CESIUM ACCUMULATION IN PLANTS
AND ITS ECOPHYSIOLOGICAL EFFECTS

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Abstract

Cesium-137, as a major Chernobyl fallout contaminant, is still persistent in the environment. It is being found in many agricultural products – e.g. vegetables – enhancing the naturally occurring radioactivity to which the global society is exposed every day. In this study, our recent experimental data on the cesium circulation in biota are presented. They include: various ways of cesium uptake by plants after root and foliar contamination, cesium/potassium discrimination as a factor influencing the extent of ^{137}Cs accumulation etc. Cesium is being taken up by roots and translocated to the organs, where intensive growth takes place, e.g. young leaves. But Cs may be also assimilated by leaves if applied with the fallout. Afterwards it may be rapidly transported down the plant, what was documented in onion (*Allium cepa*). In cress (*Lepidium sativum*), cesium is being accumulated mainly in the leaves, what (in higher levels) causes decrease in the growth of biomass, tissue hydration and disturbance in the photosynthetic gas exchange parameters. The obtained results and some previous studies are discussed due to evaluate the risk of the radiocesium endangerment and the possible ways of utilizing plants for phytoremediation of highly polluted areas.

Introduction

The problem of contamination with artificial radionuclides, in particular cesium-137, has been a subject of many studies since the disaster in Chernobyl NPP in 1986 (1, 2, 3). Many of them focused on some monitoring or ecotoxicological issues. In fact, exposure to radiocesium does depend on some biogeochemical processes: transport and complexing in the soil, uptake and accumulation in plants and animals, recirculation, bacterial and fungal immobilization, etc., to name a few of them.

Nowadays, it is obvious that the role of plants in the circulation of cesium cannot be overestimated. Cesium is taken up by some plants to the enormous extent (3, 4) and forced to accumulate in selected tissues and organs (4). It is taken up by roots and leaves (5). Accumulating in the green part (leaves, stems), cesium enters trophic chains in the ecosystems (4, 6). The plants seem to affect concentration of cesium in their surrounding. Thus, it is necessary to study the mechanisms governing the migration of radiocesium in biotic and abiotic environment, its cycling and recycling.

Cesium is not only passive while moving through the plants. Even at low concentrations, stable cesium may influence physiological homeostasis of the plants (7). Further it may result as a change in the ecological constitution of the area.

In this paper, we summarize our past results, published elsewhere (4, 8, 9), with some newly collected data due to let some light in the real role of cesium in nature.

Methods

Determination of transfer factor

Onion bulbs were grown in garden soil (Kronen Blumenerde, Eugen Stohp GmbH, pH 5-6), previously contaminated with $^{137}CsCl$. After 10 d growth, the seedlings were cropped, washed, dried (105 °C) and they undergone beta radiation measurement by the use of scintillation analyzer.

The transfer factor (TF) value was calculated using the formula:

TF = (^{137}Cs concentration in the plant DW [Bq/kg]) / (^{137}Cs concentration in the soil DW [Bq/kg])

Cesium allocation in the onion root

Onion seedlings were grown in the liquid medium for 7 days. Afterwards they were transported into eppendorf tubes filled with 0.3 mM CsCl traced with $^{137}CsCl$ and incubated for 72 h. Then, the roots were washed with distilled water and divided in five 2-mm sectors beginning at the root tip. All the sectors undergone beta radiation measurements with a scintillation counter due to assess relative Cs content.

Influence of Ca^{2+} and TEA^{+} on the uptake of cesium in cress

Cress seedlings were grown in the hydroponic culture (on perlite) for 7 days. The liquid medium was a modified Mayer solution with addition of 1 mM $CaCl_2$ or 10 mM tetraethylammonium chloride (TEA). CsCl concentration was 0.3 mM. Activities of ^{137}Cs have been determined by means of scintillation analyzer.

Influence of stable cesium on the growth of cress

Cress seedlings were germinated and grown in hydroponics for 6 days in total. Different variants of the modified Mayer nutrient solution, containing 0 to 150 mM CsCl or KCl, were supplied. Then the seedlings were cropped and both fresh and dry weight was measured.

Results

Some of our previous results (discussed in this work) are already published (1, 2, 3) and are not presented in this section.

The obtained transfer factor (TF) for cesium (in onion) is: 2.87 (kBq/kg DW plant)/(kBq/kg DW soil). The distribution of cesium after 10 d soil culture shows a high accumulation in the leaves, then roots, but not in the bulb (Fig.1).

Fig.2 shows a local accumulation pattern for cesium along onion root. The highest accumulation occurs in the apical zone of the root and the Cs concentration goes down at the elongation zone.

Cs uptake in cress is slightly affected by 10 mM tetraethylammonium chloride (an inhibitor of KIR channels (Fig.3). No influence of 1 mM Ca^{2+} was observed.

Figure 1: Accumulation of cesium in the onion organs after 10 days (soil culture).

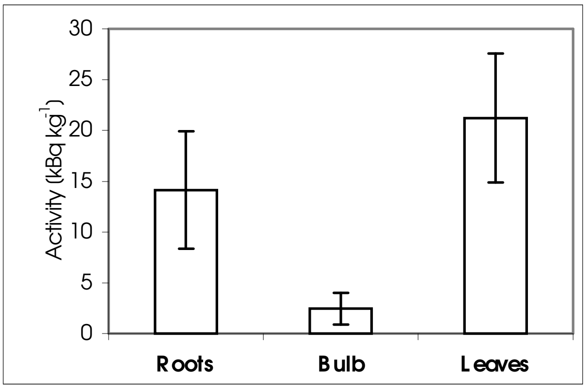
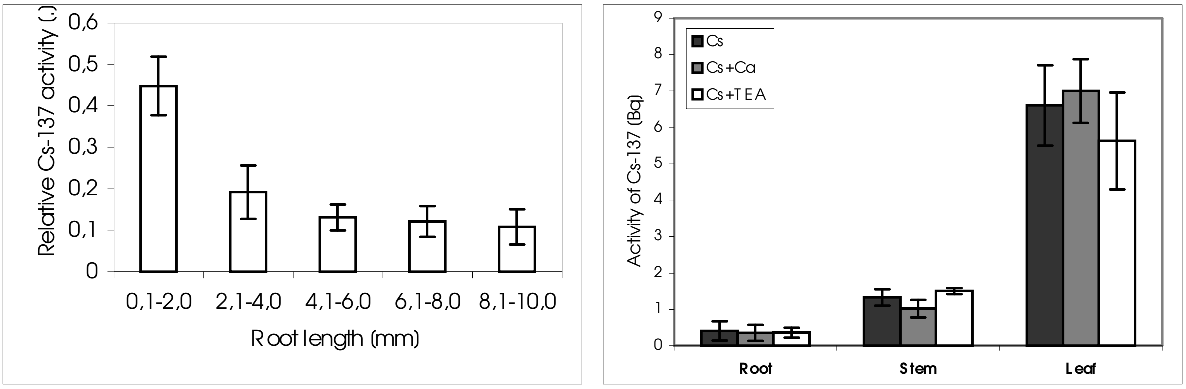
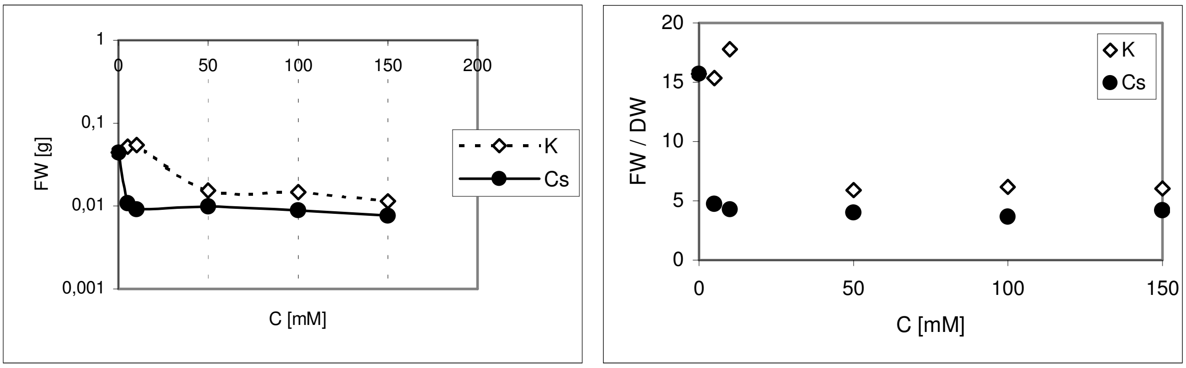


Figure 2: Short-term accumulation of cesium in the apical zone of onion root (left). Influence of Ca and TEA on the transport of cesium to the leaves of cress (right).



Graphs in the Fig. 4 indicate influence of low cesium concentrations (5 mM). Potassium causes a decrease in the accumulation of biomass and tissue hydration if applied in greater concentration (up to 5 mM).

Figure 3: Comparison of the influence of cesium and potassium stress on the fresh weight (left). Comparison of the influence of cesium and potassium stress on fresh-to-dry weight ratio (right).



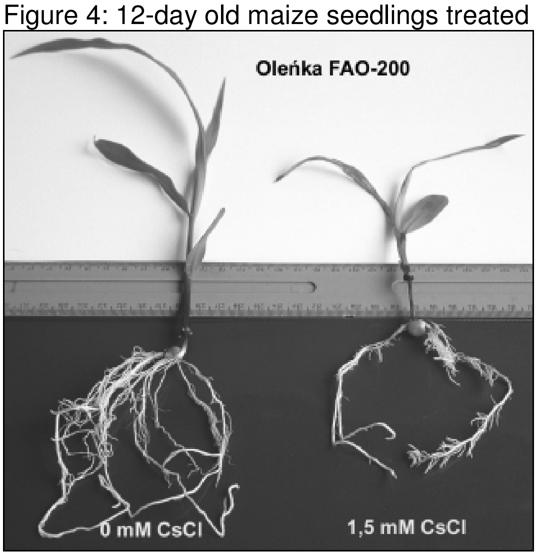
Discussion

Transport of cesium to the root cells seems to be mediated mostly by K^+-H^+ symporter, which is thought to be located in plasmalemma (8). This occurs while roots are surrounded by 0.3 mM Cs solution. However, some authors suggest that the uptake of cesium may be also facilitated by voltage independent (VIC) channels (10). As observed for other xenobiotics (11), cesium is mostly accumulated in the apical part of the root tip (Fig.2). It may be explained by the high density of the abovementioned carriers in the cell membrane.

Even on slightly polluted area, onion accumulates significant amounts of radiocesium, as its TF value is quite high: 2.87 (kBq/kg DW plant)/(kBq/kg DW soil). Other plants reach much lower transfer factors (2, 3), often below 1 unit. It makes the onion plant a potential phytoremediator to be applied where radioactive contamination occurs (4). Cesium is well accumulated in the rapidly growing parts, i.e. leaves (Fig.1). Since cesium is still an important radioactive contaminant of foods in Poland (12), it may help to reduce the dose of naturally occurring radioactivity (NOR), to which the society is exposed.

The role of cesium in the mineral nutrition of plants is unknown (7). Cesium ion is thought to be non-toxic for plants if its concentration is lower than 0.2 mM. Our tests with nutrient solutions containing up to 150 mM have confirmed toxicity of stable cesium in very small concentrations (about 3 mM; Fig.3; 9).

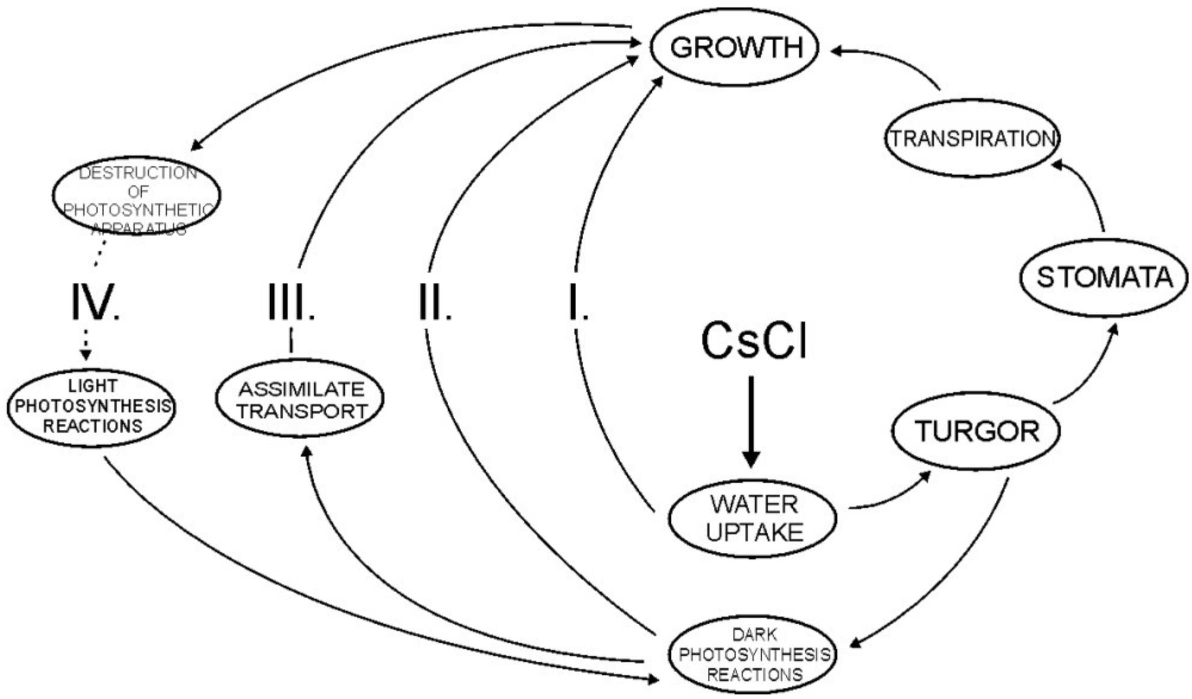
Figure 4: 12-day old maize seedlings treated with stable cesium (© M.A. Bazala).



In cress, the stress response for cesium was much higher than for potassium (9; Fig.3). Probably cesium causes a systemic reaction of the plants, in which a cascade of genes is expressed (13). As the water uptake is disturbed (at the presence of CsCl), plants produced shorter and thicker roots. In the soils with water potential lower than in the plants, some species use so called “contractile roots”, what ensures better hydraulic contact with the surrounding soil (14). Such roots can also be observed in maize plants after CsCl treatment (Fig.4). The decreased fresh-to-dry weight ratio is not the only one symptom of osmotic stress. There is lowered photosynthetic water utilization efficiency, measured

as photosynthetic-to-transpiration intensity ratio P/E. Under cesium treatment, disturbance in the water balance occurs (Fig.3), and furthermore decrease in the photosynthetic carbon reduction efficiency. Since cesium decreases plant dry weight (Fig.3; 9), one could conclude about significant decrease in the accumulation of organic matter. It might be an effect of disturbance in the water balance – water uptake and transpiration, and also disturbance in photosynthesis, which are the effect of osmotic stress. The control function of stomata in respect to photosynthetic CO_2 assimilation and transpiration is modified at the presence of cesium. Closing the stomata limits transpiration while photosynthetic CO_2 assimilation is unchanged, during a short-term growth of seedlings on CsCl. It is consistent with a rule of compromise between maximization of photosynthesis and minimization of transpiration (15). However, in the case of longer growth on CsCl, especially at higher light level, retardation of photosynthesis is stronger than in case of transpiration.
The collected results (Fig.3, 4; 9) enable to suggest a scheme of influence of cesium on physiological processes in plants. Both primary (I.) and secondary (II.-IV.) interactions may be distinguished. It seems that limitation in the water uptake is a primary stress effect evoked by stable cesium. Further, cellular turgor is being decreased, what enables closing the stomata and limits transpiration. Due to the abovementioned, the transport of ions from the roots to the shoots is retarded. Growth processes are also inhibited then. The effect of collapse in tissue hydration, due to osmotic stress, is a decrease of photosynthetic CO_2 reduction efficiency (II.), so the limitation of assimilates (necessary for the growth of biomass), and retardation of assimilate transport (III.). Significant disturbance in the growth processes may lead to destruction of photosynthetic apparatus, what can influence light reactions of photosynthesis (IV.). However, such an effect has not been observed in our experiments (9). It can be concluded that the processes observed in the Fig.5 are typical plant responses, which occur in case of abiotic stress and are in accordance with literature.

Figure 5: Probable influence of stable cesium on physiological processes in plants.



Conclusions
The experiments, carried out, point enormous uptake and translocation of cesium in onion *Allium cepa* L. and cress *Lepidium sativum* L., in both seminatural conditions and in short-term solution culture tests.
Cesium is taken up by the apical zone of the root and transported toward the acropetal direction and in parallel, assimilated by the leaves and transported basipetally into the root. The root uptake occurs via H^+-K^+ symporter. This process goes rapidly at low pH of the nutrient solution. It is retarded by potassium. But it is not influenced neither by Ca^{2+} and nor TEA^+. The vertical cesium transport toward the upper onion organs is non-specific. This element is accumulated in the different storage organ tissues within an unequal extent (mainly in the internal part). In the root, cesium occurs mainly in the

form of Cs^+, as it is being supplied with the nutrient solution. Both onion and cress show significant capability to extract cesium from the soil.
Millimolar concentrations of cesium chloride induce a strong osmotic stress in the cress seedlings. It is shown in the decrease of water uptake and hydration of the tissues. Millimolar cesium concentration in the nutrient solution, decreases stomatal conductance, transpiration and plant growth. Longer osmotic stress lowers efficiency of the photosynthetic carbon reduction cycle and decreases the growth of biomass. Translocation of photosynthetic metabolites in the cesium-stressed plants was also retarded. No remarkable influence of cesium on the chlorophyll fluorescence can be noticed.

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