Natural soil amendments – Impact on the uptake of toxic elements in arugula (*Eruca sativa*) and lettuce (*Lactuca sativa*)

Oana Cadar[1*], Eniko Kovacs[1], Marin Șenilă[1], Claudiu Tănăselia[1], Anamaria Iulia Torok[1], Marius Roman[1], Vanessa Fierro[2]

[1] *INCDO INOE 2000, Research Institute for Analytical Instrumentation Subsidiary, 400293 Cluj-Napoca, Romania, oana.cadar@icia.ro*

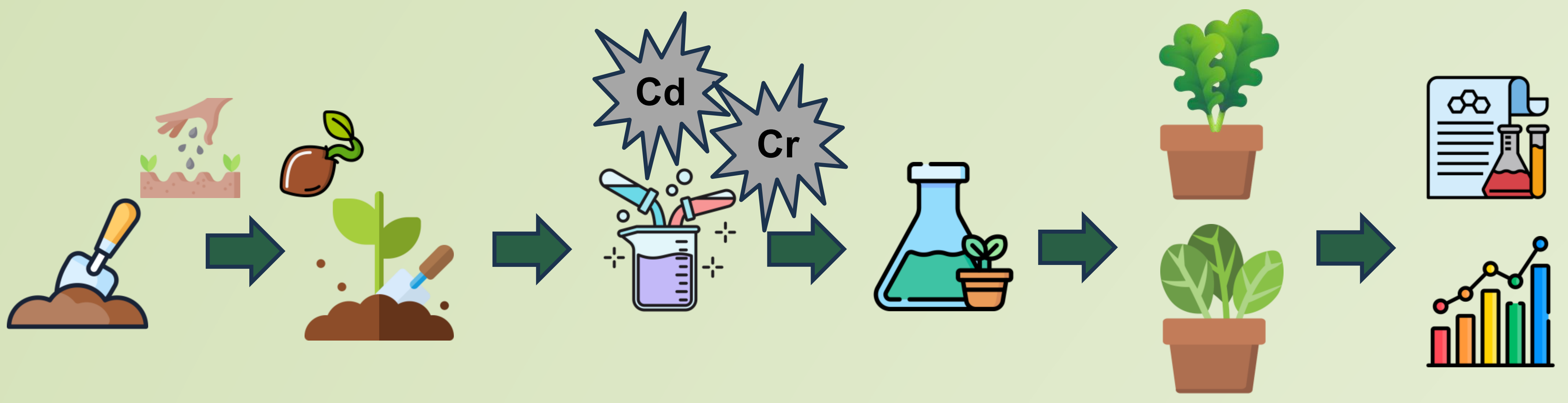
[2] *CNRS-Centre National de la Recherche Scientifique, Université de Lorraine- IJL, 88000 Epinal, France*

INTRODUCTION

- Soil contamination by toxic elements represents a significant global environmental challenge with serious implications for ecosystem integrity and human health. Current estimates indicate that more than 20 million hectares of land worldwide are affected by such pollution [1].
- Natural soil amendments, such as agricultural by-products, organic waste, biochar, zeolites, compost, and clay minerals, have emerged as promising strategies for improving the physicochemical properties and fertility of contaminated soils. These materials can supply essential nutrients while simultaneously reducing the bioavailability of toxic elements, thereby enhancing plant growth and overall soil quality.
- Activated carbon has gained considerable attention due to its high surface area, porosity, and strong adsorption capacity, making it effective for immobilizing toxic elements. Additionally, activated carbon also improves nutrient retention, water-holding capacity, and soil aeration, which collectively contribute to better crop nutrition and soil health [2].
- Similarly, natural and modified zeolites, owing to their widespread availability, low cost, and environmental compatibility, have been widely studied as amendments for remediating contaminated soils. Their effectiveness is primarily attributed to mechanisms such as ion exchange, adsorption, and precipitation, which reduce the mobility and bioavailability of heavy metals and metalloids [3].
- This study evaluates the effect of wood-based activated carbon, natural zeolites, and their combined application on the growth of arugula (*Eruca sativa*) and lettuce (*Lactuca sativa*) under Cd and Cr stress. It specifically investigates the efficacy of these amendments in reducing Cd and Cr concentrations in artificially contaminated soils and examines their influence on the uptake and accumulation of these toxic elements in plant tissues.

EXPERIMENTAL PART

- A pot experiment was conducted to investigate the effects of wood-based activated carbon and natural zeolites on the growth of arugula (*Eruca sativa*) and lettuce (*Lactuca sativa*), as well as bioavailability of Cd and Cr in soils artificially contaminated at a concentration of 10 mg/kg $CdSO_4$ and $Cr(NO_3)_3$. The experiment was carried out without the addition of NPK fertilizers.
- The experimental treatments included toxic element-contaminated soil amended with wood-based activated carbon and/ or natural zeolites at the following application rates (w/w): 0% (control-**C0**), 0% (contaminated control-**CC0**), 2% activated carbon (**AC2**), 2% natural zeolite (**NZ2**), and a combined treatment of activated carbon 2% and natural zeolite 2% (**AC2NZ2**).
- The experiment was conducted in plastic pots filled with the prepared soil mixtures, which served as substrates for the transplantation of 15-day-old arugula and lettuce seedlings.
- Soil preparation, analytical procedures, pot setup, and plant sampling and analysis were conducted according to the methodology described in a previous study [3].



- **Physico-chemical characteristics of pre-experimental, uncontaminated soil**

Sample	pH	C_T	N_T	Humic acids	Cd_T	Cr_T	CEC	Surface area
	-	%	%	%	mg/kg	mg/kg	meq/100 g	m^2/g
Soil	8.61	2.91	1.24	1.64	0.09	0.21	63.1	321

- **Textural parameters of wood-based activated carbon (France)**

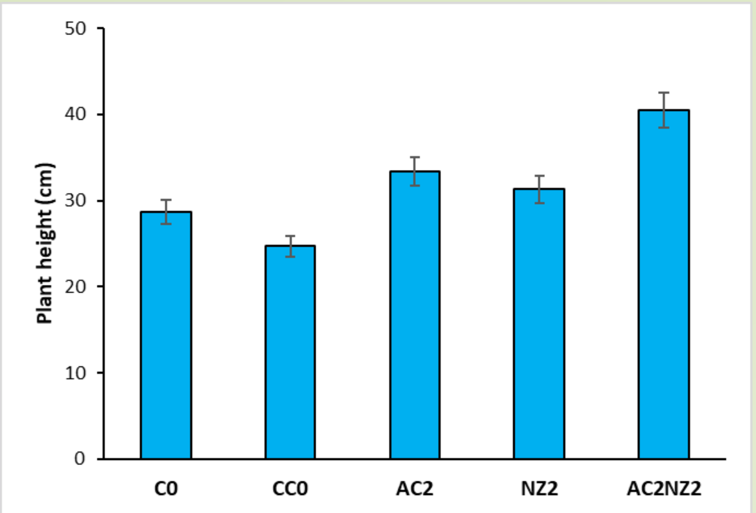
Sample	Specific surface area		Pore volumes					
	A_{BET}	$S_{2D\text{-}NLDFT}$	$V_{0.95}$	V_t	V_{micro}	$V_{s\mu}$	$V_{u\mu}$	V_{meso}
	m^2/g	m^2/g	cm^3/g	cm^3/g	cm^3/g	cm^3/g	cm^3/g	cm^3/g
AC	931	1215	0.51	0.52	0.36	0.17	0.20	0.16

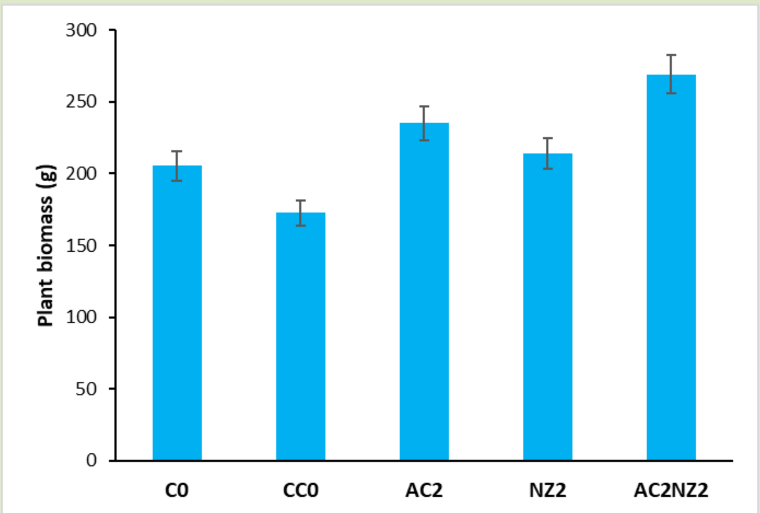
- **Physico-chemical characteristics of natural zeolite (Romania)**

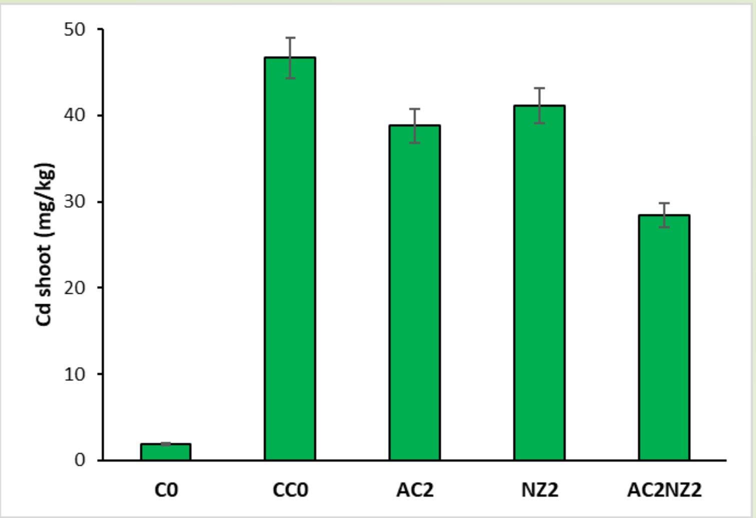
Sample	Na_2O	K_2O	CaO	MgO	SiO_2	Al_2O_3	Fe_2O_3	MnO
	%	%	%	%	%	%	%	%
Natural zeolite	1.68	1.72	3.87	0.54	69.63	13.41	1.42	0.03
Sample	**LOI**	**pH**	**Cd**	**Cr**	**CEC**	**C_T**	**N_T**	**SSA**
	%	-	mg/kg	mg/kg	meq/100g	%	%	m^2/g
Natural zeolite	7.39	9.47	0.14	3.98	141	<0.01	<0.01	70

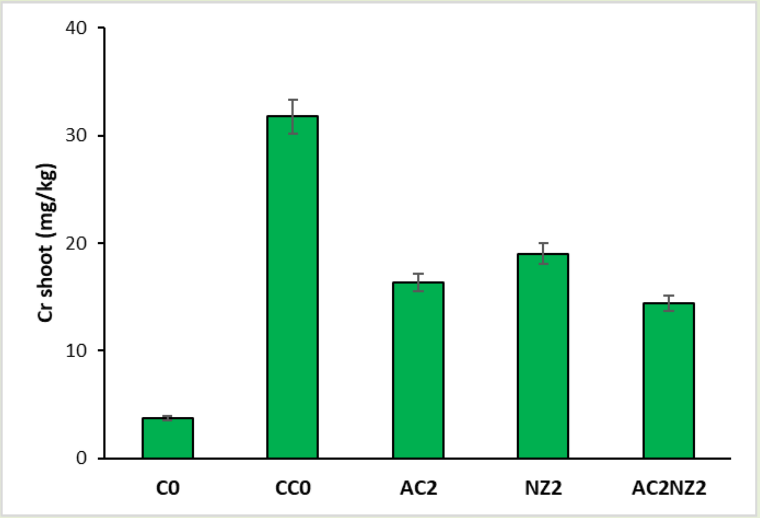
RESULTS and DISCUSSION

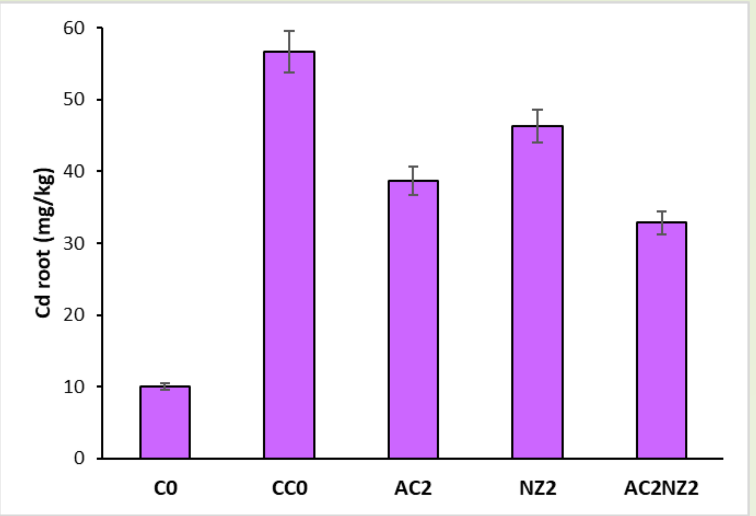
- The use of a **zeolite-activated carbon composite** as a soil amendment has proven to be an effective strategy for improving soil quality and promoting plant growth in soils contaminated with toxic elements.
- This treatment yielded the most significant improvements in plant performance, with increases of approximately 40% in plant height and 36% in fresh biomass.
- Furthermore, the soil amendment significantly reduced the toxic element accumulation, decreasing shoot concentrations of Cd and Cr by approximately 33% and 50%, respectively, and root concentrations by about 40% for Cd and 45% for Cr.
- In addition to its immobilization capacity, the composite amendment enhanced photosynthetic pigment levels, including chlorophyll and carotenoids, indicating a positive impact on plant physiological function.
- These findings highlight the potential of zeolite–activated carbon composites in mitigating toxic elements stress and restoring soil-plant systems in contaminated environments.

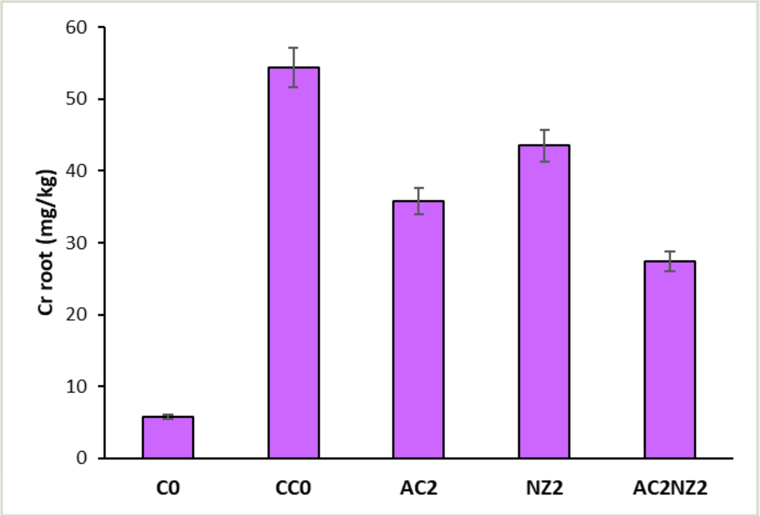












CONCLUSIONS

- The application of **zeolite-activated carbon composite** (**AC2NZ2**) has demonstrated effectiveness in improving soil quality and promoting plant growth in contaminated soils.
- In particular, the synergistic action of activated carbon and natural zeolites contributes to the immobilization of toxic elements, while simultaneously improving soil nutrient availability and increasing plant chlorophyll content.
- Despite these beneficial outcomes, the environmental and agronomic risks associated with the amendment, particularly concerning its application rate and timing, require careful optimization. Therefore, further research is essential to determine the optimal dosage and application strategies zeolite-activated carbon composites and, as well as to evaluate its long-term impact on soil health and crop performance under toxic element stress.

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