154.97
	Pb	154.50	190.75	144.75	127.25	154.31	
Mean – Średnia A/C		154.50	176.75	147.38	141.25		
Mean – Średnia C		142.33	153.58	139.50	128.79		
Mean – Średnia B/C		Cd 142.33 Pb 142.33	Cd 150.83 Pb 156.33	Cd 144.00 Pb 135.00	Cd 141.83 Pb 115.75		
Mean – Średnia B		Cd 144.75		Pb 137.35			

$NIR_{0.05}$ A (cultivar – odmiana) = 8.88
$NIR_{0.05}$ B (metal) = 7.25
$NIR_{0.05}$ A · B = n.s. r.n.
$NIR_{0.05}$ C (dose – dawka) = 10.26
$NIR_{0.05}$ A · C = n.s. r.n.
$NIR_{0.05}$ B · C = 14.50
$NIR_{0.05}$ A · B · C = n.s. r.n.

* dose of metal dawka metalu:
I – control – kontrola
II – 1 mg Cd dm^{-3}; 100 mg Pb dm^{-3}
III – 5 mg Cd dm^{-3}; 500 mg Pb dm^{-3}
IV – 10 mg Cd dm^{-3}; 1000 mg Pb dm^{-3}

An analysis of the mean total yield of the particular cultivars grown in all substrates has shown that the highest total yield was obtained by 'Titania' cultivar, the next was 'Hawaii' and the smallest yield was found in 'Mann im Mond' cultivar.

When we compare the effect of the studied metals on the total yield, we can see that higher yields were obtained in the substrates with cadmium in case of 'Mann im Mond' and in 'Hawaii' cultivars, in comparison with the yield obtained in the substrates with lead.

Increasing doses of cadmium and lead exerted a significant effect on the yield increase of the studied cultivars. The cultivar 'Mann im Mond' showed the highest yield in the substrates with increased cadmium and lead contents (1 mg Cd dm^{-3} and 100 mg Pb dm^{-3}). The smallest yield was found in the substrates with a medium contamination with cadmium and lead (10 mg Cd dm^{-3} and 1000 mg Pb dm^{-3}). 'Hawaii' cultivar reached the highest yield in substrates with small contaminated by heavy metals (5 mg Cd dm^{-3} and 500 mg Pb dm^{-3}), while the lowest total yield was found in the substrates with a medium contamination with these metals (10 mg Cd dm^{-3} and 1000 mg Pb dm^{-3}). The highest total yield of 'Titania' cultivar was obtained in substrates with increased heavy metal contents (1 mg Cd dm^{-3} and 100 mg Pb dm^{-3}). The smallest yield was recorded in substrates with a medium contamination with Cd and Pb.

Similar results were obtained by Ciurzyńska and Gawroński [2002], who studied the usefulness of feathered cabbage (*Brassica oleracea*) and Chinese cabbage (*Brassica pekinensis*) for phytoremediation. They found that low lead concentration, i.e. such one which does not exceed the soil background, exerted an effect on the increment of fresh matter of feathered cabbage leaves and of Chinese cabbage. They showed that after the application of the highest lead doses (45 mg Pb dm^{-3}), both the feathered cabbage and the Chinese cabbage reacted with a decreased weight. Stress-generating lead evokes a specific plant reaction. On the done hand, it is connected with the irreversible disturbance of the structure and function of cells which can lead to a disorder in the growth and development of plants and in extreme cases, it may even lead to the death of the organism. On the other hand, a stimulus of this type can contribute to an increased tolerance in relation to other stress generating factors [Woźny 1995].

In the experiment carried out by Bosiacki and Golcz [2008], increasing doses of lead caused significant decrease of the yield of common sunflower and scarlet sage, in comparison with the control. When we accept as 100% the yield of plants obtained by growing them in a substrate without any addition of metals, we find that the yield decreases. In common sunflower, it decreased by 22.2% (100 mg Pb dm^{-3}); by 30.2% (500 mg Pb dm^{-3}); by 61.1% (1000 mg Pb dm^{-3}). In scarlet sage, yield decreased by: 12.77% (100 mg Pb dm^{-3} by 37.6% (500 mg Pb dm^{-3}); by 71.6% (1000 mg Pb dm^{-3}). In case of Marigold, a smaller yield in relation to the control was obtained in substrates with an addition of 500 and 1000 mg Pb dm^{-3}. The yield decreased by 9.7% (500 mg Pb dm^{-3}); and by 50% (1000 mg Pb dm^{-3}). A significant increase of Marigold yield was obtained in substrates where 100 mg Pb dm^{-3} was introduced and the yield was by 37.3% higher, in comparison with the control.

In the studies by Bosiacki [2008], it was shown that with the increase of cadmium doses, the yields of common sunflower and scarlet sage decreased, in comparison with the control. When we accepted as 100% the yield obtained by growing the plants in a substrate without any metal addition, we found a yield decrease; in common sunflower, the yield decreased by 21% (at the dose of 1 mg Cd dm^{-3}); by 39% (5 mg Cd dm^{-3}); by 45% (10 mg Cd dm^{-3}). In scarlet sage, there was a decrease by 16.5% (at the dose of 1 mg Cd dm^{-3}); by 24% (5 mg Cd dm^{-3}); by 40% (10 mg Cd dm^{-3}). A significant increase of the yield of Marigold in the substrates with a dose of 10 mg Cd dm^{-3} was statistically proven, in comparison with the control.

Yield of inflorescences. Among the studied cultivars of Marigold, the highest mean yield of inflorescences was obtained by 'Titania' cultivar (64.79 g $plant^{-1}$) a smaller yield was shown by 'Mann im Mond' (28.72 g $plant^{-1}$) and the smallest yield was found in 'Hawaii' (25.56 g $plant^{-1}$), (tab. 2). The difference between the cultivars 'Mann im Mond' and 'Hawaii' was not statistically proven.

Analysis of inflorescence yield showed that 'Mann im Mond' cultivar obtained a higher yield than the control with the dose of 1000 mg Pb dm^{-3}. In the remaining combinations, the differences in the yields were insignificant. In turn, in 'Hawaii' cultivar, a drop in the yield was found, in comparison with the control after the application of 10 mg Cd dm^{-3}. Differences in the yield were also found in the analysis of the inflorescence yield of 'Titania' cultivar. These plants were characterized by a higher yield of

Table 2. Yield of inflorescences of the particular cultivars (g plant^{-1} fresh mass)
Tabela 2. Plon kwiatostanów badanych odmian (g · roślina^{-1} św.m.)

Cultivar Odmiana	Metal	I*	II	III	IV	Mean Średnia A/B	Mean Średnia A
'Mann im Mond'	Cd	30.00	29.50	23.50	24.75	26.94	28.72
	Pb	30.00	39.50	24.75	27.75	30.50	
Mean – Średnia A/C		30.00	34.50	24.13	26.25		
'Hawaii'	Cd	28.25	32.00	21.50	14.00	23.94	25.56
	Pb	28.25	23.25	30.25	27.00	27.19	
Mean – Średnia A/C		28.25	27.63	25.88	20.50		
'Titania'	Cd	68.00	76.50	52.00	59.25	63.94	64.79
	Pb	68.00	76.50	62.75	55.25	65.63	
Mean – Średnia A/C		68.00	76.50	57.38	57.25		
Mean – Średnia C		42.08	46.21	35.79	34.67		
Mean – Średnia B/C		Cd 42.08 Pb 42.08	Cd 46.00 Pb 46.42	Cd 32.33 Pb 39.26	Cd 32.67 Pb 36.37		
Mean – Średnia B		Cd 38.27		Pb 41.11			

NIR $_{0.05}$ A (cultivar – odmiana) = 6.79
NIR $_{0.05}$ B (metal) = n.s. r.n.
NIR $_{0.05}$ A · B = n.s. r.n
NIR $_{0.05}$ C (dose – dawka) = 7.84
NIR $_{0.05}$ A · C = n.s. r.n.
NIR $_{0.05}$ B · C = n.s. r.n.
NIR $_{0.05}$ A · B · C = n.s. r.n.

* dose of metal – dawka metalu:
I – control – kontrola
II – 1 mg Cd dm^{-3}; 100 mg Pb dm^{-3}
III – 5 mg Cd dm^{-3}; 500 mg Pb dm^{-3}
IV – 10 mg Cd dm^{-3}; 1000 mg Pb dm^{-3}

Table 3. Number of flowers of the particular cultivars
Tabela 3. Liczba kwiatostanów badanych odmian

Cultivar Odmiana	Metal	I*	II	III	IV	Mean Średnia A/B	Mean Średnia A
'Mann im Mond'	Cd	4.50	5.25	5.00	3.50	4.56	4.75
	Pb	4.50	5.25	4.50	5.50	4.94	
Mean – Średnia A/C		4.50	5.25	4.75	4.50		
'Hawaii'	Cd	8.25	7.00	7.00	4.75	6.75	7.13
	Pb	8.25	8.00	6.25	7.50	7.50	
Mean – Średnia A/C		8.25	7.50	6.63	6.13		
'Titania'	Cd	16.00	10.75	7.75	6.25	10.19	10.78
	Pb	16.00	8.50	8.50	12.50	11.38	
Mean – Średnia A/C		16.00	9.63	8.13	9.38		
Mean – Średnia C		9.59	7.46	6.50	6.67		
Mean – Średnia B/C		Cd 9.59 Pb 9.59	Cd 7.67 Pb 7.26	Cd 6.59 Pb 6.42	Cd 4.83 Pb 8.60		
Mean – Średnia B		Cd 7.17		Pb 7.94			

NIR $_{0.05}$ A (cultivar – odmiana) = 1.58
NIR $_{0.05}$ B (metal) = n.s r.n.
NIR $_{0.05}$ A · B = n.s. r.n.
NIR $_{0.05}$ C (dose – dawka) = 1.82
NIR $_{0.05}$ A · C = 3.16
NIR $_{0.05}$ B · C = 2.58
NIR $_{0.05}$ A · B · C = n.s. r.n.

* dose of metal – dawka metalu:
I – control – kontrola
II – 1 mg Cd dm^{-3}; 100 mg Pb dm^{-3}
III – 5 mg Cd dm^{-3}; 500 mg Pb dm^{-3}
IV – 10 mg Cd dm^{-3}; 1000 mg Pb dm^{-3}

inflorescences, in comparison with the control after the application of the lowest doses of both metals, i.e. 1 mg Cd dm^{-3} and 100 mg Pb dm^{-3}. Successive higher doses of cadmium (5 and 10 mg Cd dm^{-3}) and the highest dose of lead (1000 mg Pb dm^{-3}) caused a significant decrease of the inflorescence yield of Marigold, in comparison with the control (without any metal addition).

Number of flowers. The presented experiments showed that 'Titania' cultivar was characterized by the greatest number of flowers (10.78 flowers per plant), while 'Mann im Mond' showed the smallest flower number (tab. 3). 'Titania' cultivar reacted with a decreased number of flowers under the influence of increasing doses (both of cadmium and lead), in comparison with the control. 'Hawaii' cultivar, which developed, on the average, 7.13 flowers on each plant, after the application of 10 mg Cd dm^{-3} and 500 mg Pb dm^{-3}, decreased its number of flowers, in comparison with the control (without any metal addition).

Yield of leaves. Comparison of the mean yield of leaves obtained from the particular cultivars revealed that the cultivars 'Mann im Mond' and 'Hawaii' were characterized by a higher yield of leaves than 'Titania' cultivar (tab. 4).

Table 4. Yield of leaves of the particular cultivars (g $plant^{-1}$ fresh mass)
Tabela 4. Plon liści badanych odmian (g · roślina^{-1} św.m.)

Cultivar Odmiana	Metal	I*	II	III	IV	Mean Średnia A/B	Mean Średnia A
'Mann im Mond'	Cd	44.25	55.00	53.75	49.25	50.56	47.81
	Pb	44.25	46.25	52.25	37.50	45.06	
Mean – Średnia A/C		44.25	50.63	53.00	43.38		
'Hawaii'	Cd	46.00	47.25	55.25	48.00	49.13	47.03
	Pb	46.00	48.75	47.50	37.50	44.94	
Mean – Średnia A/C		46.00	48.00	51.38	42.75		
'Titania'	Cd	44.75	39.50	46.00	41.50	42.94	42.28
	Pb	44.75	55.25	33.75	32.75	41.63	
Mean – Średnia A/C		44.75	47.38	39.88	37.13		
Mean – Średnia C		45.00	48.67	48.08	41.08		
Mean – Średnia B/C		Cd 45.00 Pb 45.00	Cd 47.25 Pb 50.08	Cd 51.67 Pb 44.50	Cd 46.25 Pb 35.92		
Mean – Średnia B		Cd 47.54		Pb 43.88			

$NIR_{0.05}$ (cultivar – odmiana) A = 4.51
$NIR_{0.05}$ B (metal) = 3.68
$NIR_{0.05}$ A · B = n.s. r.n.
$NIR_{0.05}$ C (dose – dawka) = 5.21
$NIR_{0.05}$ A · C = n.s. r.n.
$NIR_{0.05}$ B · C = 7.37
$NIR_{0.05}$ A · B · C = n.s. r.n

* dose of metal – dawka metalu:
I – control – kontrola
II – 1 mg Cd dm^{-3}; 100 mg Pb dm^{-3}
III – 5 mg Cd dm^{-3}; 500 mg Pb dm^{-3}
IV – 10 mg Cd dm^{-3}; 1000 mg Pb dm^{-3}

In the substrates, where cadmium was introduced, in comparison with substrates with lead, the yield of leaf fresh matter was higher in the cultivars 'Mann im Mond' and 'Hawaii'.

At the same time, 'Mann im Mond' reached the highest yield with the dose of 1 mg Cd dm^{-3} while 'Hawaii' did the same with the dose of 5 mg Cd dm^{-3}.

After the application of increasing lead doses, in comparison with the control, the highest leaf yield in 'Mann im Mond' grown in a substrate with the dose of 500 mg Pb dm^{-3} and in 'Titania', the highest leaf yield was obtained in the substrate with 100 mg Pb dm^{-3}. In all three cultivars, a significant drop of leaf yield was found in plants grown in the substrate with the dose of 1000 mg Pb dm^{-3}. In the substrate with the dose of 500 mg Pb dm^{-3}, a smaller leaf yield was shown in 'Titania' cultivar, in comparison with the control (without any lead addition).

Yield of stalks. Comparison of the mean yield of stalks showed that the highest yield was shown by 'Hawaii' cultivar, while 'Titania' presented the smallest yield (tab. 5). No significant differences were found in stalk yield under the influence of increasing doses of cadmium and lead. However, some tendencies to changes were observed. Cadmium did not cause any effect on the yield of the fresh matter of stalks in 'Mann im Mond', but in the two other cultivars, there were some tendencies to an increase of the stalk mass, in comparison with the control. Those cultivars showed the greatest mass of stalks with the dose of 10 mg Cd dm^{-3}. Lead introduced to the substrate in the dose of 500 and 1000 mg dm^{-3}caused a drop in stalk yields of 'Mann im Mond' and in 'Hawaii' cultivars, in relation to plants grown in a substrate without any addition of this metal. In case of 'Titania', an increase of stalk matter was found after an addition of 100 and 500 mg Pb dm^{-3}, in comparison with the control.

Table 5. Yield of stalks of the particular cultivars (g $plant^{-1}$ fresh mass)
Tabela 5. Plon łodyg badanych odmian (g · roślina^{-1} św.m.)

Cultivar Odmiana	Metal	I*	II	III	IV	Mean Średnia A/B	Mean Średnia A
'Mann im Mond'	Cd	61.50	62.75	61.00	62.50	61.94	56.97
	Pb	61.50	57.50	47.00	42.00	52.00	
Mean – Średnia A/C		61.50	60.13	54.00	52.25		
'Hawaii'	Cd	62.50	63.25	67.00	71.75	66.13	62.09
	Pb	62.50	63.00	58.50	48.25	58.06	
Mean – Średnia A/C		62.50	63.13	62.75	60.00		
'Titania'	Cd	41.75	46.75	52.00	54.50	48.75	47.91
	Pb	41.75	59.00	48.25	39.25	47.06	
Mean – Średnia A/C		41.75	52.88	50.13	46.88		
Mean – Średnia C		55.25	58.71	55.63	53.04		
Mean – Średnia B/C		Cd 55.26 Pb 55.26	Cd 57.59 Pb 59.83	Cd 60.00 Pb 51.26	Cd 62.92 Pb 43.17		
Mean – Średnia B		Cd 58.94		Pb 52.38			

$NIR_{0.05}$ A (cultivar – odmiana) = 4.82
$NIR_{0.05}$ B (metal) = 3.94
$NIR_{0.05}$ A · B = n.s. r.n
$NIR_{0.05}$ C (dose – dawka) = n.s. r.n
$NIR_{0.05}$ A· C = n.s. r.n
$NIR_{0.05}$ B · C = 7.88
$NIR_{0.05}$ A · B· C = n.s. r.n

* dose of metal – dawka metalu:
I – control – kontrola
II – 1 mg Cd dm^{-3}; 100 mg Pb dm^{-3}
III – 5 mg Cd dm^{-3}; 500 mg Pb dm^{-3}
IV – 10 mg Cd dm^{-3}; 1000 mg Pb dm^{-3}

The mean total yield of all cultivars in the substrate with the addition of cadmium was higher than of plants grown with an addition of lead.

Kulich and Kulichova [1984], who studied phytoxicity of lead, found that the doses up to 1000 mg Pb kg^{-1} of mixed soil did not cause any statistically proven differences in the yielding of oats and lucerne. Kucharski et al. [1996] studied the effect of air and soil pollution on the yields of selected edible plants. They found that high lead concentrations in soil exerted a no significant negative effect on the yield of bean, potatoes and lettuce, in spite of the fact that lead content in the tissues of those plants exceeded the admissible amounts of Pb according to Polish standards. Gawęda [1995] showed that lead doses up to 600 mg Pb $\cdot dm^{-3}$ did not cause any significant decrease of lettuce and small radish yields. Khan and Frankland [1983] informed about a significant decrease of small radish yield at lead dose of 1000 mg Pb $\cdot$ dm^{-3}. Kuduk [1995] investigated the reaction of pea (*Pisum arvense*) to different doses of lead in soil. An experiment was carried out in pots of 2 dm^3 capacity. The pots were filled with loamy sand with the following $PbCl_2$ doses corresponding to the following amounts of Pb in mg per 1 kg of soil: 0, 25, 50, 100, 250, 500, 1000, 5000. The doses applied in that experiment exerted an effect on the germination, growth and yield of dry matter. At the doses up to 500 mg Pb dm^{-3}, a higher increment of shoots (by 4.8 to 6 cm) was observed, in comparison with plants of the control. Distinctly negative effect took place when the applied dose of lead amounted to 5000 mg Pb dm^{-3}. In that situation, there followed a three times smaller length of shoots and roots, a decrease of dry matter yield and a complete impediment of root module development.

Table 6. The content of cadmium and lead in substrates after end of experiment (mg dm^{-3})
Tabela 6. Zawartość kadmu i ołowiu w podłożach po zakończeniu doświadczenia (mg $\cdot$ dm^{-3})

Cultivar Odmiana	Dose of metal – Dawka metalu, mg dm^{-3}							
	Cd				Pb			
	0	1	5	10	0	100	500	1000
'Mann im Mond'	0.12	0.84	2.89	6.86	2.35	66.74	327.09	763.65
'Hawaii'	0.18	0.57	2.37	6.13	2.70	64.74	290.75	594.70
'Titania'	0.14	0.59	4.36	7.77	2.76	83.36	375.26	770.35

The content of cadmium and lead i substrates after end of experiment. Cadmium and lead content in substrates in which plants were grown (tab. 6) increased with the increasing Cd and Pb doses introduced into the substrate. It was shown that the least content of cadmium and lead after the termination of experiment was in the substrate where *Tagetes erecta* 'Hawaii' plants were cultivated with the exception of the control substrate.

CONCLUSIONS

1. Analysis of the mean total yield of the particular cultivars grown in all substrates has shown that the highest total yield was reached by 'Titania' cultivar, in the second place was 'Hawaii' and the smallest yield was obtained from 'Mann im Mond'.

2. 'Mann im Mond' cultivar reached the highest yield in substrates with increased contents (1 mg Cd dm^{-3} and 100 mg Pb dm^{-3}). The smallest yield was found in substrates with a medium contamination with cadmium and lead (10 mg Cd dm^{-3} and 1000 mg Pb dm^{-3}).

3. 'Hawaii' cultivar reached the highest yield in substrates with small contaminations by the studied metals (5 mg Cd dm^{-3} and 500 mg Pb dm^{-3}), while the smallest total yield was found in substrates with a medium contamination with cadmium and lead (10 mg Cd dm^{-3} and 1000 mg Pb dm^{-3}).

4. The highest total yield of 'Titania' cultivar was obtained in the substrate with an addition of 1 mg Cd dm^{-3} and 100 mg Pb dm^{-3}, while the smallest yield was found in substrates with a medium contamination with cadmium and lead.

5. The smallest amounts of cadmium and lead, regardless of the applied dose, remained in the substrate in which 'Hawaii' cultivar was grown.

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FITOEKSTRAKCJA KADMU I OŁOWIU PRZEZ WYBRANE ODMIANY *Tagetes erecta* L. CZ. I. WPŁYW Cd I Pb NA PLONOWANIE

Streszczenie. Celem badań przeprowadzonych w Katedrze Nawożenia Roślin Ogrodniczych, Uniwersytetu Przyrodniczego w Poznaniu było stwierdzenie wpływu wprowadzonych dawek kadmu i ołowiu (skażenia podłoża) na plon poszczególnych organów, wybranych odmian, aksamitki wzniesionej oraz czy rośliny te będą nadawały się do obsadzania gleb skażonych tymi metalami. Rośliny wykorzystane w doświadczeniu zostały posadzone w pojemnikach bezodpływowych w tunelu foliowym. Badane odmiany *Tagetes erecta* L. posadzono w sztucznie zanieczyszczone kadmem i ołowiem podłoże. Kadm i ołów wprowadzono w następujących dawkach: Cd – 0 (kontrola); 1; 5; 10 mg · dm^{-3}; ołów – 0 (kontrola); 100; 500; 1000 mg · dm^{-3}. Analizy statystyczne wykonane w niniejszej pracy dotyczyły analizy wariancji dla masy liści, masy łodyg, masy kwiatostanów, ilości kwiatostanów. Najwyższy średni plon ogólny poszczególnych odmian rosnących we wszystkich podłożach uzyskała odmiana 'Titania', następnie odmiana 'Hawaii', najmniejszy natomiast plon stwierdzono u odmiany 'Mann im Mond'. Najmniej kadmu i ołowiu, bez względu na wielkość dawki, pozostało w podłożu, w którym uprawiana była odmiana 'Hawaii'.

Słowa kluczowe: fitoekstrakcja, kadm, ołów, *Tagetes erecta* L.

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