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Uptake and distribution of caesium and its influence on the physiological processes in croton plants (*Codiaeum variegatum*)

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Abstract Croton (*Codiaeum variegatum*) belongs to the salinity-resistant plants. This paper presents some experimental data in order to assess usefulness of croton plants for phytoremediation of caesium-contaminated soils. The plants were grown in a greenhouse, in the soil contaminated with 0.03, 0.3, 1, 3, 5 and 10 mM CsCl solution enriched with ^{137}Cs as a radiotracer. The croton plant demonstrated high resistance to increasing CsCl salinity of the soil. This conclusion was based on the observation that the above-ground organ fresh-to-dry weight ratio was constant. However, this value was lower for the roots. The young-to-old leaf dry weight ratio was decreasing while the concentration of CsCl in the soil was increasing. The increase in soil CsCl concentration was associated with the decrease in photosynthesis as well as a rise in the intra-tissue concentration of CO_2 and increase of the CO_2 stomatal conductance. Photosynthetic water utilization efficiency was constant in the range of 0.03–1 mM CsCl and it was only lower with higher CsCl concentration. This situation gives an evidence that croton plant is highly resistant to the soil CsCl salinity. The ^{137}Cs radiotracer experiment showed the maximal accumulation of caesium with 0.3 mM CsCl, a lower one with 0.03 mM, and poor accumulation with 3 and 5 mM CsCl solutions. The transfer factor value for ^{137}Cs (plant-to-soil) was about 10, which proved a high ability of croton plants to accumulate caesium to a high extent. However, the highest accumulation took place in the roots. The intensive phytoextraction of caesium from the soil may indicate its potential capacity for bioremediation. The reported observation warrants further studies.

Key words bioremediation • caesium uptake • caesium distribution • croton plants • phytoextraction

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Introduction

Radioactive contamination originating from the Chernobyl NPP accident is still a major problem in radioecology. The safety requirements for nuclear facilities are more severe every year, however, there is still a real endangerment from the large-scale radioactive contamination in the future, e.g. from the possible explosion of so called dirty bombs, constructed by radical terrorist groups. Thus, decontamination procedures need to be invented so as to re-cultivate the polluted area. The ability of plants to take up (phytoextraction) and accumulate (bioaccumulation) trace elements present in the soil, due to clean it without major financial and organisational effort, is recognized already. Good caesium accumulators are looked for since radioisotopes of this element (^{137}Cs and ^{134}Cs) are wide-spread soil contaminants. They should be characterized by a fast growth, high productivity and ability to take up the radionuclides from the soil and to accumulate them in the above-ground organs efficiently, comparing with the root (huge part of the root system remains in the soil after the bioremediation harvest).

Caesium, as other elements, exhibits its toxic properties in plants because it evokes osmotic stress [2]. Not all the species, however, respond in the same way. Plants growing in the saline soils, having a high tolerance to salinity and to the osmotic stress, are halophytes [4]. Croton plant (*Codiaeum variegatum*) represents this ecologic group. The aims of this experimental work were to investigate the influence of various caesium concentrations on the growth of croton plants and the metabolic changes in photosynthesis, transpiration and stomatal conductance after the treatment with stable caesium. Later on it was supposed to find out the accumulation of ^{137}Cs in the croton plants including concentration factors for pairs of different organs. These studies were undertaken to estimate the possibility to apply croton plants for the purpose of phytoremediation.

Materials and methods

The croton seedlings were obtained from a Polish supplier (Gospodarstwo Ogrodnicze RIM Kowalczyk S.J., Warsaw, Poland). The plants were cultivated in the greenhouses (average day temperature 26°C, average humidity 40%, average PAR intensity 150 μmol m^{-2}s^{-1}, 16 h-light photoperiod). Distilled water was supplied every day.

Different solutions of stable caesium chloride (CsCl) were added in order to estimate its influence on the physiological processed of the plants. Fresh (FW) and dry (DW) weight of the plant organs were measured and used to express the tissue hydration (FW/DW).

The photosynthetic intensity measurements were carried out every week beginning with the second week of the culture. An integrated CO_2 meter (CI-301 CO_2 Gas Analyzer, CID Inc., USA) was used. The open system and the gas flow of 0.2 dm^3 min were applied. The intact integral leaves were placed in the chamber with 6.25 cm^2 active surface. The gas exchange parameters (P – photosynthesis [mol m^{-2} s^{-1}], E – transpiration [mmol m^{-2} s^{-1}], C – stomatal conductance [mmol m^{-2}s^{-1}]) were determined every minute, memorized and they have undergone statistical treatment. A set of 30 measurements for each experimental variant was done (each plant measured twice using different leaves). The medium-age leaves were taken for these measurements. The first 10 values were discarded, as a short period of acclimatization was assumed.

^{137}CsCl standard, purchased in Polatom (Otwock-Świerk, Poland), was used throughout the radiotracer experiments. The fresh plants were taken out of the pots, divided into stem, young and old leaves, and roots. The soil residues were rinsed with water and the samples weighted (fresh weight) and then dried at 105°C (until the constant weight was established) and weighted again (dry weight). The milled plant samples and the dry soil (used for the culture) have undergone radioactivity measurements (100 min, all in the same geometry) by means of a scintillation analyzer (Inter-Polon Sp. z o.o., Warsaw, Poland; power supply ZWN-21M, analyzer A-22M, scaler P-21 and a polymer beta-sensitive scintillation detector). Calibration of the scintillation detector was carried out by means of an activity standard.

The concentration factor (CF) for ^{137}Cs was calculated dividing ^{137}Cs activity concentration in the upper organs by that value for the lower organs and represented in (kBq kg^{-1} "upper organ" DW)/(kBq kg^{-1} "lower organ" DW). The transfer factor (TF) was calculated for a selected plant organ and soil and give in (kBq kg^{-1} plant organ DW)/(kBq kg^{-1} soil DW). Dry weight of the plant tissue was used throughout the radioactivity calculations. Data treatment was carried out using MS Excel 2000 software.

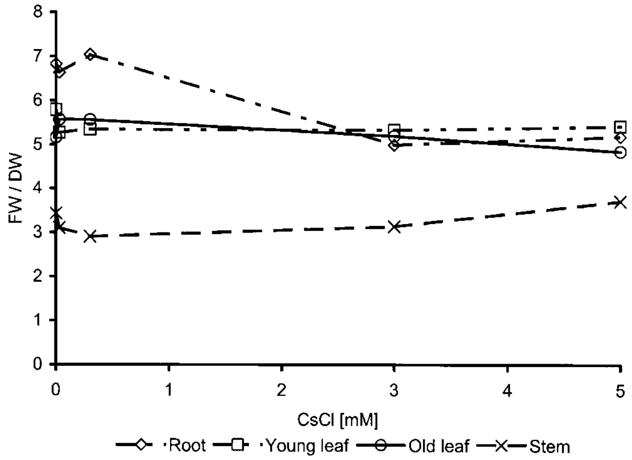

Fig. 1. The fresh-to-dry weight (DW) ratio of croton organs depending on the concentration of CsCl in the soil.

Results

The fresh-to-dry weight ratio for the roots was decreasing in the range 0.03–3 mM (Fig. 1). However, for young and old leaves it remained the same, irrespective of concentration. The ratio for the stem was increasing in the section 3–5 mM CsCl. The ratio of dry weight of young leaves to old ones was distinctly decreasing with the increase in CsCl concentration in the section 0.03–3 mM (Fig. 2). The shoot-to-root dry weight ratio was increasing in the section 0–3 mM and was decreasing in the section 3–5 mM CsCl (Fig. 3). The decrease in photosynthetic intensity, as well as simultaneous increase in CO_2 concentration in the whole range of CsCl concentration, was observed (Fig. 4). The water utilization efficiency (P/E) in the plant was decreasing in the whole range of concentration, but stomatal conductance was increasing in the section 0.03–3 mM CsCl in the soil (Fig. 5).

Proportional distribution of ^{137}Cs for the roots was decreasing in the section 0.03–3 mM, for the stem it was increasing in the whole range of concentration, for old leaves it was increasing in the section 0.03–3 mM, and for young leaves it was decreasing in the section 0.03–3 mM CsCl (Fig. 6). Proportional share of the root in dry weight

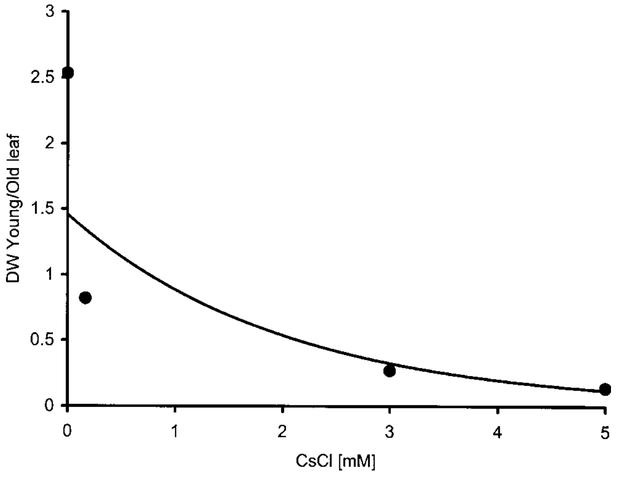

Fig. 2. The young-to-old leaf DW ratio depending on the concentration of CsCl in the soil.

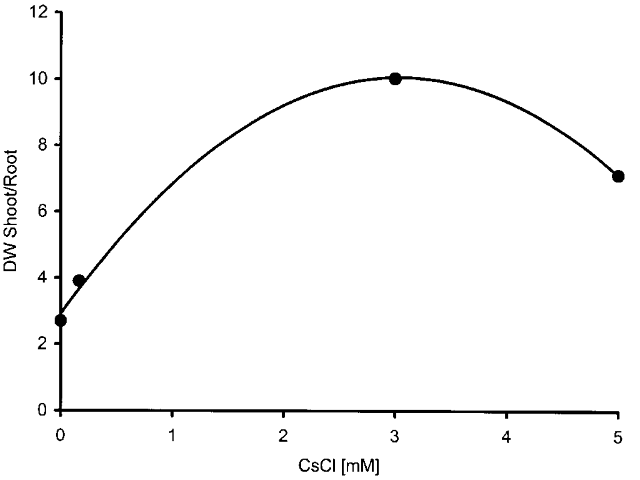

Fig. 3. The shoot-to-root DW ratio depending on the concentration of CsCl in the soil.

of the plant was decreasing in the section 0.03–3 mM, for the stem it was increasing in the range 0.03–3 mM, and then decreasing from 3 to 5 mM. Old leaf share was increasing, although, for young leaves it was decreasing in the whole range of concentration (Fig. 7). The transfer factor was the highest with the concentration of 0.3 mM, then with 0.03 mM. Among all studied transfer factors, the highest value was obtained for the transfer of ^{137}Cs from the soil to the roots (Fig. 8). The young-to-old leaf concentration factor was the highest in the whole range of concentrations. The stem-to-young leaf concentration factor was slightly lower. The root-to-shoot, stem-to-young and old leaf concentration factors did not exceed 1 unit (Fig. 9).

Discussion and conclusions

The study revealed potential usefulness of croton plants for phytoremediation of the soil contaminated with caesium, because in the whole range of CsCl concentration the shoot was the major part of plant dry weight (Figs. 3 and 7). According to the assumptions, the croton plant, as a repre-

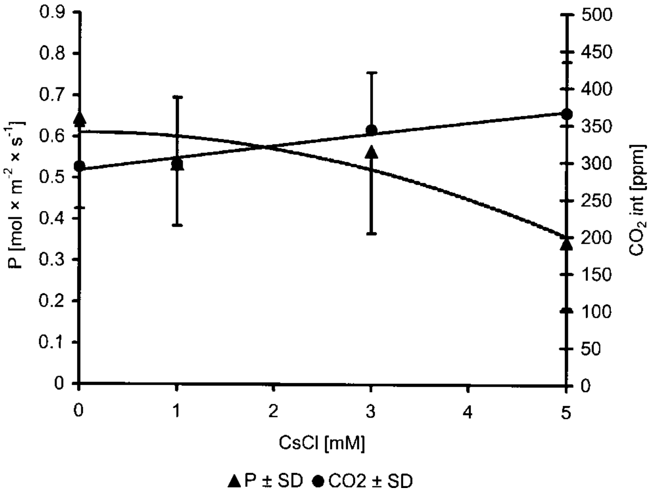

Fig. 4. The intensity of photosynthetic assimilation of CO_2 and internal CO_2 concentration for croton leaves depending on the CsCl concentration in the soil (after 2 weeks of plant growth in the soil contaminated with CsCl).

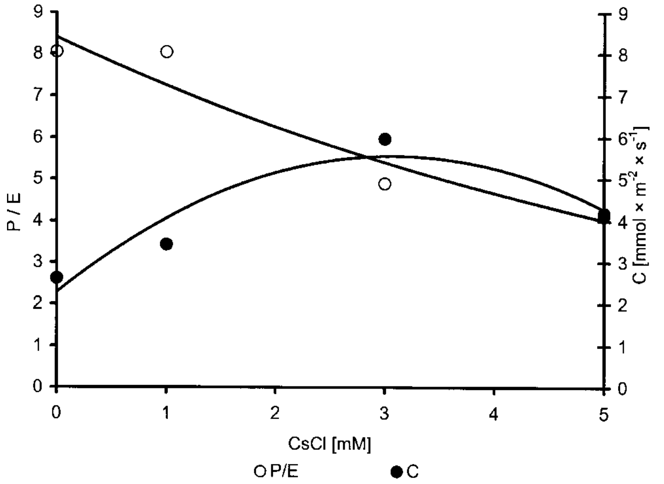

Fig. 5. The photosynthetic water utilization efficiency and stomatal conductance in the croton leaves depending on CsCl concentration in the soil (after 2 weeks of plant growth in the soil contaminated with CsCl).

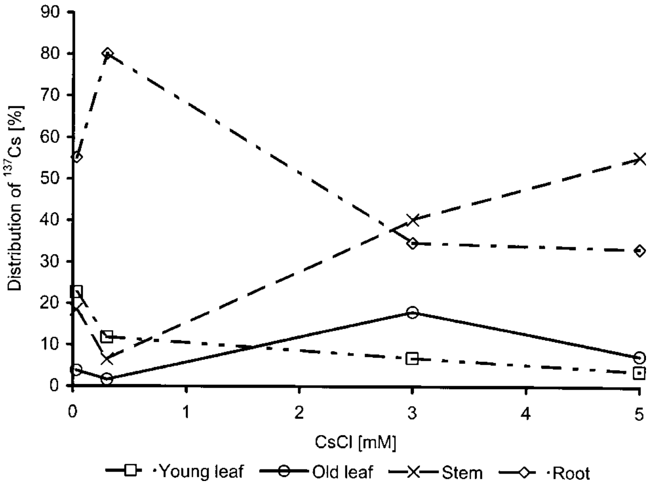

Fig. 6. Percent distribution of ^{137}Cs in the croton plants.

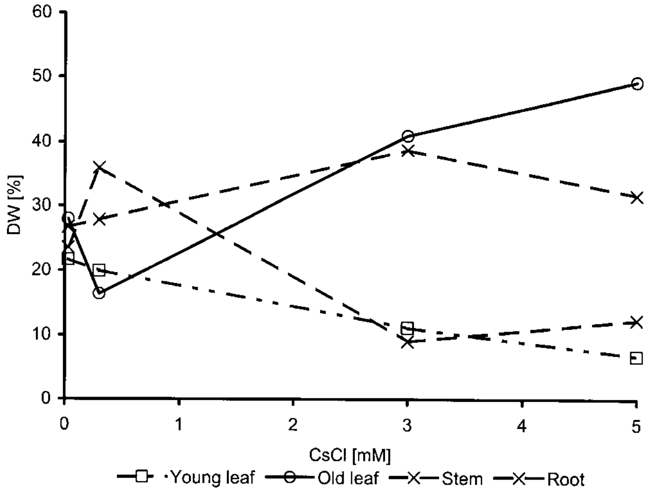

Fig. 7. Dry weight share of all the organs of the croton plant depending on CsCl concentration in the soil.

Fig. 8. The transfer factor of ^{137}Cs from the soil to the croton organs.

sentative of halophytes, showed a high resistance to the increasing soil caesium salinity. This is evidenced by the nearly constant fresh-to-dry weight ratio calculated for the aboveground plant organs, i.e.: young and old leaves, when treated with stable caesium. The FW/DW ratio was slightly changed for the stem (Fig. 1). It was somehow lowered in the roots, which indicates a decreasing root tissue hydration under the influence of a higher CsCl concentration. However, the results reveal some qualitative changes in the shoot which are caused by CsCl, i.e. a well marked decrease in the young-to-old leaf DW ratio under the influence of increasing CsCl concentration in the soil (Fig. 2).

The study of physiological processes in the leaves was aimed at explaining the impact of CsCl concentration on the observed changes. It was proved that with the increasing CsCl concentration the photosynthesis decreases (Fig. 4). The collapse in photosynthesis is associated with the increase of intra-tissue CO_2 concentration (Fig. 4); this can indicate intensification of respiration processes. As the medium-age leaves were used in this experiment, one can judge that the young-to-old leaf DW ratio was reduced, due to changes in the dynamic equilibrium between assimilation and dissimilation of CO_2. The growing stomatal conductance, associated with increased CsCl concentration, indicated opening of stomata (unlimited leaf transpiration), as shown in Fig. 5. Such a response is contrary to that observed in the non-halophyte plants, which show a smaller degree of stomata opening and lower transpiration intensity under the influence of stable caesium [1].

In spite of the decrease in photosynthesis resulting from the increasing CsCl concentration, the photosynthetic water utilization efficiency remained unchanged with the CsCl concentration from 0.03 to 1 mM. It decreased with higher CsCl concentrations. The last observations carry the point that croton plant is highly resistant to the soil caesium salinity.

The presence of ^{137}Cs in all the studied organs of the croton plant (Fig. 6) demonstrates the uptake of caesium from the soil and its long distance transport, like in other plants, e.g. wheat [5]. The use of radiocaesium tracer helped to make the evidence that croton plant accumulated the greatest amount of caesium with the 0.3 mM CsCl solution, less with 0.03 mM CsCl and the least with 3 and 5 mM (Fig. 8), while the highest accumulation took place in the root. The obtained ^{137}Cs soil-to-plant transfer factor, which amounts to about 10, proves a high ability of croton plants for caesium bioaccumulation. However, high concentration of caesium in the roots makes the possibility of using croton plants in the soil bioremediation rather controversial. Nonetheless, croton belongs to the group of plants that can grow in a relatively wide range of CsCl concentrations and can be used for phytoextraction of caesium from the soil. The studies on influence of CsCl on halophytes are pioneer and their results show that one should focus on the role of halophytes in phytoextraction of contaminated soils.

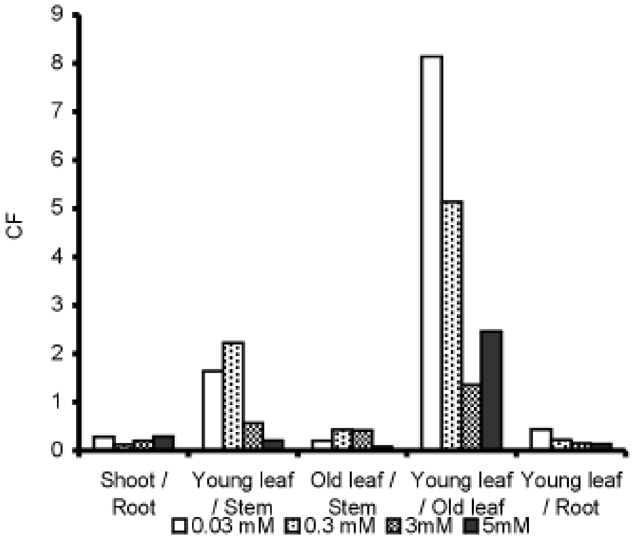

Fig. 9. The concentration factors of ^{137}Cs from the lower to the upper croton organs.

The distribution of radiocaesium in the croton plant strongly depended on the CsCl concentration in the soil (Fig. 6), because with the increase in CsCl concentration it was dropping in the roots and young leaves, but going up in the stem and (slightly) in the old leaves. A high young-to-old leaf concentration factor can explain the decrease in their dry weight (Fig. 9). The changes in the root DW share (Fig. 7) may be an effect of disturbance in the root metabolism resulting from extremely high caesium accumulation in this organ which was observed during the radiotracer studies (Fig. 9). The fall of the root DW share in the croton plants could be explained with the caesium transfer from xylem to phloem [3], as well as with a limited transport of assimilates from the leaves to the roots, which takes place with phloem participation.

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