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PROCEEDINGS

The distribution of ^{137}Cs in maize (*Zea mays* L.) and two millet species (*Panicum miliaceum* L. and *Panicum maximum* Jacq.) cultivated on the caesium-contaminated soil

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Abstract The plants of three species (*Zea mays* L., *Panicum miliaceum* L. and *Panicum maximum* Jacq.) were grown on the soil contaminated with 0.3 mM CsCl solution traced with ^{137}Cs, in the greenhouse. For all the species, the fresh-to-dry weight ratio was equal in the caesium-treated plants and in the control group after 3 weeks of culture. The shoot-to-root fresh weight and dry weight ratios were decreased in maize, unchanged in *Panicum miliaceum* and increased in *Panicum maximum*, comparing to the control without caesium treatment. The shoot/soil and also root/soil transfer factors (TF) for ^{137}Cs (measured by means of NaI gamma spectrometer) were always the highest in maize, then lower in *Panicum miliaceum* and the lowest in *Panicum maximum*. All the plants seem to be hyperaccumulators of caesium. The root/soil TF was especially high in maize, i.e. 55 (kBq kg^{-1} biomass)/(kBq kg^{-1} soil). The shoot/root concentration factor (CF) for ^{137}Cs was the lowest in maize, higher in *Panicum miliaceum* and the highest in *Panicum maximum*. The hyperaccumulation of ^{137}Cs in the whole plant was the highest in maize, lower in *Panicum miliaceum* and the lowest in *Panicum maximum*. The proved ability of the investigated plants for phytoextraction of the soil caesium points to the possibility to utilise these plants in the soil bioremediation. From this point of view, *Panicum maximum* seems to be the most useful plant because it accumulates caesium mainly in the shoot, and maize would be the least useful species since it has the highest accumulation in the root.

Key words bioremediation • caesium hyperaccumulation • phytoextraction

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Introduction

The accidents of nuclear reactors and explosions of nuclear bombs are the main reasons of the emissions of radioisotopes into the natural environment. These substances contaminate water resources, soils and the air. This way, they enter the elemental circulation in the trophic chains of different ecosystems. The ability of plants to take up (phytoextraction) and accumulate different elements, present in the growing medium, is used for purification of the contaminated areas (bioremediation).

Much effort aims at finding the plants that are hyperaccumulators of radionuclides [5]. Some very important features of such plants are high biomass productivity and the uptake of radionuclides from the soil and their accumulation in the above-ground parts, e.g. in the leaves, stems and seeds. At the same time, the concentration in the roots should be the lowest. It may be possible to diminish the concentration of toxic substances in the contaminated area to a high extent by agricultural processes, removal and deactivation of the crops. There is a diversity of tolerance to the environmental contamination among both agricultural and wild plants.

Research on caesium accumulation in the common agricultural plants is being done also for some other reasons [2, 3]. Generally, these plants are cultivated for consumption. Knowing their ability to take up toxic substances from the

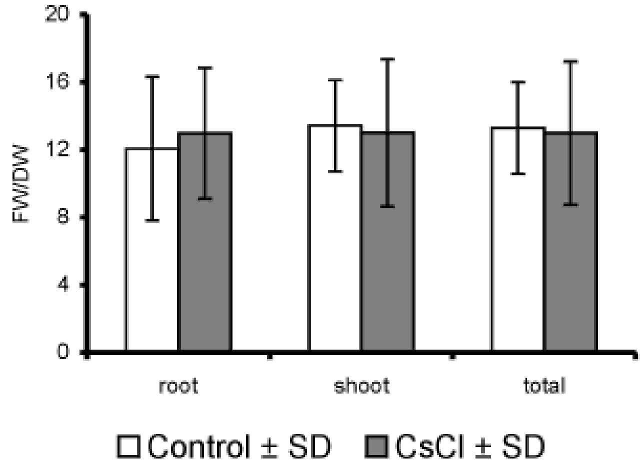

Fig. 1. Fresh-to-dry weight ratio in maize (*Zea mays*).

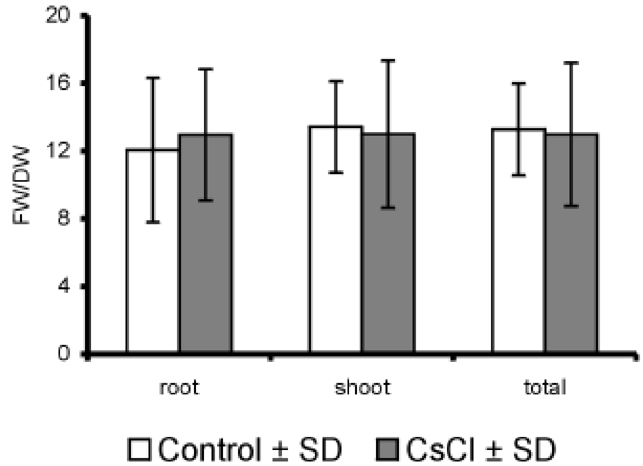

Fig. 2. Fresh-to-dry weight ratio in millet (*Panicum miliaceum*).

contaminated areas, it is possible to identify whether they fulfil the safe food standards.

Maize and millet are major species of agricultural interest. These are C_4-type plants. They have a very high photosynthetic efficiency, and are characterised by a very fast growth of biomass, while they have relatively little water needs. They are also highly tolerant to the soil salinity [4].

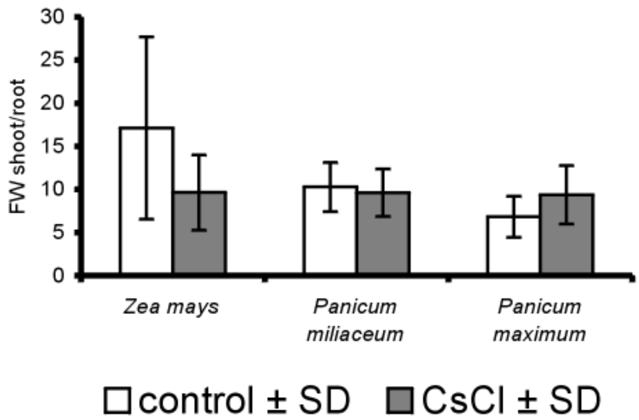

Fig. 3. Fresh-to-dry weight ratio in millet (*Panicum maximum*).

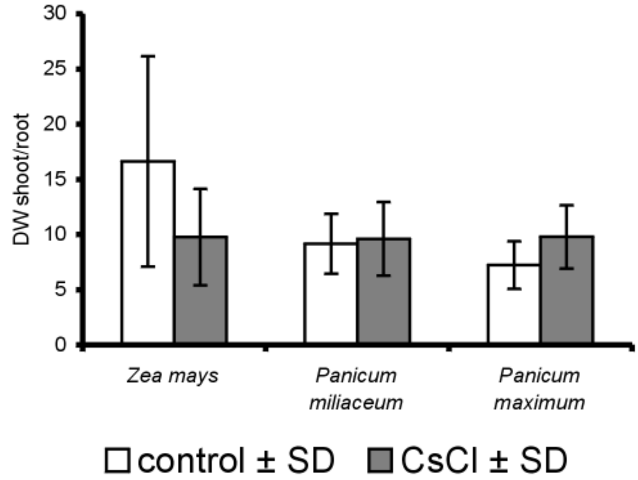

Fig. 4. Shoot/root fresh weight ratio.

A number of factors were taken into account while choosing maize and millet for the study of uptake and accumulation of caesium from the soil. These factors are the following: fast growth, considerable advantage of the above-ground part over the root, inedibility of the roots, and the above mentioned tolerance to the soil salinity. Also a high participation of the seeds in the human diet and that of the leaves in animal food was considered important.

Materials and methods

The seeds of maize (*Zea mays* L.) and two species of millet (*Panicum miliaceum* L. and *Panicum maximum* Jacq.) were incubated with a piece of wet cellulose in a plastic cuvette covered with aluminium foil with holes, at the temperature of 30°C. The mean daytime temperature was 26°C, humidity 40% and PAR intensity 150 μmol m^{-2} s^{-1}. The photoperiod was set on 16 hrs. *Panicum miliaceum* was left for germination for 2 days, maize for 3 days and *Panicum maximum* for 4 days. Different incubation times were a result of different germination speed. The seedlings of similar dimensions were selected for the further experiments. The culture was prepared in two pots: one with 0.3 mM CsCl (40 kBq of ^{137}CsCl tracer) and the control. 20 seedlings of each species were placed in each pot. The pots were put into the greenhouse and watered regularly. The soil was from Euglen Storhp GmbH. The radioactive tracer ^{137}CsCl was from Polatom (Otwock-Świerk, Poland).

After taking out of the soil, the plants were rinsed, so as to get rid of the medium residues, and divided into roots and shoots. The respective parts of the plants were weighted and dried at 105°C (24 hrs.). Separate parts of the plants were weighted using and analytical weight within 0.0001 g accuracy and then homogenised and put into the measurement flasks.

The radioactivity measurements were performed by means of an NaI gamma spectrometer (Canberra Packard) during 24 hrs. Analysis of the collected spectra was made by means of the Genie 2000 software. The IAEA standards were used for the energy and activity calibration. Treatment of the data was carried out using MS Excel 2000 software.

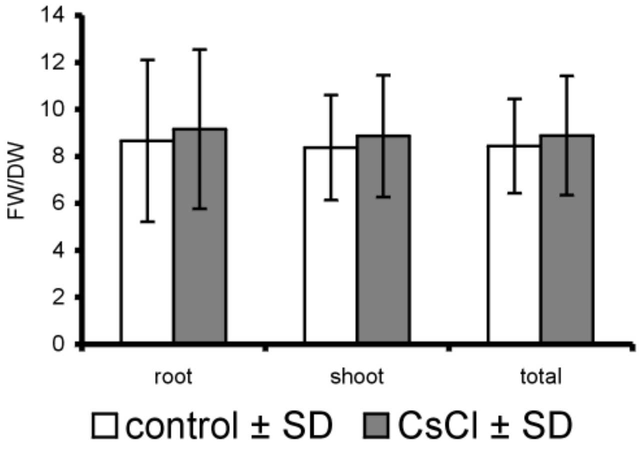

Fig. 5. Shoot/root dry weight ratio.

Results and discussion

0.3 mM and higher CsCl concentrations evoke osmotic stress in many plants [2]. However, there are no changes in the fresh-to-dry weight ratio in maize, and in the both species of millet (Figs. 1–3). Therefore, no decrease in the shoot and root tissue hydration within the CsCl treatment can be observed. It proves a high resistance of these plants to salinity. The variations observed in the maize shoot-to-root fresh and dry weight ratio (Figs. 4 and 5) demonstrate

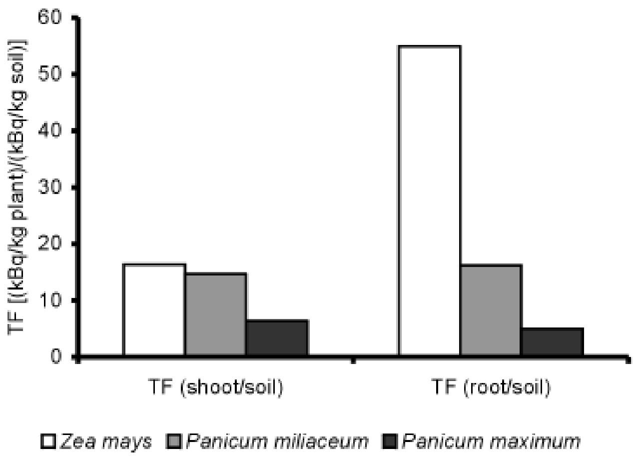

Fig. 6. Transfer factors for ^{137}Cs.

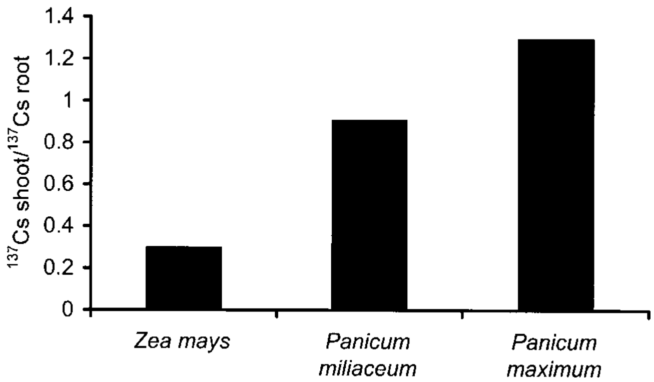

Fig. 7. Shoot/root concentration factors for ^{137}Cs.

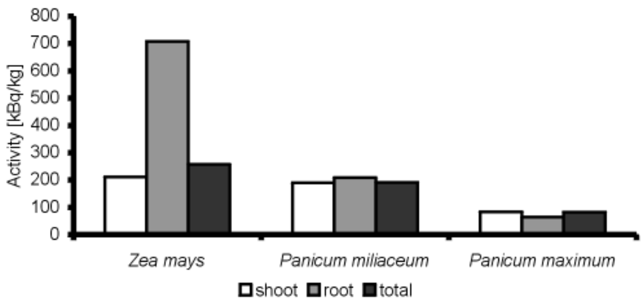

Fig. 8. Accumulation of ^{137}Cs in the respective organs of the plants.

changes in the productivity of these plants or changes of the assimilate transport from the shoot to the root. The decrease in this ratio, resulting from an increasing participation of the root biomass, indicates the tendency of the root to enlarge its biomass in the plant growing in the CsCl-contaminated soil. Such a strategy enables survival of the plant by maintenance of the increased potential of the root materials which play the role of the respiration substrates. The data obtained from the experiments on maize indicate a typical reaction of its roots to salinity by creating so called contractile roots (fatter and shortened) [1]. This strategy has not been observed in *Panicum miliaceum* and *Panicum maximum*. In contrast, this relation is increased in *Panicum maximum*, as compared with the control group.

At the same soil pH and CsCl concentration, the transfer factors (TF) for ^{137}Cs differed significantly, depending on the organ, in the groups of the investigated plants (Fig. 6). In maize, the TF was much higher for the root than for the shoot; in *Panicum miliaceum* slightly higher for the root than for the shoot; and slightly higher for the shoot in *Panicum maximum*.

The shoot/root activity ratio was the highest in *Panicum maximum*, lower in *Panicum miliaceum* and the lowest in maize (Fig. 7). The obtained results showed a hyper-accumulation of caesium in maize plants and in the both millet species. The extent of caesium accumulation in the total plant biomass (Fig. 8) can be compared in the investigated species as follows:

Zea mays > *Panicum miliaceum* > *Panicum maximum*

The proved ability of the investigated plants for phytoextraction of the soil caesium points to the possibility to utilise these plants in the soil bioremediation. From this point of view, *Panicum maximum* seems to be the most useful plant since it accumulates caesium mainly in the shoot, and maize is the least useful species because it is characterised by the highest caesium accumulation in the root.

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