Utilization of hemp (*Cannabis* sativa L.) in a circular economy model: investigating the use of hemp for phytoremediation of Pb-contaminated soils and bioenergy production.

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In line with the pace of development of the modern world, the amount of waste produced is constantly increasing at global level, resulting in the gradual pollution of ecosystems with a multitude of organic chemicals and inorganic substances which under normal conditions are not present in the natural environment. Potential Toxic Elements (PTE's) such as Cd, Pb, Cu, Zn etc. are increasingly found in high concentrations in soils, posing significant risks to the environment and human health (Golia et al., 2021). The removal of these metals is considered essential for the decontamination of soils. An alternative, cost-effective and environmentally friendly solution for the remediation of these soils is phytoremediation (Quagliata et al., 2021). It is a biological restoration, based on the utilization of special plants, in order to sequester soil pollutants via their root system and effectively remove them from the soil (Golia et al., 2023).

Industrial hemp (*Cannabis sativa* L.) presents highly favorable prospects as a phytoremediator, as it has deep roots and is tolerant to the accumulation of different metals and metalloids (Placido and Lee, 2022). Additionally, in contrast to the most plants used in bioremediation, hemp offers the potential to contribute towards a circular economy model with biproducts of yield and dead biomass being able to be used to produce various substitutes or alternative sources for the production of daily domestic or industrial products (Golia et al., 2023). However, despite its considerable potential, hemp remains an underutilized resource in a circular economy model framework.

In this work, hemp (*Cannabis sativa* L.) was investigated as a potential phytoremediation species and its produced biomass after the harvest was tested for bioenergy production. For this purpose, a pot experiment was conducted under Mediterranean environment, with soil obtained from the Elgo Dimitra Farm, northern Greece. The soil sample was subjected to contamination by the addition of appropriate calculated volumes of Pb solutions. Specifically, aqueous solutions of $Pb(NO_3)_2$ were prepared and added to the soils so that the final Pb concentration in the soils appeared at three levels (Control, A and B), respectively polluted with 0, 150 and 300 mg Pb kg^{-1}. Afterwards, incubation followed in plastic bags for two weeks with mixing at regular intervals to achieve absolute homogenization. The moisture content of each pot was also maintained at 70% by weighing the pots twice a week to compensate for evapotranspiration losses. After the incubation period the contaminated soil was placed in pots and sowing was carried out with the variety Felina 32. In each case, there were ten replicates. The plants were harvested 3 months after their establishment in the pots.

At the end of the experiment, plant growth (height, and aerial and root dry biomass) was measured and then the plants were collected and divided into the following parts: underground (roots) and above ground (stems and leaves). After the completion of the aforementioned experimental procedure, Pb concentrations were measured with Aqua Regia method in the different plant tissues of hemp and the capacity of the polluted biomass to produce bioenergy (J $g^{-1}_{dry\ biomass}$) was determined by an oxygen bomb calorimeter (IKA C 6000). The soil samples used in the pot experiments were air-dried and sieved from 2 mm and submitted to various physicochemical analyses. They were analyzed using methods described in Golia et al. (2021) for the estimation of soil pH values, Electrical Conductivity (EC), particle size distribution, organic carbon and $CaCO_3$. Available and pseudo-total concentrations of Pb were measured by DTPA extraction and Aqua Regia method, respectively, and determined by Atomic Absorption Spectrophotometry (AAS), using flame (F-AAS) or the graphite furnace (GF) technique.

In Figure 1, the pseudo-total and available concentration of Pb in soil treatments and Pb concentrations in the different plant tissues (above ground and underground part of plant) of *C. sativa* are presented. In both soil and plant samples, Pb extracted concentrations were not detected at $Pb_{control}$ treatment and are therefore not shown in Fig. 1, whereas at Pb_{Alevel} and Pb_{Blevel} were gradually increased. Specifically, the highest Pb concentration was observed in the plant's roots, while a significantly lower concentration was found in the aboveground parts, corroborating the results of comparable studies (Golia et al. 2021, 2023).

The impact of added Pb on the plant growth and the bioenergy production (J g^{-1} dry biomass) was evaluated. Both the dry matter content of leaves, stems, and roots and the bioenergy production seem to have not been adversely affected by the high concentrations of Pb. This finding can likely be attributed to nitrate (N), which was added along with Pb. This is an indication of the fact that Pb toxicity stress was rather masked by the beneficial effect of added nitrate (Hamani et al., 2023). In Figure 2, the results for bioenergy production (J g^{-1}) in its treatment are shown.

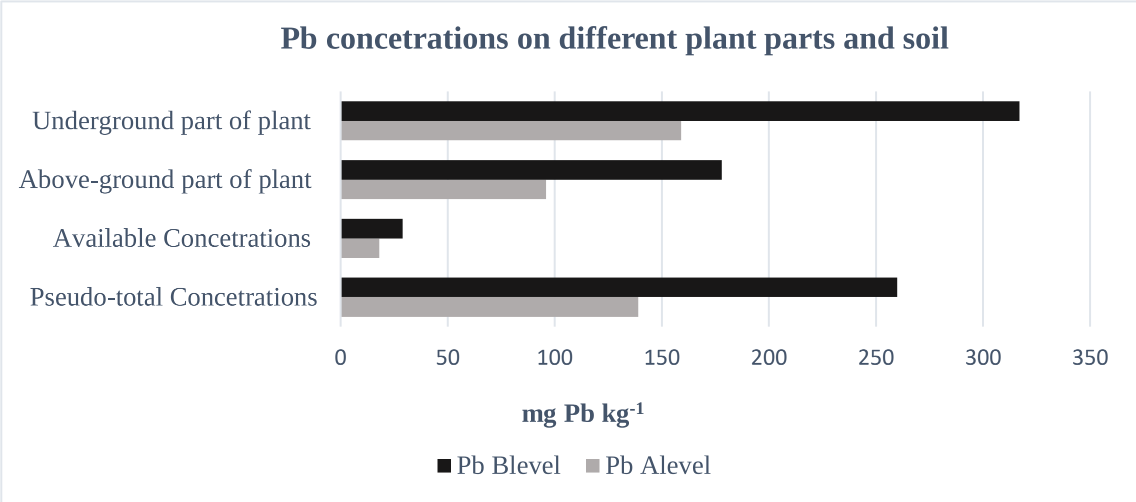

Figure 1. Pb concentrations (mg kg^{-1}) on different plant parts and soil.

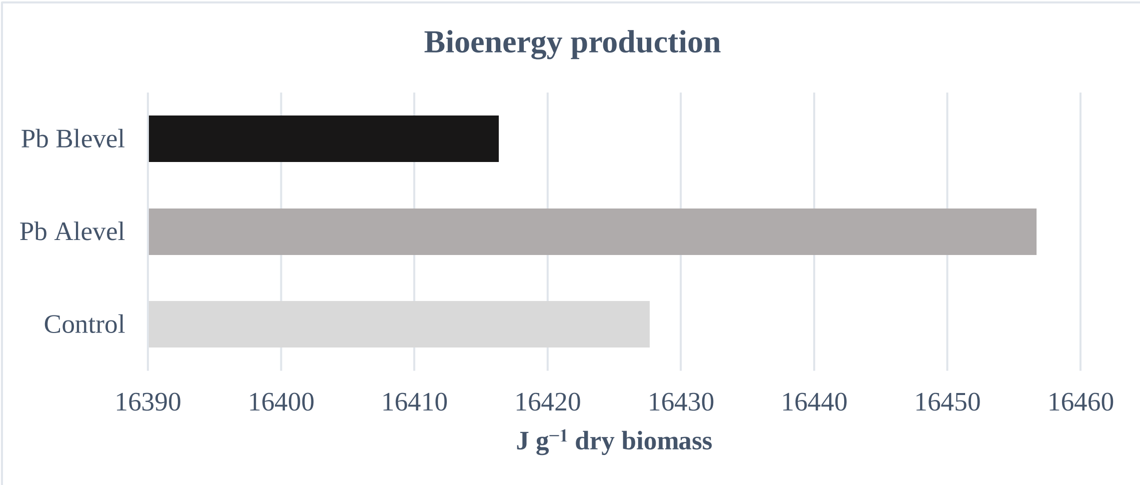

Figure 2. Bioenergy production (J g^{-1} dry biomass) in each treatment

As a promising crop, industrial hemp shows potential for cleansing contaminated soils, primarily accumulating pollutants in its subterranean parts, while its stems and leaves used for the production of high-value products are nearly devoid of pollutants and therefore suitable for utilization in a circular economy model framework.

References:

Golia, E. E., Angelaki, A., Giannoulis, K. D., Skoufogianni, E., Bartzialis, D., Cavalaris, C., & Vleioras, S. (2021). Evaluation of soil properties, irrigation and solid waste application levels on Cu and Zn uptake by industrial hemp.

Quagliata, G., Celletti, S., Coppa, E., Mimmo, T., Cesco, S., & Astolfi, S. (2021). Potential use of copper-contaminated soils for hemp (Cannabis sativa L.) cultivation. Environments, 8(11), 111.

Hamani, A. K. M., Abubakar, S. A., Wang, G., Kama, R., Kurihara, T., Liu, K., Gao, Y., & Duan, A. (2023). Optimized application of combined nitrogen and microbial decomposing inoculants increases wheat (Triticum aestivum L.) physiological growth and mitigates global warming potential under different water regimes. Environmental and Experimental Botany, 206, 105170.

Placido, D. F., & Lee, C. C. (2022). Potential of industrial hemp for phytoremediation of heavy metals. Plants, 11(5), 595.

Golia, E. E., Bethanis, J., Ntinopoulos, N., Kaffe, G. G., Komnou, A. A., & Vasilou, C. (2023). Investigating the potential of heavy metal accumulation from hemp. The use of industrial hemp (Cannabis Sativa L.) for phytoremediation of heavily and moderated polluted soils. Sustainable Chemistry and Pharmacy, 31, 10096.