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PHYTOEXTRACTION OF CADMIUM AND LEAD BY SELECTED CULTIVARS OF *Tagetes erecta* L. PART II. CONTENTS OF Cd AND Pb IN PLANTS

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Abstract. In the Department of Plant Fertilization, University of Life Sciences in Poznań, a vegetation experiment (in plastic tunnel) was carried out in which the substrate was artificially contaminated with cadmium and lead and three cultivars of *Tagetes erecta* L. were planted in it: 'Mann im Mond', 'Hawaii' and 'Titania'. The substrate was artificially contaminated with increasing doses of metals: Cd – 0 (control); 1; 5; 10 mg dm^{-3}; Pb: 0 (control); 100; 500; 1000 mg dm^{-3}. The objective of studies was to investigate which organs of *Tagetes erecta* L. cumulated the greatest amounts of cadmium and lead, what amounts of Cd and Pb move from the substrate to the organs of the studied cultivars and whether the studied cultivars of Marigold are suitable for the remediation of soils polluted with cadmium and lead. The metals contained in the particular plant organs, after dry mineralization, were identified by the method of atomic spectrophotometer AAS-3 of Zeiss Company. In all studied cultivars, the highest contents of cadmium were found in leaves, smaller amounts were shown in stalks, while inflorescences contained the smallest Cd amounts. The highest amounts of lead in all studied cultivars were found in the stalks, smaller amounts in the leaves and the least amount was shown in the inflorescences The greatest contents of cadmium and lead were found in the organs of 'Hawaii' cultivar, both in the leaves, stalks and inflorescences. The studied cultivars of *Tagetes erecta* can be utilized for the remediation of soils polluted by heavy metals.

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

INTRODUCTION

According to Salt et al. [1998], the term phytoextraction means the utilization of plants which uptake contaminations from the soil and accumulate them in their plant organs to be removed together with the plant yield from the field. This method is used to purify soils of heavy metals and organic substrates. Actually, the majority of papers

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deal with the phytoextraction of metallic contaminations from soils [Ciura et al. 2001]. Phytoextraction bases on the properties of the so called hyperaccumulators – plants which genetically and physiologically are able to accumulate great amounts of heavy metals without toxicity symptoms [Boyd and Martens 1994]. The majority of species belong to *Brasicaceae* and *Febaceae* families [Raskin et al. 1994]. Willow (*Salix sp.*) is also a good phytoremediator characterized by a high accumulation and ability to displace metals, particularly zinc and cadmium, as well as to create high increments of biomass [Greger 1997].

In case of the application of phytoremediation on urbanized areas, the discussed plants, next to the purification function on polluted areas, could also perform an aesthetic function. This proposal seems to be particularly attractive, since towns use to be decorated every year with ornamental plants.

The above mentioned reasons have contributed to the idea of performing studies with the purpose to answer the following questions:

– which organs of Marigold cumulate the greatest amounts of Cd and Pb

– what amounts of Cd and Pb move from the substrate to the organs of the studied plants

– whether the studied cultivars of *Tagetes erecta* L. are suitable to remediate soils polluted with Cd and Pb.

MATERIAL AND METHODS

Experiment was carried out in the Department of Horticultural Plant Fertilization, University of Life Sciences in Poznań. The material and method were have talked over in part first the relating places, way of foundation and realization of vegetative experience.

Three months after the replantation into containers with the artificially polluted substrate, in full-bloom of plants, samples of plant materials and substrate were taken. Before the liquidation of the experiment, the containers were irrigated to obtain a constant weight. Then, the plants were cut down. Each plant was weighed separately and the masses of the particular organs (stalks, leaves, inflorescences) were also separately weighed. In the plant materials, the water content was determined in order to calculate the dry weight of plants. From each container, samples were taken from the plant material (inflorescences, leaves and stalks) and from the substrate, in each container separately, for the determination of Cd and Pb contents. The collected plant materials (inflorescences, leaves, stalks) were dried for 48 hours in an extraction drier at 55°C. Then, the material was ground and from each sample, 2.5 g was transferred to a porcelain crucible and it was mineralized in a combustion furnace LINN, Electro Therm at 450°C. The remainders after mineralization were dissolved in 10% HCl and they were transferred to flasks of 50 cm^3 capacity. The contents of Cd and Pb in the particular plant organs were determined by the atomic absorption method with AAS-3 spectrophotometer (Zeiss Co.).

In the plant material, water content was determined by weight method. Samples of plant material were dried at 105°C to a constant mass. From the difference of weights, the water content was calculated.

After the termination of the experiment, the soluble forms of cadmium and lead in the substrate were determined in Lindsey's extract. The substrate, in the amount of 50 cm^3 was poured with 200 cm^3 of extraction solution and it was shaken for 30 minutes. The suspension was filtered and in the filtrate, cadmium and lead were determined by the ASA flame technique.

Statistical analyses made in this study refer to the analysis of variance for the content of Cd and Pb in leaves, stalks and inflorescences. Statistical analyses were carried out in Statobll program, 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

The success of phytoextraction, according to Kucharski et al. [1996] depends primarily on the selection of an adequate plant species. Raskin et al. [1994] reported that the majority of species accumulating great amounts of heavy metals belong to *Brasicaceae* and *Fabiaceae* families. Bosiacki [2008] carried out studies on three ornamental plant species: *Helianthus annus* 'Pacino', *Salvia splendens* 'Fuego': *Tagetes erecta* 'Inca Yellow'. These plants were planted in a substrate artificially polluted with cadmium. The author found that cadmium was mainly accumulated in leaves and shoots and then in inflorescences. The least amount of this metal was found in the roots, with the exception of *Tagetes erecta*, where more Cd was found in roots than in leaves and shoots, while the least amount was found in inflorescences. The greatest amount was shown in the roots of *Tagetes erecta*, in the leaves and shoots of *Salvia splendens* and in inflorescences of *Helianthus annus*. Tyksiński and Kurdubska [2005] in their studies affirmed differential to accumulation of cadmium and lead between changes of lettuce.

Cadmium content in the particular organs of the studied cultivars of *Tagetes erecta* L. species. In the here presented studies, together with the growth of Cd doses introduced to the substrate, an increase of Cd in the particular organ parts was identified (fig. 1, 2, 3).

In the control substrate, where no Cd was introduced, the greatest amount of this metal was found in the leaves of 'Hawaii' cultivar (fig. 1). The remaining cultivars, where no differences in the Cd content in leaves were found, were characterized by a smaller content of cadmium.

After the application of the dose of 1 mg Cd dm^{-3}, the highest content of Cd was found in 'Hawaii' cultivar, a smaller Cd content was shown by 'Mann im Mond' cultivar and the smallest Cd amount was present in 'Titania' cultivar.

The content of Cd in the leaves of 'Titania' cultivar grown in the substrate with an addition of 5 mg Cd dm^{-3} was smaller than in the two remaining cultivars (by 8.7%, in comparison with 'Mann im Mond' and by 11.5%, in comparison with 'Hawaii' cultivar.

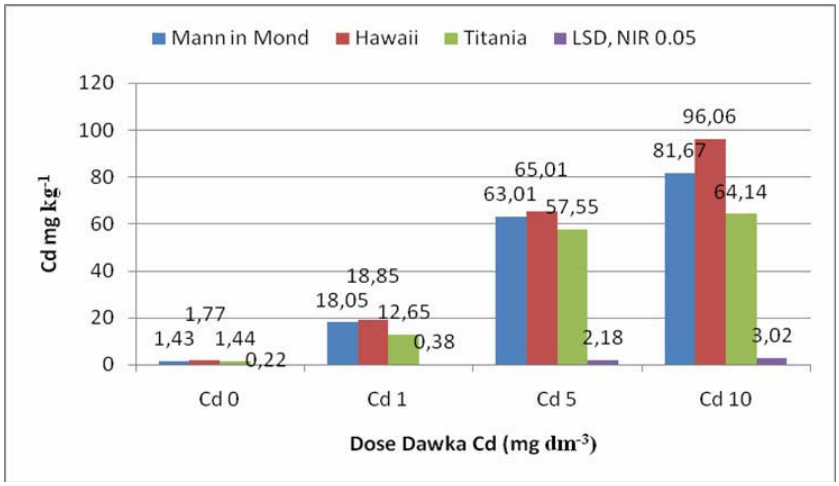

Fig. 1. Content of cadmium in the leaves of the studied cultivars of *Tagetes erecta* L. (mg kg^{-1} d.m.)
Ryc. 1. Zawartość kadmu w liściach badanych odmian aksamitki wzniesionej (mg·kg^{-1} s.m.)

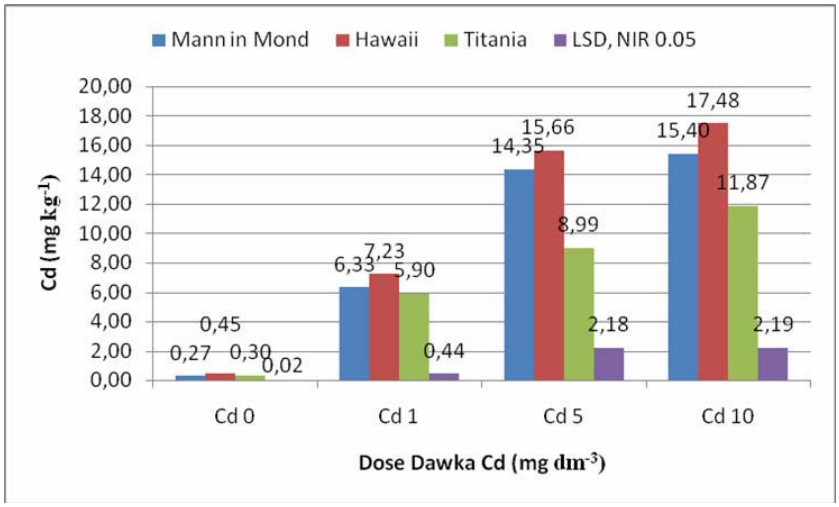

Fig. 2. Cadmium content in stalks of the studied *Tagetes erecta* L. cultivars (mg kg^{-1} d.m.)
Ryc. 2. Zawartość kadmu w łodygach badanych odmian aksamitki wzniesionej (mg·kg^{-1} s.m.)

No significant differences in Cd content was found in the leaves of 'Mann im Mond' and 'Hawaii' cultivars grown in the same substrate.

After the application of the metal dose of 10 mg Cd dm^{-3}, a definitely highest cadmium content was found in the leaves of 'Hawaii' cultivar, a significantly smaller amount was shown by 'Mann im Mond' and the least Cd content was present in 'Titania'.

Analysis of Cd content in the stalks of the three studied cultivars showed that in the substrate without any addition of metal, the least amount of Cd in stalks was shown by 'Mann im Mond', a significantly greater amount was present in 'Titania" and the highest amount was found in 'Hawaii' cultivar (fig. 2).

After the application of Cd dose in the amount of 1 mg Cd dm^{-3}, the least Cd amount was found in the stalks of 'Titania' cultivar, while the highest Cd amount was identified in the stalks of 'Hawaii' cultivar.

In case of plants grown in the substrate with an addition of 5 mg Cd dm^{-3}, no significant differences were found in the stalks of 'Mann im Mond' and 'Hawaii'. Stalks of these cultivars were characterized by a higher amount of Cd, in comparison with the stalks of 'Titania' cultivar.

Significant differences were also found in Cd content in the stalks of the studied cultivars with the dose of 10 mg Cd dm^{-3}. The greatest amount of Cd was shown in 'Hawaii' and the least amount in stalks was identified in 'Titania' cultivar.

In the combination of plants grown in the substrate without any addition of heavy metal (Cd), the least amount of this element was shown in the inflorescences of 'Hawaii' cultivar, slightly more Cd was found in the inflorescences of 'Mann im Mond', while the greatest amount was detected in 'Titania' cultivar (fig. 3).

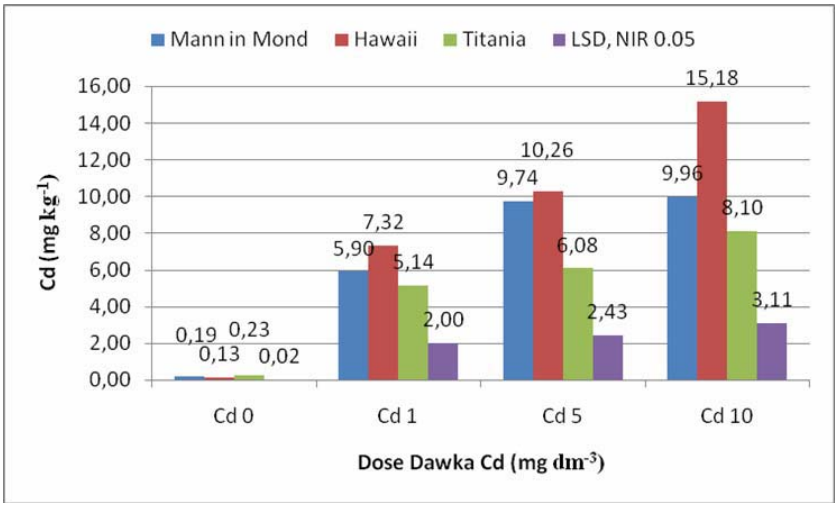

Fig. 3. Cadmium content in inflorescences of the studied cultivars of *Tagetes erecta* L. (mg kg^{-1} d.m.)
Ryc. 3. Zawartość kadmu w kwiatostanach badanych odmian aksamitki wzniesionej (mg·kg^{-1} s.m.)

After the application of cadmium dose in the amount of 1 mg Cd dm^{-3} , the greatest amounts of Cd were found in the inflorescences of 'Hawaii' cultivar, while the smallest amounts were shown by 'Titania'. The cultivar 'Mann im Mond' (for which statistical analysis did not reveal any significant differences, in comparison with 'Hawaii' and 'Titania') was characterized by an intermediate Cd content in the inflorescences.

Analysis of plants grown in the substrate with an addition of 5 mg Cd dm^{-3} showed the highest amount of cadmium in the inflorescences of 'Hawaii' cultivar, a slightly

smaller amount, but statistically a significant one, was shown in 'Mann im Mond', while the smallest amount of Cd was found in the inflorescences of 'Titania'.

The dose of 10 mg Cd dm^{-3} of substrate showed the highest amount of Cd in 'Hawaii' inflorescences, while 'Titania' cultivar was characterized by the smallest amount of Cd.

Bosiacki and Golcz [2008] conducted an experiment with three ornamental plants: *Helianthus annus* 'Pacino'; *Salvia splendens* 'Fuego'; *Tagetes erecta* 'Inca Yellow'. The plants were grown in a substrate artificially contaminated with lead.. The authors found that lead was mainly accumulated in the roots of the plants, then in the leaves and shoots, while the least content of this metal was shown by the inflorescences. Among the studied species of ornamental plants grown in the substrates with introduced lead, the highest amount of Pb was found in the organs of *Tagetes erecta,* with the exception of leaves and shoots of common sunflower (*Helinathus annus*) grown in the substrate with 1000 mg Pb dm^{-3}. The plants of *Tagetes erecta* were characterized by the highest uptake of lead.

Lead content in the particular organs of the studied cultivars of *Tagetes erecta* L. species. The experiment showed that with the increase of lead doses introduced to the substrate, its content in the particular plant organs increased as well (fig. 4, 5, 6).

In the combination in which Pb was not introduced, the highest content of this element was shown by the leaves of 'Hawaii' and 'Mann im Mound' cultivars (fig. 4). The least amount of lead was found in 'Titania'. In the substrate with the addition of 100 mg Pb dm^{-3}, the highest Pb content was shown by 'Hawaii' cultivar, while the leaves of the two remaining cultivars contained a smaller lead amount, but the difference has not been statistically proven.

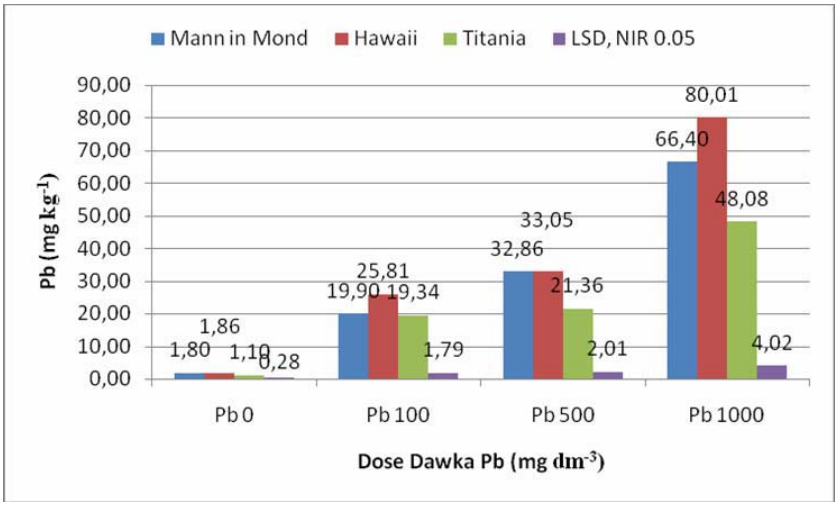

Fig. 4. Lead content in the leaves of the studied cultivars of *Tagetes erecta* L. (mg kg^{-1} d.m.)
Ryc. 4. Zawartość ołowiu w liściach badanych odmian aksamitki wzniesionej (mg·kg^{-1} s.m.)

Statistical analysis did not show any significant differences either in 'Hawaii' or in 'Mann im Mond' which were grown in the substrate with an addition of 500 mg Pb dm^{-3}. At the same time, a higher amount of lead was found in the leaves of 'Hawaii' cultivar. The least Pb amounts were found in the leaves of 'Titania'.

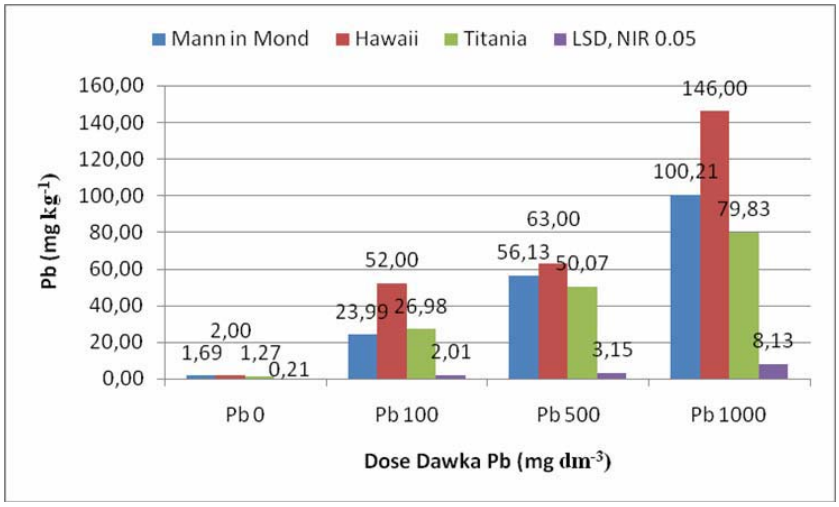

Fig. 5. Lead content in the stalks of the studied *Tagetes erecta* L. cultivars (mg kg^{-1} d.m.)
Ryc. 5. Zawartość ołowiu w łodygach badanych odmian aksamitki wzniesionej (mg·kg^{-1} s.m.)

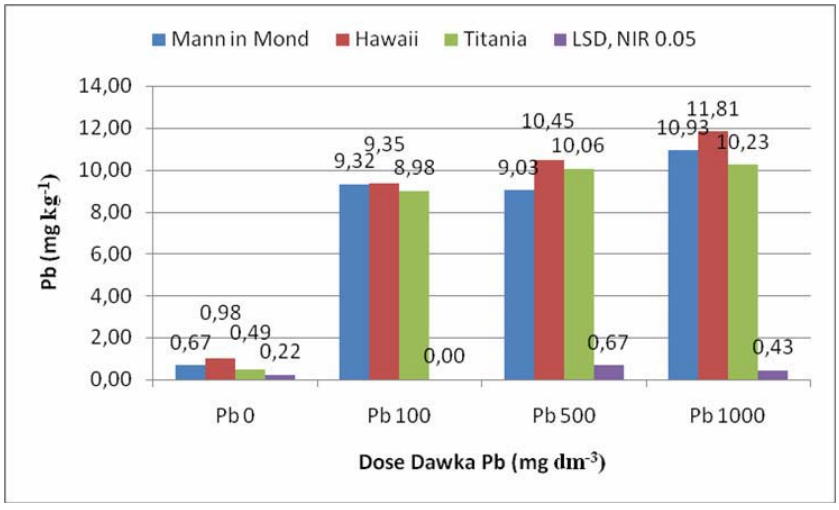

Fig. 6. Lead content in the inflorescences of the studied *Tagetes erecta* L. cultivars (mg kg^{-1} d.m.)
Ryc. 6. Zawartość ołowiu w kwiatostanach badanych odmian aksamitki wzniesionej (mg · kg^{-1} s.m.)

In plants grown in a substrate with an addition of 1000 mg Pb dm^{-3}, the highest amount of lead was found in the leaves of 'Hawaii' cultivar, a smaller amount was in 'Mann im Mond', while the least amount was shown by the leaves of ' Titania'.

Analysis of the mean content of lead in the stalks of the particular cultivars explicitly indicated that regardless of the lead dose introduced into the substrate where the plants were grown, the greatest amount of this element was contained in the stalks of 'Hawaii' cultivar (fig. 5). The smallest amounts of Pb were found in the stalks of 'Titania' grown in the substrate without any addition of lead, as well as in the substrates with an addition of 500 and 1000 mg Pb dm^{-3}. Only in the substrate with an addition of 100 mg Pb dm^{-3}, the least amount of lead was shown by the stalks of 'Mann im Mond' cultivar. This was the only exception, in all remaining combinations, the stalks of 'Mann im Mond' cultivar showed an intermediate lead content, in comparison with the two remaining cultivars.

Analysis of the mean Pb content in the inflorescences indicated that 'Hawaii' cultivar grown in a substrate without any lead addition contained more of this element than the 'Mann im Mond' and 'Titania' cultivars, which were grown in the same substrate (fig. 6). No differences were found in the lead contents in the inflorescences of 'Mann im Mond' and 'Titania' cultivars.

In all three cultivars grown in the substrate with an addition of 100 mg Pb dm^{-3}, no significant differences were found in the amount of lead accumulated in the inflorescences. Only some tendencies of changes were noticed in the content of Pb in the inflorescences of the studied cultivars. The highest Pb amounts were found in 'Hawaii', smaller ones in 'Mann im Mond' and the smallest amounts in the inflorescences of 'Titania' cultivar.

'Hawaii' cultivar in the substrate with an addition of 500 mg Pb dm^{-3} accumulated the greatest amount of lead in the inflorescences. Slightly smaller amounts (however not statistically proven) were accumulated by the inflorescences of 'Titania'. The least amount of Pb was fouind in the inflorescences of 'Mann im Mond' cultivar.

In plants grown in the substrate with an addition of 1000 mg Pb dm^{-3}, significant differences of lead content in the inflorescences were found. The highest Pb contents were shown by 'Hawaii' cultivar, an intermediate amount was found in 'Mann im Mond', while the least Pb amount characterized 'Titania' cultivar.

Uptake of cadmium and lead by above-ground parts of the studied cultivars of *Tagetes erecta* L. species. A higher yield of dry matter was obtained in the cultivar 'Mann im Mond' in substrates where cadmium was introduced in the amount of 1 and 5 mg dm^{-3}, in comparison with the yield obtained in the substrate without this metal (fig. 7), Increasing Cd doses introduced to the substrate were accompanied by an increased uptake of this metal by the 'Mann im Mond' cultivar, The greatest Cd uptake was shown in plants grown in the substrate with an addition of 10 mg Cd · dm^{-3}.

Dry matter yield of 'Hawaii' cultivar in the substrate with Cd addition in the amounts of 1 and 5 mg dm^{-3} was higher, in comparison with the yield obtained in the substrate without any Cd addition. The highest dry matter yield was shown in the substrate with the dose of 5 mg Cd dm^{-3}. The lowest yield of 'Hawaii' dry matter was found in the substrate with 10 mg Cd dm^{-3}. Analysis of the mean Cd uptake by this cultivar

indicated that with the increase of Cd doses, the uptake of this element increased as well.

A higher dry matter yield of 'Titania' cultivar was obtained only in the substrate with 1 mg Cd dm^{-3}, in comparison with the control. In the substrate with an addition of 5 and 10 mg Cd dm^{-3} , a smaller yield of dry matter was obtained, as compared with the yield from substrates without any addition of cadmium. The highest Cd uptake was shown by plants grown in substrates with an addition of 5 mg Cd dm^{-3}.

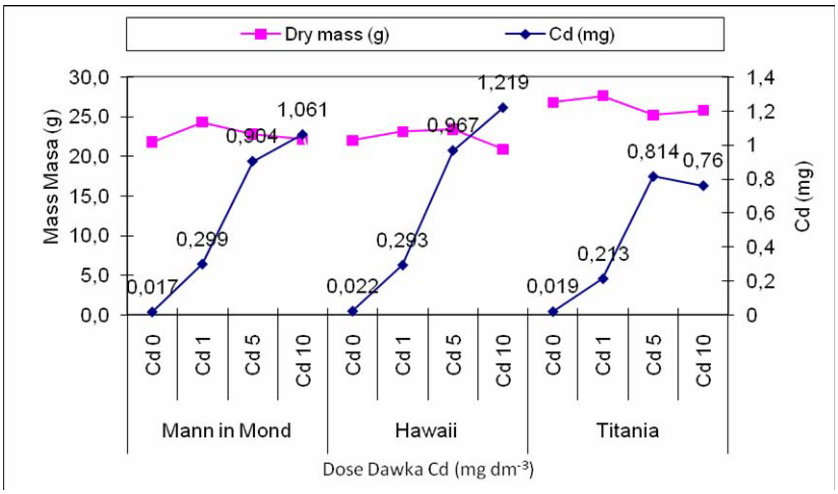

Fig. 7. Total yield of overground dry matter of the studied *Tagetes erecta* L. cultivars and cadmium uptake by these plants

Ryc. 7. Plon ogólny wyrażony w suchej masie oraz pobranie kadmu przez badane odmiany *Tagetes erecta* L.

A comparison of all three studied cultivars showed that the highest uptake of cadmium characterized the 'Hawaii' cultivar.

In the studies of Bosiacki [2008], among three species of ornamental plants, the highest cadmium uptake was shown by the plants of *Tagetes erecta.*

Increasing doses of lead, in the amount of 500 and 1000 mg dm^{-3}, introduced to the substrate caused a drop in the dry matter of 'Mann im Mond' cultivar, in comparison with the control (fig. 8). A higher yield of this cultivar dry matter, in relation to the control, was found only in the substrate with the addition of 100 mg Pb dm^{-3}. Increasing Pb doses introduced to the substrate were accompanied by an increased uptake of lead by this cultivar.

The highest yield of dry matter in 'Hawaii' cultivar was shown in the substrate with an addition of 500 mg Pb dm^{-3}. The highest Pb uptake was found in plants grown in the substrate with an addition of 1000 mg Pb dm^{-3}, where this cultivar showed the lowest yield of dry matter.

The highest dry matter yield of 'Titania' cultivar was obtained in the substrate with an addition of 100 mg Pb dm^{-3}. The least dry matter yield was found in plants grown in

the substrate with an addition of 1000 mg Pb dm^{-3}. Similarly as in the other cultivars of *Tagetes erecta* L., lead uptake was increasing with the increasing doses of lead added to the substrate.

All three studied *Tagetes erecta* L. cultivars grown in the substrate with an addition of 1000 mg Pb dm^{-3} were characterized by the highest uptake of lead.

Comparison of all three studied cultivars indicated that 'Hawaii' was characterized by the highest Pb uptake.

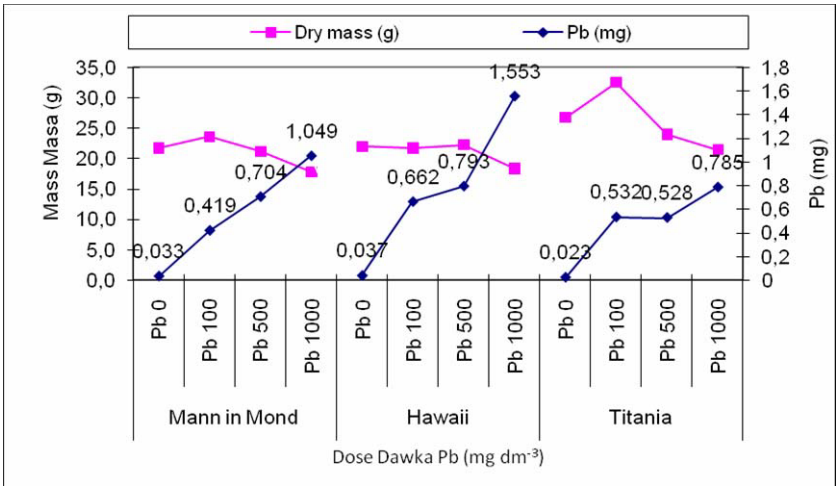

Fig. 8. Total yield of overground dry matter of the studied *Tagetes erecta* L. cultivars and lead uptake by these plants

Ryc. 8. Plon ogólny wyrażony w suchej masie oraz pobranie ołowiu przez badane odmiany *Tagetes erecta* L.

Bosiacki and Golcz [2008] planted three species of ornamental plants (*Helianthus annus* 'Pecino', *Salvia splendens* 'Fuego' and *Tagetes erecta* 'Inca Yellow' into a substrate artificially contaminated with lead. They found that the highest uptake of lead was shown by *Tagetes erecta* plants. In investigations have carried out by Wińską-Krysiak and Bernat [2008] it was affirmed differential lead uptake by particular organs of *Robinia pseudoaccacia* L.

CONCLUSIONS

1. Cadmium and lead contents in plants depended on the concentration of this element in the substrate. With the increase of the heavy metal amount in the substrate, its content in the plants increased as well.

2. In all studied cultivars, the highest contents of cadmium were found in leaves, smaller amounts were shown in stalks, while inflorescences contained the smallest Cd amounts.

3. The highest amounts of lead in all studied cultivars were found in the stalks, smaller amounts in the leaves and the least amount was shown in the inflorescences

4. The greatest contents of cadmium and lead were found in the organs of 'Hawaii' cultivar, both in the leaves, stalks and inflorescences.

5. Among the studied cultivars of *Tagetes erecta*, the highest cadmium and lead uptake by above-ground parts of plants was a shown by 'Hawaii' cultivar, while 'Titania' contained the least amounts of the heavy metals.

6. The studied cultivars of *Tagetes erecta* can be utilized for the remediation of soils polluted by heavy metals.

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FITOEKSTRAKCJA KADMU I OŁOWIU PRZEZ WYBRANE ODMIANY *Tagetes erecta* L. CZ. II. ZAWARTOŚĆ Cd I Pb W ROŚLINACH

Streszczenie. W Katedrze Nawożenia Roślin Ogrodniczych, Uniwersytetu Przyrodniczego w Poznaniu przeprowadzono pojemnikowe doświadczenie wegetacyjne (w tunelu foliowym), w którym w sztucznie zanieczyszczone kadmem i ołowiem podłoże posadzono trzy odmiany gatunku *Tagetes erecta* L.: 'Mann im Mond'; 'Hawaii'; 'Titania'. Podłoże sztucznie zanieczyszczono wzrastającymi dawkami metali: Cd – 0 (kontrola); 1; 5;

10 mg · dm^{-3}; ołów – 0 (kontrola); 100; 500; 1000 mg · dm^{-3}. Celem przeprowadzonych badań było stwierdzenie, które organy aksamitki wzniesionej kumulują największe ilości kadmu i ołowiu, jakie ilości kadmu i ołowiu przechodzą z podłoża do organów badanych odmian oraz czy badane odmiany aksamitki wzniesionej będą nadawały się do zagospodarowywania gleb skażonych kadmem i ołowiem. Metale w poszczególnych organach roślinnych po mineralizacji na sucho oznaczono metodą absorpcji atomowej spektrofotometrem AAS-3 firmy Zeiss. U wszystkich badanych odmian największe zawartości kadmu stwierdzono w liściach, mniejsze w łodygach, natomiast najmniejsze w kwiatostanach. Największe zawartości ołowiu u wszystkich badanych odmian stwierdzono w łodygach, mniejsze w liściach, natomiast najmniejsze w kwiatostanach. Największe zawartości kadmu i ołowiu stwierdzono w organach odmiany 'Hawaii', zarówno w liściach, łodygach, jak i w kwiatostanach. Badane odmiany aksamitki wzniesionej mogą być wykorzystywane do zagospodarowania gleb skażonych metalami ciężkimi.

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

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