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ACCUMULATION OF CADMIUM IN SELECTED SPECIES OF ORNAMENTAL PLANTS

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Abstract. In the spring-summer season in the years 2005 and 2006 (every year) three vegetation experiments were carried out with three species of ornamental plants: common sunflower (*Helianthus annus* 'Pacino'), scarlet sage (*Salvia splendens* 'Fuego'), tagetes erecta (*Tagetes erecta* 'Inca Yellow'). These plants were planted in a substrate artificially contaminated by cadmium. Doses of cadmium applied in the experiment represent different degrees of contamination. The dose of 1 mg Cd · dm^{-3} indicates natural contents; 5 mg Cd · dm^{-3} – small contamination; 10 mg Cd · dm^{-3} – large contamination. The objective of the presented studies was the determination what quantities of cadmium pass from the substrate to the organs of the studied plants and which plant organs accumulate the greatest amounts of cadmium. Cadmium was mainly accumulated in leaves and shoots, then in inflorescences. While the least amount of this metal was found in the roots with the exception of *Tagetes erecta* where the greatest amount of cadmium was found in roots, then in leaves and shoots, while the lest amount was in inflorescences. The greatest cadmium contents were found in the roots of *Tagetes erecta*, in leaves and shoots of *Salvia splendens*, and in the inflorescences of *Helianthus annus*. Among the studied ornamental plant species, the plants of *Tagetes erecta* were characterized by the highest cadmium uptake.

Key words: cadmium, ornamental plants, *Helianthus annus, Tagetes erecta, Salvia splendens,* phytoremediation

INTRODUCTION

The economic activity of man leads to the accumulation in the environment of many harmful substances such as remainders of herbicides, crude oil derivative materials, radioactive elements, heavy metals. One of the ecosystem components in which these substances accumulate is the soil. Contaminated soil becomes the source of toxic compounds for all links of the alimentary chain [Ciura et al. 2001]. There exist several methods of limiting the access of heavy metals to the plants in the soil, like e.g. by the

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introduction of organic substances or by liming. However, these methods do not purify the soil of the harmful elements. There are some promising study results on the application of phytoremediation for soil purification. Schonoor [2002] describes photoremediation as a technology utilizing higher plants for stabilization, removal or limitation of the quantity of contaminations from soils, bottom sediments, surface and underground waters. Such plants which are genetically and physiologically able to accumulate great amounts of heavy metals without symptoms of toxicity have been called by Boyd and Martens [1994] hyperaccumulators.

The objective of the presented studies was the determination of the effect of cadmium doses introduced into the substrate on the yield of selected species of ornamental plants, as well as the determination what quantities of cadmium pass from the substrate to the organs of the studied plants and which plant organs accumulate the greatest amounts of cadmium.

MATERIAL AND METHODS

Pot experiments were carried out in an unheated greenhouse in the Department of Horticultural Plant Fertilization of the August Cieszkowski Agricultural University in Poznań in the years 2005 and 2006. Vegetation experiments included three ornamental plant species represented by selected cultivars, one from each species: common sunflower (*Helianthus annus* 'Pacino'), scarlet sage (*Salvia splendens* 'Fuego'), tagetes erecta (*Tagetes erecta* 'Inca Yellow'). These plants were planted in a substrate artificially contaminated by cadmium. The experiment was carried out in outflow-less containers of 1 dm^3 capacity, in random design. The experimental factors included: three ornamental plant species, increasing doses of cadmium: 0 (control); 1; 5; 10 $mg \cdot dm^{-3}$.

Doses of cadmium applied in the experiment represent different degrees of contamination. The dose of 1 $mg\ Cd \cdot dm^{-3}$ indicates natural contents; 5 $mg\ Cd \cdot dm^{-3}$ – small contamination; 10 $mg\ Cd \cdot dm^{-3}$ – medium contamination. In the spring-summer season in the years 2005 and 2006, three vegetation experiments were carried out with three species of ornamental plants. Each vegetation experiment consisted of four combinations, and each combination had ten replications. One replication was represented by one plant grown in one container of 1 dm^3 capacity. The substrate in which all three ornamental plant species were grown consisted of raised peat. The content of nutritive components, pH (in H_2O) and EC ($m\ S \cdot cm^{-1}$) in raised peat were determined by universal method before and after liming. In order to obtain the pH within the interval 6.5–7.0, raised peat was limed. The $CaCO_3$ dose in the amount of 6.5 $g \cdot dm^{-3}$ was determined on the basis of naturalization curve. Raised peat with calcium carbide was thoroughly mixed in a bowl and then, it was used for filling the containers. After 14 days, macrocomponents, microcomponent and cadmium were added. Macrocomponents were introduced in the form of chemically pure reagents (potassium nitrate KNO_3, potassium monophosphate KH_2PO_4, ammonium nitrate NH_4NO_3) and the following levels were reached: 150 N; 90 P; 200 K. No calcium and magnesium were introduced because in the peat after liming, the content of these components was high. Microcomponents in the amount of 0.2 $g \cdot dm^{-3}$ were introduced in the form of Polichelate LS-7 produced by the Institute of Artificial Fertilizers in Puławy. Cadmium was applied in the form of cadmium sulphate $3CdSO_4 \cdot 8H_2O$. Cadmium, macrocomponents and microcomponents were introduced separately to each container. In mid-March, seeds of *Salvia splendens* and *Tagetes erecta* were sown. The seeds were sown by hand into boxes of 30×48×8 cm dimensions. The seeds of *Helianthus annus* were point sown by single grain on the 10th of May into multiplets. In April, the plants of *Salvia splendens* and *Tagetes erecta* were planted out into multiplets. In May, the seedlings of *Salvia splendens* and *Tagetes erecta* were planted, one plant per one container. At the beginning of June, the seedlings of *Helianthus annus* were planted, also one plant in one container. The ornamental plants was irrigation by tap water.

Liquidation of each of the experiments consisted in the cutting of the aboveground part of the studied plant and weighing it. The full blooming plants were taken to analyses. The root system after removal from the container was thoroughly rinsed in water to get rid of the rests of substrate and then, it was weighed. All plant parts were weighed separately: inflorescences, leaves together with shoots, roots.

The fresh weight of the particular organs of the plants from the container were summed up. In the above plant material, water content was determined in order to calculate the dry matter. Samples were also taken from the substrate in each container where the studied plants were grown in order to determine the soluble forms of cadmium.

The gathered plant material (flowers, leaves with shoots and roots) was dried up in an extractor drier at 55°C for 48 hours. The dried material was ground in a mixer. Air dry plant material in the amount of 2.5 g was transferred to a porcelain crucible and it was subjected to mineralization in a combustion furnace (LINN, Electro Therm) at 450°C. Remainders after mineralization were solved in 10% HCl and were transferred to flasks of 50 cm^3 capacity. Cadmium content in the particular plant organs was determined by atomic absorption method with a spectrophotometer AAS-3 (Zeiss). Cadmium in the substrate was determined in Lindsey's extract. Statistical analyses carried out in this work referred to the analysis of variance for plant yield (weight of flowers, leaves with shoots and roots); analysis of variance for plant height; analysis of variance for plant diameter; analysis of variance for Cd content in: flowers, leaves and shoots (together) and in roots. Statistical analyses were carried out in Statobl program– single-variate analysis of variance for factorial orthogonal experiments. Differences between mean values were determined at significance level of $\alpha = 0.05$.

RESULTS AND DISCUSSION

Analysis of the effect of increasing cadmium doses on the yield of *Helianthus annus* and *Salvia splendens* (fig. 1) has shown that together with the increasing doses of the metal, the plant yield decreased in comparison with the control. When we accept that the yield of plants obtained when they were grown without cadmium addition represented 100%, we find that the yield of *Helianthus annus* decreased by: 21% (dose 1 mg Cd $\cdot$ dm^{-3}); 39% (5 mg Cd $\cdot$ dm^{-3}); 45% (10 mg Cd $\cdot$ dm^{-3}). In *Salvia splendens*, the yield decreased by: 16.5% (dose 1 mg Cd $\cdot$ dm^{-3}); 24% (5 mg Cd $\cdot$ dm^{-3}); 40% (10 mg Cd $\cdot$ dm^{-3}). A stimulating action of cadmium on the yield increase in *Tagetes*

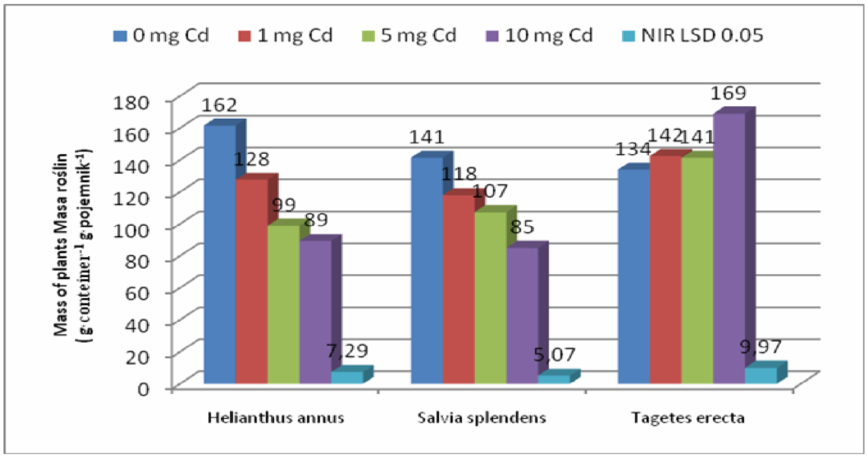

Fig. 1. The influence of cadmium on the yield of ornamental plants – fresh mass (mean from 2005–2006)

Ryc. 1. Wpływ kadmu na plon roślin ozdobnych – świeża masa (średnia z 2005–2006)

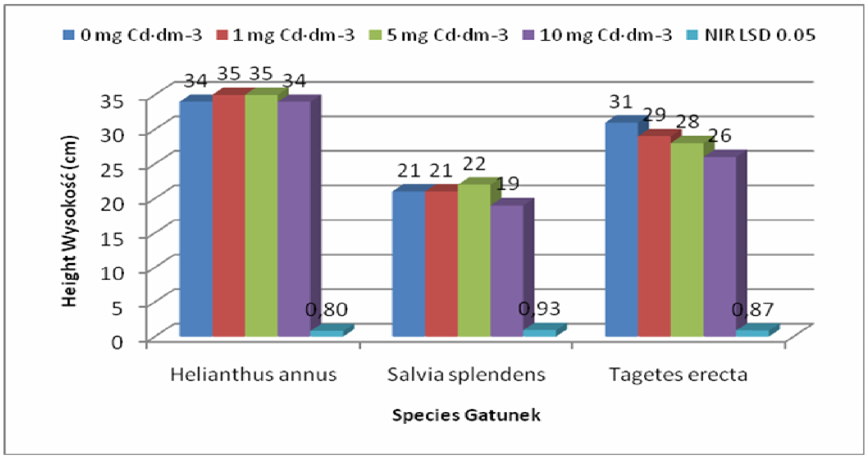

Fig. 2. The influence of cadmium on the height of ornamental plants (mean from 2005–2006)

Ryc. 2. Wpływ kadmu na wysokość roślin ozdobnych (średnia z 2005–2006)

erecta was found by the introduction of cadmium doses: 1; 5 and 10 mg Cd · dm^{-3} (fig 1). A statistically proven significant yield increase of *Tagetes erecta* in the substrates with the dose of 10 Cd · dm^{-3} was found in comparison with the control. The favorable effect of cadmium on the yielding was found by many researchers, but, so far, it has not been explained. In substrates where the doses of 1 and 5 mg Cd · dm^{-3} were introduced, a tendency to yield increase was found in comparison with the control, but it was not statistically significant. So far, it has not been shown whether cadmium is necessary for normal development of plants [Kabata-Pendias and Pendias 1999]. However, it is known that cadmium significantly inhibits plant growth by the decreased activity of some oxidation processes, photosynthesis and fat transformations, and at the same time, it decreases plant demand for oxygen [Klima 1992].

During the experiment, measurements of plant height and diameters were carried out. Analysis of the height of *Helianthus annus* indicated that with the increase of cadmium doses, the height of plants was subject to small but statistically significant changes in comparison with the control (fig. 2). No statistically significant changes were found between the height of plants grown in control substrates without cadmium and the height of plants grown in substrates with an addition of 10 mg Cd · dm^{-3}. A stimulating effect of cadmium on the height of *Helianthus annus* was found with the doses of 1 and 5 mg Cd · dm^{-3} · Similar action of cadmium was found in *Salvia splendens* (fig. 2), the dose of 5 mg Cd · dm^{-3} showed a stimulating effect on the height of *Salvia splendens* plants, while a higher dose of cadmium 10 mg · dm^{-3} had a negative effect on plant height. In case of *Tagetes erecta*, it was shown that with the increase of cadmium, the height of plants decreased (fig. 2).

Many authors believe that problems of water economy in plants resulting in consequence of disturbances within the root system are the most important aspect of the negative action of heavy metals on the physiological and metabolical processes of the total organism. Physiological changes occurring in plants with an excess of cadmium result from disturbances of the processes of photosynthesis, transpiration and transportation of nitrogen compounds. Cadmium ions show a high relationship with sulphohydrolic groups of different compounds with which they create links, particularly frequent are the connections with cystine and proteins with a structure similar to methionine [Woźny et al. 1990]. Those authors also argue that plants show a resistance to high concentrations of cadmium and to these plants belongs among others oats. Such plants create different protein compounds, the so called phytocholatins which bind cadmium and neutralize its toxicity. Buczek [1984] studied the physiological reactions of plants to the toxic action of cadmium. He showed that in the first place it decreases the number of chloroplasts in the cell, and then, there increases the content of chlorophyll dyes and therefore, the amount of chlorophyll in leaves can be used as a quick method of showing the toxic action of cadmium on some plants.

Analysis of cadmium effect on the diameter of *Helianthus annus* (fig. 3), has shown that with the increase of cadmium doses, the plant diameter decreases. An exception is the dose of 10 mg Cd · dm^{-3}, where a stimulating action of cadmium on the plant diameter was found. Somewhat different effect of cadmium on plant diameter was found in scarlet sage (fig. 3). In substrates with a dose of 0; 1; 5 mg Cd · dm^{-3}, no significant differences between cadmium dose and the height of scarlet sage plant was found. On the other hand, in substrates with an addition of 10 mg Cd · dm^{-3}, it was found that this dose had a reducing effect on the increase of plant diameter in comparison with the control. In case of *Tagetes erecta*, it was found that cadmium doses have a significant effect on plant diameter (fig. 3). It was shown that the increase of cadmium doses had a negative effect on *Tagetes erecta* plants, with the exception of the dose 10 mg Cd · dm^{-3}, where a greater diameter was found than in the substrates with the dose of 5 mg Cd · dm^{-3}.

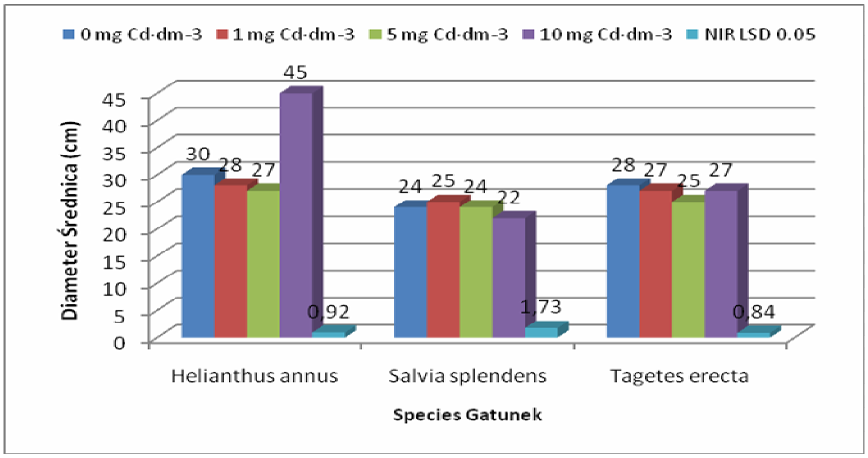

Fig. 3. The influence of cadmium on the diameter of ornamental plants (mean from 2005–2006)
Ryc. 3. Wpływ kadmu na średnicę roślin ozdobnych (średnia z 2005–2006)

The content of cadmium in substrates. Cadmium content in substrates in which plants were grown (fig. 4) increased with the increasing Cd doses introduced into the substrate. It was shown that the greatest amount of cadmium after the termination of experiment was in the substrate where *Salvia splendens* plants were cultivated with the exception of the control and the substrate with an addition of 1 mg Cd · dm^{-3}, where higher cadmium contents were found in which *Helianthus annus* was grown. The least content of cadmium was found in the substrate where *Tagetes erecta* was cultivated.

Cadmium content in the particular organs of the studied ornamental plant. Cadmium is mainly accumulated in the root zone, but, depending on the plant species and on the efficiency of root detoxication mechanisms, rather significant amounts of this element penetrate to the aboveground parts of plants. Negative action of cadmium on the morphology and structure of plant organs is not proportional to the content of this element in the tissue. Krupa [1999] argued that the toxic effect of cadmium is visible primarily in the root zone, where we can observe growth inhibition, slime-mould of root tips, morphological and anatomic anomalies.

In the particular plant organs of *Helianthus annus*, it was found that with the increase of cadmium doses added to the substrate, its content in the studied organ increased (fig. 5, 6, 7). The greatest contents of this element were found in leaves and shoots, while the smallest amounts were in roots with the exception of the control (0 mg Cd · dm^{-3}), where lower contents of cadmium were found in the inflorescences. A similar distribution of cadmium in plant organs was found in *Salvia splendens* (fig. 5, 6, 7). It was shown that with the increase of Cd doses, there increased the cadmium content in the plant as well. The greatest amount of this element was found in leaves and shoots of *Salvia splendens* with the exception of the control (0 mg Cd·dm^{-3}), where higher cadmium contents were found in the roots. The lowest cadmium contents were found in roots except in the control (0 mg Cd · dm^{-3}). Where lower content of this metal was found in the inflorescences.

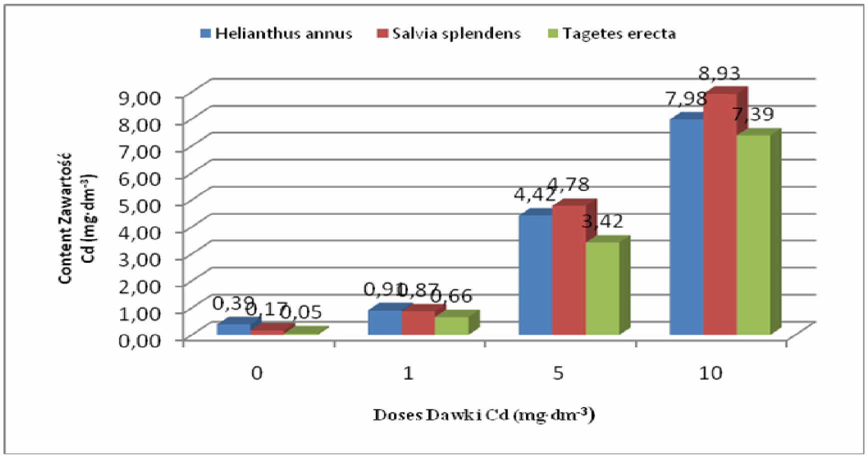

Fig. 4. The content of cadmium in substrate after end of experiment (mg·dm^{-3}) – mean from 2005–2006

Ryc. 4. Zawartość kadmu w podłożu po zakończeniu doświadczeń (mg·dm^{-3}) – średnia z 2005–2006

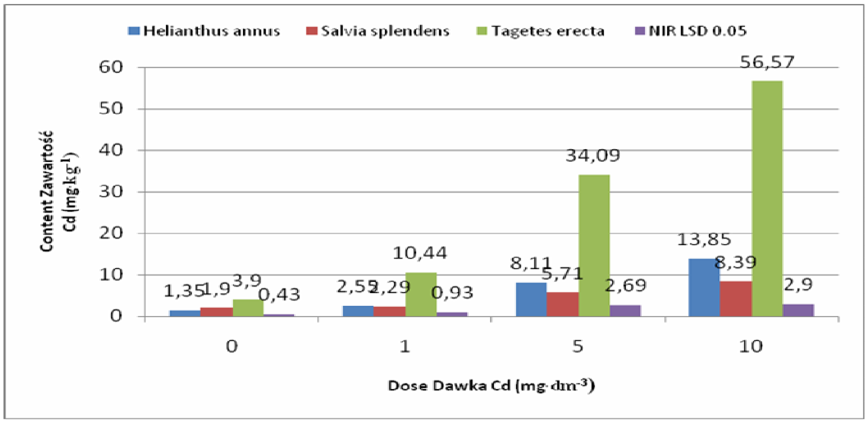

Fig. 5. Cadmium content in the roots of the studied ornamental plant species (mg·kg^{-1}d.m) – mean from 2005–2006

Ryc. 5. Zawartość kadmu w korzeniach badanych gatunków roślin ozdobnych (mg·kg^{-1}s.m.) – średnia z 2005–2006

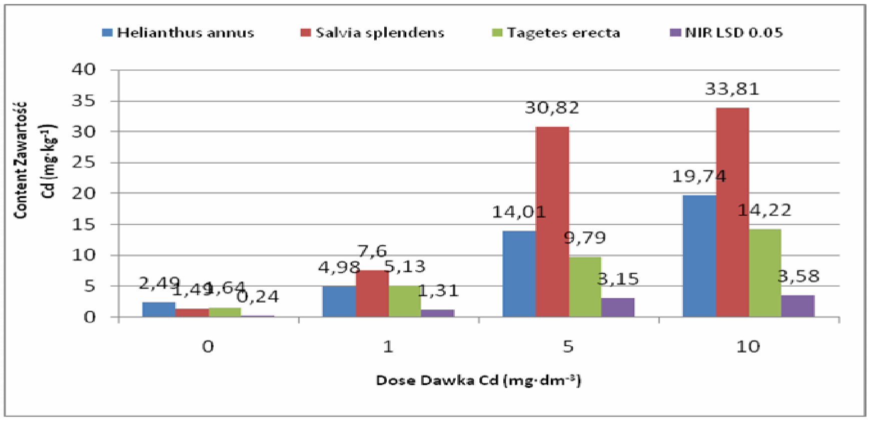

Fig. 6. Cadmium content in the leaves and speeds of the studied ornamental plant species (mg·kg^{-1}d.m) – mean from 2005–2006

Ryc. 6. Zawartość kadmu w liściach i pędach badanych gatunków roślin ozdobnych (mg·kg^{-1}s.m.) – średnia z 2005–2006

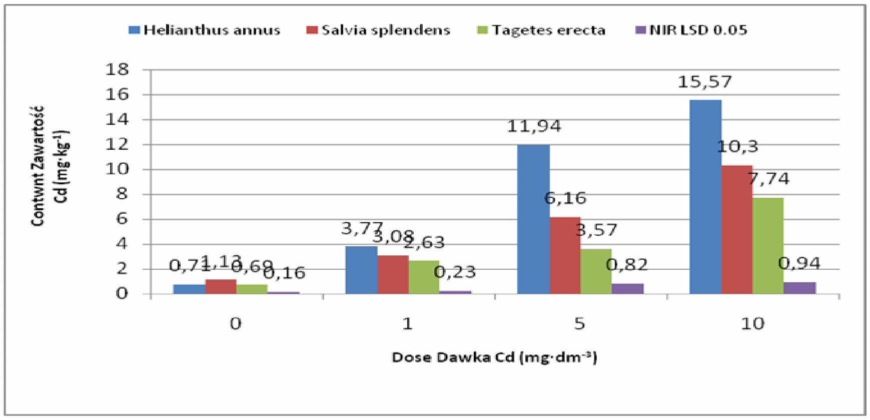

Fig. 7. Cadmium content in the inflorescences of the studied ornamental plant species (mg·kg^{-1}d.m) – mean from 2005–2006

Ryc. 7. Zawartość kadmu w kwiatostanach badanych gatunków roślin ozdobnych (mg·kg^{-1}s.m.) – średnia z 2005–2006

In plants of *Tagetes erecta*, it was also found that with the increased doses of cadmium, its content in the plant increased as well (fig. 5, 6, 7). The highest contents of this element were found in the roots of *Tagetes erecta* grown in all substrates. The lowest cadmium content was found in the inflorescences of all *Tagetes erecta* plants grown in the studied substrates. When we observe the above mentioned three diagrams with cadmium content and its distribution in the plants, we can find that the uptake and displacement of cadmium deep into the plant is different. This fact results primarily from differences in the physiological structure of plants and also from the plant ability to uptake and accumulate this element. A significant role is also played by plant height and plant weight. Similar conclusions were drawn by Kabata-Pendias et al. [1995]. They found that the amount of uptaken and retained heavy metals by plants depends on many factors: on the type of substrate, its composition and reaction, on the amount and chemical form of the component, on the species, cultivar, plant part, etc. The uptake of trace elements from soils and from air by plants frequently exceeds their physiological requirements.

Cadmium content in the roots of the studied ornamental plant species was increasing with the increase of cadmium dose added to the substrate (fig. 5). The highest cadmium contents were found in the roots of *Tagetes erecta* grown in all substrates. Lower contents of cadmium were found in the roots of *Salvia splendens* with the exception of roots grown in the substrate without cadmium addition. In this substrate, the lowest cadmium content was shown by the roots of *Helianthus annus*.

In the leaves and shoots of the studied plants, it was found that with the increase of cadmium doses, there increased also the amount of this metal (fig. 6). The greatest amount of cadmium was shown by leaves and shoots of *Salvia splendens* with the exception of plant material sampled from the control substrate without cadmium addition. Among the studied plants grown in the substrate without cadmium, higher contents of this metal were found in leaves and shoots of *Helianthus annus*. The lowest contents of cadmium were found in leaves and shoots of *Tagetes erecta* grown in all substrates with the exception of substrates where 1 mg Cd · dm^{-3} was introduced and where the lowest contents were found in common sunflower. It was just sunflower which demonstrated the highest cadmium accumulation in the inflorescences when compared with the other plants (fig. 7). This may result from sunflower plant ability to transportation and accumulation of cadmium deep in the plant. The content of cadmium in inflorescence depends on inflorescence weight which in sunflower is significantly higher than in the remaining species. The lowest cadmium contents were found in the inflorescences of *Tagetes erecta*.

Cadmium uptake by ornamental plant species. The yield of dry weight of *Helianthus annus* and *Salvia splendens* plants grown in substrates to which increasing doses of cadmium were introduced was lower in relation to the control (fig. 8). Cadmium uptake by these two ornamental plant species was similar. It was found that with the increasing cadmium doses, there increased the uptake of this metal by common sunflower and scarlet sage, while the yield of these plants decreased. A smaller yield of plants was accompanied by a higher cadmium uptake. The yield of *Tagetes erecta* increased with the increase of cadmium doses introduced into the substrate in comparison with the yield of plants grown in a substrate without any addition of this metal. It was found that the uptake of cadmium by *Tagetes erecta* increased with the increase of cadmium doses. The yield of *Tagetes erecta* was accompanied by the increase of cadmium uptake, The highest Cd uptake was obtained in *Helianthus annus* grown in a substrate with an addition of 10 mg Cd · dm^{-3}, in *Salvia splendens* in the substrate with an addition of

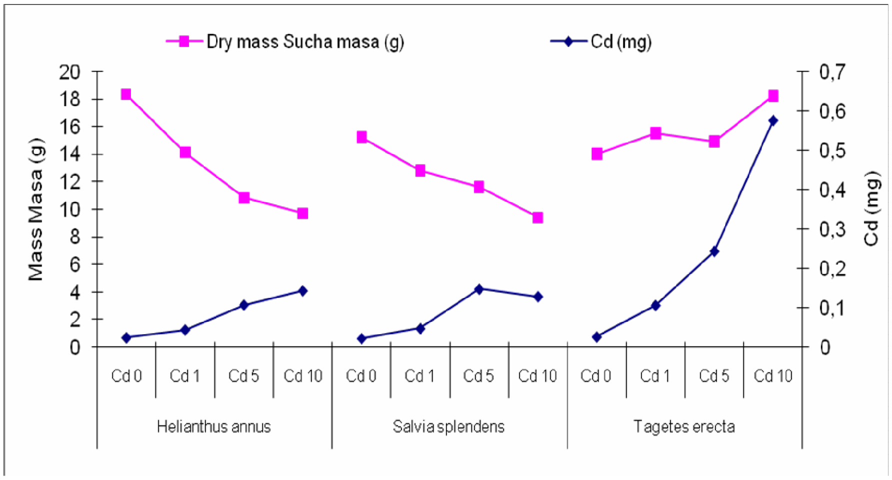

Fig. 8. Cadmium uptake by ornamental plant species (mean from 2005–2006)
Ryc. 8. Pobranie kadmu przez gatunki roślin ozdobnych (średnia z 2005–2006)

5 mg Cd · dm^{-3} and in *Tagetes erecta* in the substrate with 10 mg Cd · dm^{-3}. Among the studied ornamental plants, *Tagetes erecta* was characterized by the greatest cadmium uptake.

CONCLUSIONS

1. Increase of cadmium content in the substrate caused a yield decrease in all studied species with the exception of *Tagetes erecta* where an increase of plant yield was found.
2. The greatest amount of cadmium after the termination of experiments was found in the substrate where *Salvia splendens* was grown, while the lowest cadmium content was shown by the substrate where *Tagetes erecta* was cultivated.
3. Cadmium was mainly accumulated in leaves and shoots, then in inflorescences. While the least amount of this metal was found in the roots with the exception of *Tagetes erecta* where the greatest amount of cadmium was found in roots, then in leaves and shoots, while the lest amount was in inflorescences.
4. The greatest cadmium contents were found in the roots of *Tagetes erecta*, in leaves and shoots of *Salvia splendens*, and in the inflorescences of *Helianthus annus*.
5. Among the studied ornamental plant species, the plants of *Tagetes erecta* were characterized by the highest cadmium uptake.
6. The studied species of ornamental plants can be cultivated on soils contaminated by cadmium, but an attempt to use them for a quick purification of soil from cadmium is completely unreal.

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AKUMULACJA KADMU W WYBRANYCH GATUNKACH ROŚLIN OZDOBNYCH

Streszczenie. W sezonie wiosenno-letnim w roku 2005 oraz 2006 (każdego roku) prowadzono trzy doświadczenia wegetacyjne z trzema gatunkami roślin ozdobnych. W sztucznie zanieczyszczone kadmem podłoże posadzono trzy gatunki roślin ozdobnych: *Helianthus annus* 'Pacino', *Salvia splendens* 'Fuego', *Tagetes erecta* 'Inca Yellow'. Dawki kadmu zastosowane w doświadczeniach odzwierciedlają różny stopień zanieczyszczenia. Dawka 1 mg Cd · dm^{-3} zawartość naturalna, 5 mg Cd · dm^{-3} słabe zanieczyszczenie, 10 mg Cd · dm^{-3} silne zanieczyszczenie. Celem przeprowadzonych badań było stwierdzenie, jakie ilości kadmu przechodzą z podłoża do organów badanych roślin oraz które organy roślin kumulują największe ilości kadmu. Kadm był głównie akumulowany w liściach i pędach, mniej w kwiatostanach, a najmniej tego metalu stwierdzono w korzeniach z wyjątkiem aksamitki wzniosłej, gdzie najwięcej kadmu stwierdzono w korzeniach, liściach i pędach, a najmniej w kwiatostanach. Największą zawartość kadmu stwierdzono w korzeniach aksamitki wzniosłej, liściach i pędach szałwii lśniącej i kwiatostanach słonecznika zwyczajnego. Spośród badanych gatunków roślin ozdobnych największym pobraniem kadmu charakteryzowały się rośliny aksamitki wzniosłej.

Słowa kluczowe: kadm, rośliny ozdobne, *Helianthus annus, Tagetes erecta, Salvia splendens,* fitoremediacja

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