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HEAVY METALS CONCENTRATIONS IN *DACTYLIS GLOMERATA* L. PLANTS IN AN EXPERIMENT WITH INDUCED POLLUTION SOIL IN THE GREENHOUSE

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Abstract

This study presents the results of experiments with induced pollution, carried out in the greenhouse, which aimed at the accumulation of heavy metals (Cd, Pb, Zn and Cu) in Dactylis glomerata L. plants. The soil material used for the experiments was harvested from an unpolluted area in the Copșa Mică area. The soil has a fine texture, with a weak alkaline reaction, a medium humus content, a medium nitrogen and potassium supply and a high phosphorus content. The heavy metal contents fall within the normal limits according to Order 756/1997 on the assessment of environmental pollution. To carry out the experiments with induced pollution, the soil material was treated with the appropriate amounts of metals (Cd, Cu, Pb and Zn) from their soluble salts (acetate), and for each element 6 experimental variants were established depending on the metal content in the soil.

The results obtained were used to parameterize stochastic models that can be used to estimate the accumulation of heavy metals in Dactylis glomerata L. plants depending on the total and mobile (DTPA) content of metals in the soil. The logarithmic plots for the power regression curves estimating the stochastic dependence between the total and mobile content in the soil and aerial part of Dactylis Glomerata L. plants are distinctly statistically significant.

Key words**: heavy metals, Dactylis glomerata* **L.**, ***pollution, soil.

INTRODUCTION

Soil contamination with heavy metals is one of the major problems worldwide, due to their toxicity, persistence and accumulation in soil (Bhuiyan et al., 2021; Tan et al., 2023). The accumulation of heavy metals in soil can pose a significant threat to plants, animals and humans (Doyi et al., 2018, Sabirș et al., 2022, Crișan et al., 2025 Li et al., 2025). They can accumulate in soil as a result of natural processes or as a mineral part of the soil parent rock and induced by humans (Ojeda, 2025).

The main sources of environmental contamination with cadmium, lead, zinc and copper are the mining, metallurgical and chemical industries and others. Pollution of air, soil, plants and water with heavy metals in the vicinity of large industrial centers has become one of the most pressing environmental problems. In soils near industrial areas, the content of heavy metals is tens or hundreds of times higher than the contents in other similar soils (Atabayeva, 2016, Das et al., 2023).

Jankowski et al. (2018) point out that the actual accumulation of heavy metals in plants, including lead and cadmium with the strongest environmental impact, is mainly related to the specific bioaccumulation potential of each species. Cd readily accumulates in plants, promoting various disorders that suppress growth and can even lead to their death. Thus, plants with significant amounts of Cd in the edible parts of crop species in the food chain potentially threaten human health. Exposure to Cd has been shown to be closely linked to increased incidence of diseases in the body (Yang et al., 2020). Rebhi et al. (2025) show that soil contamination with lead even in very small amounts can inhibit photosynthesis, disrupt enzyme activity and prevent nutrient absorption in plants. Lead can negatively affect the human central nervous system, cardiovascular, digestive, irritability, insomnia and headaches, as well as behavioral disorders and learning difficulties in children under five years of age (Bedriñana et al., 2020; Yang et al., 2022).

It is known that copper and zinc are essential elements for plants in photosynthesis, chlorophyll biosynthesis, mitochondrial respiration, in the electron transport chain, and increased and excess concentrations in soil result in negative effects (Marschner 2011; Gawryluk et al., 2020; Marques et al. 2021; Kuziemska et al., 2021; These elements accumulated in soil in high concentrations cannot be degraded biologically or chemically and pose a threat to the environment, food security and human health. High concentrations of copper in soil are known to have toxic effects on microorganisms and prevent the mineralization of macronutrients such as phosphorus and nitrogen and decrease the availability of phosphorus to plants (Azeez et al. 2015). It also binds strongly to organic matter, clay minerals, and hydrated oxides of iron, aluminum, and manganese, and either reduces the concentration of these nutrients in the soil or makes them unavailable for plant absorption. Excessive accumulation in plants can inhibit root growth, destabilize membrane integrity, decrease photosynthesis, and alter enzyme activity, leading to growth inhibition and other negative effects on plants (Shabbir et al. 2020).

High zinc concentrations can cause infertility, central nervous system disorders and kidney disease (Malica et al., 2022)

Therefore, it is essential to monitor and control heavy metal concentrations in different components of the environment and especially in soil, in order to prevent toxic effects.

Dactylis glomerata L. is one of the most commonly found perennial grass species in permanent grasslands in the Copșa Mică area. The aim of this study is to evaluate the effects of different amounts of heavy metals (Cd, Pb, Zn and Cu) in the soil on the content of these elements in *Dactylis glomerata* L. plants, and to determine the accumulation capacity of this species of heavy metal contamination.

MATERIALS AND METHODS

This paper presents a study conducted in 2024, on the accumulation of heavy metals (Cd, Pb, Zn and Cu) in *Dactylis glomerata* L. plants, in experiments with induced pollution. The experiments were carried out under greenhouse conditions, in 10 kg pots. To carry out the experiments, soil material was collected from an unpolluted area in the Copșa Mică area. The soil material was collected from the surface, from the 0-20 cm layer, mixed and dried at air temperature. Before preparing the experiments, samples were collected for chemical and physical analyses. The samples were homogenized and performed in four repetitions.

The soil material was treated with amounts of metals (Cd, Cu, Pb and Zn) derived from their soluble salts (acetate). For each element, 6 experimental variants were established depending on the metal content in the soil. In establishing these content values, the following previous studies were taken into account, as well as the limit values from Order 756/1997.

• Cd: control; 3 mg·kg^{-1}; 6 mg·kg^{-1}; 9 mg·kg^{-1}; 12 mg·kg^{-1}; 15 mg·kg^{-1};

• Pb: control; 50 mg·kg^{-1}; 100 mg·kg^{-1}; 150 mg·kg^{-1}; 200 mg·kg^{-1}; 250 mg·kg^{-1};

• Zn: control; 300 mg·kg^{-1}; 600 mg·kg^{-1}; 900 mg·kg^{-1}; 1200 mg·kg^{-1}; 1500 mg·kg^{-1};

• Cu: control; 100 mg·kg^{-1}; 200 mg·kg^{-1}; 300 mg·kg^{-1}; 400 mg·kg^{-1}; 500 mg·kg^{-1};

As a test plant, *Dactylis glomerata* L. variety Magda from the Research and Development Institute for Pastures from Brașov (ICDP) was used.

The harvested soil samples were dried at room temperature, ground.

The soil material used in the experiments was analysed from a physicochemical point of view. The soil pH was determined using the potentiometric method (1:2.5 g/v, soil:water), the organic matter content was determined using the Walkley-Black method, modified after Gogoașa. Total nitrogen was determined using the Kjeldahl method. Available phosphorus and potassium in the soil were determined using the Egnèr-Riehm-Domingo method.

The contents of heavy metals in the soil (Cd, Pb, Zn and Cu) were determined by atomic absorption spectrometry, after extraction using the aqua regia method - microwave digestion. DTPA- extractable heavy metals were exctracted from soil (10 g) with 20 ml of extracting solution (0.05 M DTPA, 0.01 M $CaCl_2$ and 0.1 M tetraethylammonium adjusted to pH 7.3), according to SR ISO 14870:2002.

The plant samples were harvested, dried, chopped and ground. Then they were treated with nitric acid in a microwave digestion system. The total content of heavy metals was determined using atomic absorption spectrometry (Flame GBC 932AA or graphite furnace GBC SavanatAAZ).

Microsoft Excel 2010 was used for statistical data processing.

RESULTS AND DISCUSSIONS

The results of laboratory determinations performed for the chemical characteristics of the soil material, which is the support for carrying out the experiments, are presented in Table 1. The analysed soil has a weak alkaline reaction (pH = 7.94), medium humus content (2.71%), medium nitrogen supply (0.183%), with a high phosphorus content (53 mg·kg^{-1}) and medium potassium supply (186 mg·kg^{-1}).

Table 1. Chemical characteristics of the soil material (n=4)

Chemical properties	M.U.	Mean value
pH_{water}	-	7.94
Humus	%	2.71
Total N	%	0.183
Available P	mg·kg^{-1}	53
Available K	mg·kg^{-1}	186

The physical characteristics are given in Table 2, indicating a fine texture, medium clay (LL), without carbonates. As granulometric fractions (in mm, % of the mineral part of the soil), they contain 12.0 % coarse sand (2.0 to 0.2 mm), 44.0 % fine sand (0.2 to 0.02 mm), 19.3% silt (0.02 to 0.002 mm) and 24.7% clay (0.002 mm).

Table 2. Physical characteristics of the soil material (n=4)

Particle - size distribution (in mm) (% of the mineral part of the soil)	Mean value
Coarse sand (%) 2.0-0.2 mm	12.0
Fine sand (%) 2.0-0.02 mm	44.0
Silt (%) 0.02–0.002 mm	19.3
Clay (%) < 0.002 mm	24.7
Texture	LL

From the point of view of heavy metal contents, it is observed that the values obtained are within normal limits according to order 756/1997 on the assessment of environmental pollution. Thus, in the soil material used for the experiments in protected spaces, the following average values were determined: 0.771 $mg \cdot kg^{-1}$ Cd, 41.1 $mg \cdot kg^{-1}$ Pb, 124 $mg \cdot kg^{-1}$ Zn, 27.8 $mg \cdot kg^{-1}$ Cu, 43.9 $mg \cdot kg^{-1}$ Cr, 579 $mg \cdot kg^{-1}$ Mn and 37.2 $mg \cdot kg^{-1}$ Ni (Table 3).

Table 3. Heavy metal contents of the soil material (n=4)

Heavy metals content	M.U.	Mean value
Cd	$mg \cdot kg^{-1}$	0.771
Pb	$mg \cdot kg^{-1}$	41.1
Zn	$mg \cdot kg^{-1}$	124
Cu	$mg \cdot kg^{-1}$	27.8
Cr	$mg \cdot kg^{-1}$	43.9
Mn	$mg \cdot kg^{-1}$	579
Ni	$mg \cdot kg^{-1}$	37.2

The data obtained from the monoelement induced pollution experiments were used to parameterize stochastic models that can be employed to estimate the bioaccumulation of heavy metals in *Dactylis glomerata* L. plants, depending on the total metal content in the soil.

Atabayeva (2016) shows that Dactylis glomerata L. accumulates considerable amounts of heavy metals from the soil. The concentration of metals in shoots decreased in the following order: Zn (118.4 $mg \cdot kg^{-1}$) > Pb (79.3 $mg \cdot kg^{-1}$) > Cu (13.0 $mg \cdot kg^{-1}$) > Cd (8.7 $mg \cdot kg^{-1}$), and in roots: Pb (770.4 $mg \cdot kg^{-1}$) > Zn (304.1 $mg \cdot kg^{-1}$) > Cd (39.4 $mg \cdot kg^{-1}$) > Cu (17.5 $mg \cdot kg^{-1}$). The highest concentration was of Pb in roots.

Figure 1a presents the logarithmic diagram of a log-log regression curve that estimates the stochastic dependence between the total cadmium content in the soil and the cadmium content in the aerial parts of *Dactylis glomerata* L. plants. The value of the linear correlation coefficient (r = 0.9948***) was extremely significant, indicating a very strong correlation between the cadmium content in *Dactylis glomerata* L. plants and the cadmium content in the soil. The same trend was observed between the cadmium content in the plant and the mobile cadmium content in the soil, with a linear correlation coefficient of r = 0.9941*** (Figure 1b).

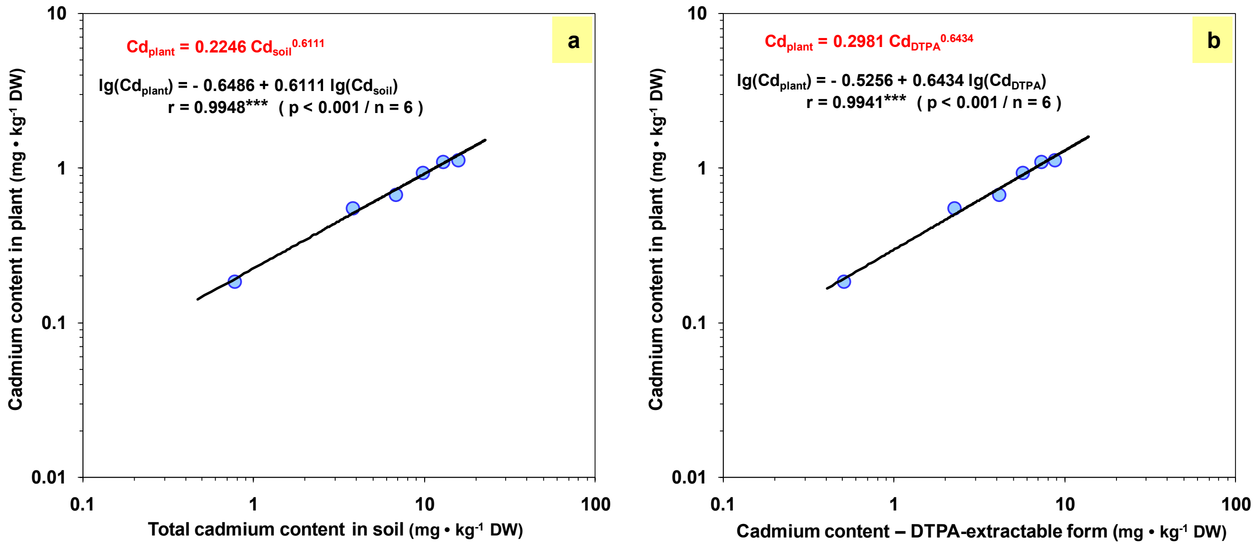

Figure 1. Log-log diagrams for regression curves that estimate the stochastic dependency between the total cadmium content in soil (a), the soil cadmium content – DTPA-extractable form (b) and the cadmium content in the *Dactylis glomerata* L. plants

Comparing the concentration of cadmium in three grass species (*Dactylis Glomerata* L., *Arrhenatherum Elatius* and *Alopecurus Pratensis*), it was found that the highest amounts (0.286 mg kg^{-1}) were accumulated by *Dactylis glomerata* L., with statistically significant differences in the aboveground parts (Jankowski et al., 2019).

The value of the linear correlation coefficient obtained for the relationship between the total lead content in the soil and that in the plant (Figure 2a), as well as between the mobile lead content in the soil and the lead content in the plant (Figure 2b), was significantly different from zero, indicating a strong correlation between the two variables. The linear correlation coefficients were r = 0.9845*** and r = 0.9815***, respectively, for the mobile forms.

Figure 3a shows the logarithmic regression curve that estimates the stochastic dependence between the total zinc content in the soil and the zinc content in the aerial parts of *Dactylis glomerata* L. plants, with a highly significant linear correlation coefficient (r = 0.9951***). Figure 3b presents the logarithmic diagram for a power-type regression curve that estimates the stochastic dependence between the mobile zinc content (DTPA) in the soil and the zinc content in *Dactylis glomerata* L. plants, with a highly significant linear correlation coefficient (r = 0.9926***).

The transfer of copper content from the soil to *Dactylis glomerata* L. plants is illustrated by exponential-type regression curves that estimate the stochastic dependence between the total copper content in the soil (Figure 4a) and the mobile copper content (Figure 4b) in the aerial parts of the plants. The linear correlation indices were significantly high in both cases, with r = 0.9825*** for the relationship between the total copper content in the soil and in the plant, and r = 0.974*** for the relationship between the mobile copper content in the soil and the copper content in the aerial parts of *Dactylis glomerata* L. plants.

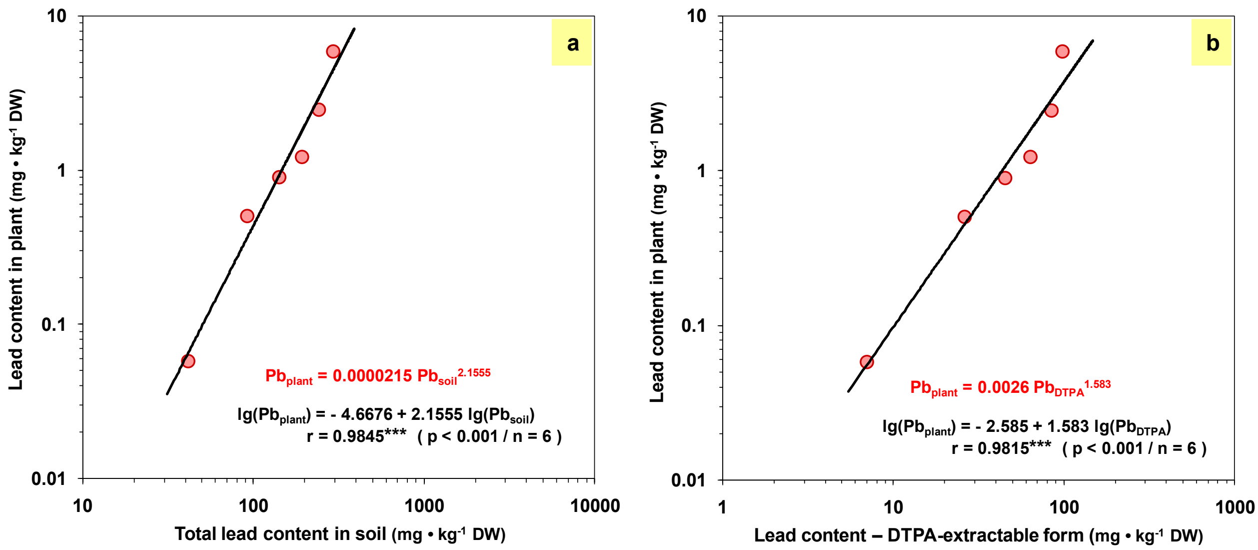

Figure 2. Log-log diagrams for regression curves that estimate the stochastic dependency between the total lead content in soil (a), the soil lead content – DTPA-extractable form (b) and the lead content in the *Dactylis glomerata* L. plants.

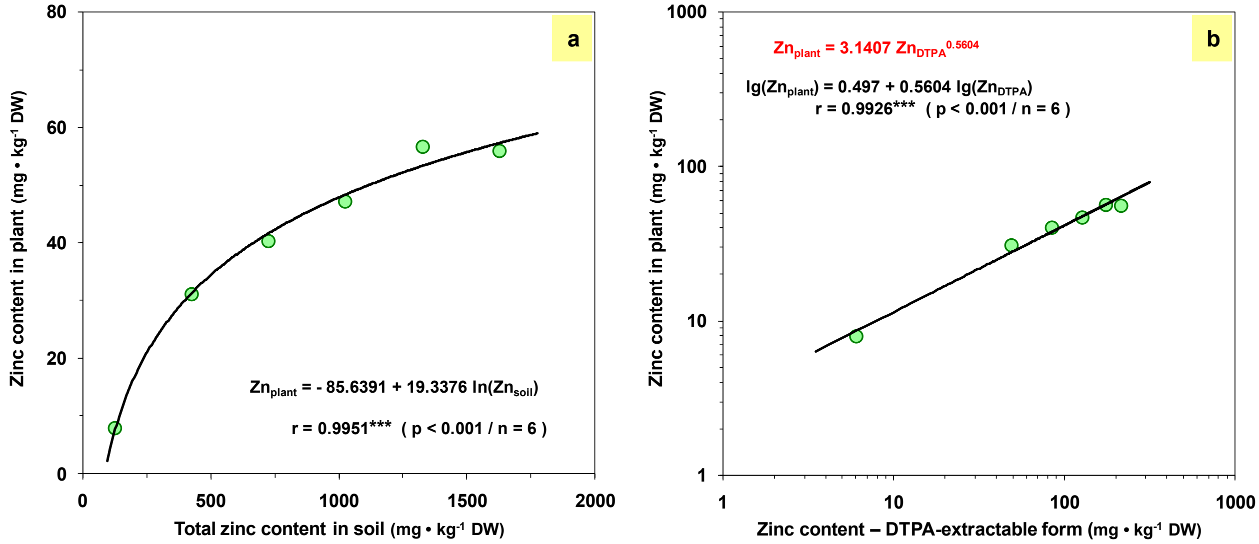

Figure 3. Regression equations that estimate the stochastic dependency between the total zinc content in soil (a), the soil zinc content – DTPA-extractable form (b) and the zinc content in the *Dactylis glomerata* L. plants.

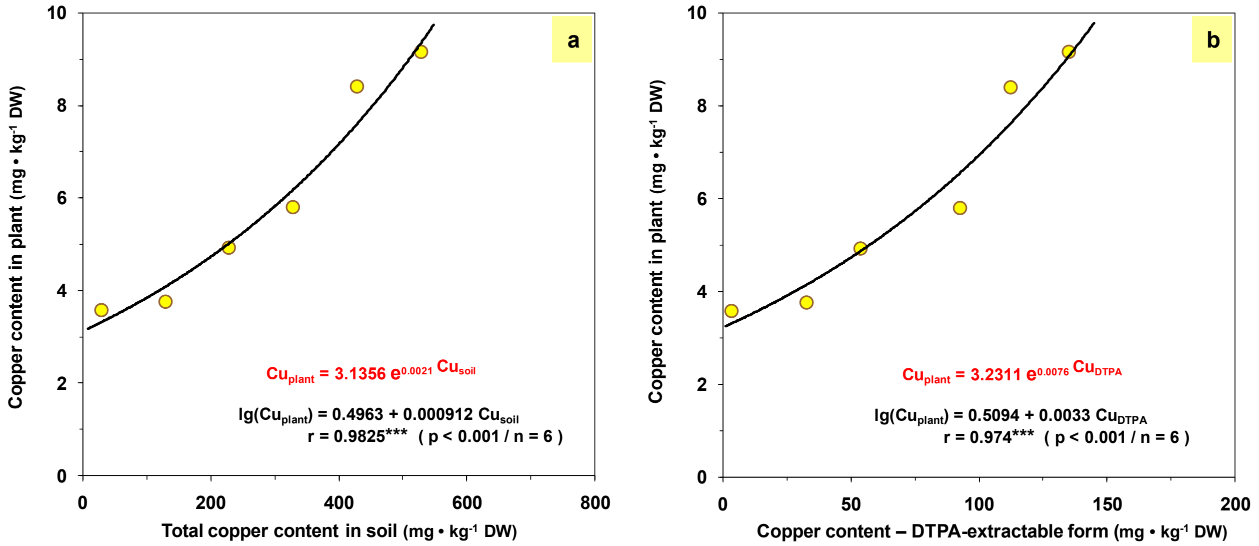

Figure 4. Exponential regression curves that estimate the stochastic dependency between the total copper content in soil (a), the soil copper content – DTPA-extractable form (b) and the copper content in the *Dactylis glomerata* L. plants.

CONCLUSIONS

This study shows the potential for accumulation of heavy metals (Cd, Pb, Zn and Cu) from soil in *Dactylis glomerata* L. plants. The soil material used for the greenhouse experiments is a fine-textured soil with a weak alkaline reaction and an average supply of nutrients. In terms of heavy metals, it falls within the normal limits according to Order 756/1997 on the assessment of environmental pollution. The results of the greenhouse experiments show a close correlation between the total and mobile content of heavy metals (Cd, Pb, Zn and Cu) in the soil and in the plant. There is a close relationship between the increase in the solubility of metals in the soil material and the applied doses.

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