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Cultivation Of Fiber Crops For Sustainable Soil Remediation And Biobased Raw Material Production For Industrial Uses

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Abstract The contamination of agricultural soils with toxic metals is an escalating issue, posing hazards to both wildlife and human populations across vast land areas. The objective of the FORTE project is to address this issue by cultivating industrial hemp, flax and kenaf on contaminated mining and agricultural lands. This approach serves a dual purpose: (i) remediating the soil and (ii) generating biomass for industrial applications. The project aims to acquire practical knowledge regarding the cultivation of these crops in heavy metal and metalloid contaminated sites, thereby contributing to the development of phytoremediation technology using fiber crops in real field conditions. Additionally, it will foster the generation of innovative materials. An economic analysis, and environmental and social impact assessments will support the sustainability and the optimization of the value chain of produced bioproducts, namely particleboards and insulation panels, and will ensure the implementation of best practices and efficient operations throughout the life cycle of these evaluated products.

Keywords: Phytoremediation, soil pollution, uptake, fiber crops, bioproducts

1. Introduction

Soil serves as an essential medium for the growth of plants, enabling biogeochemical cycles and facilitating the exchanges between plants and natural environment. However, due to anthropogenic activities, significant quantities of contaminants, including heavy metals and metalloids, are deposited in surface soils. Mining areas, in particular, are often recognized as highly contaminated sites with heavy metals, contributing to the soil contamination at about. 34% (Zhou et al., 2023). Heavy metals exhibit high biological toxicity and, unlike organic matter, they persist in the environment (Tchounwou et al., 2012). Additionally, they negatively impact the physical and chemical properties of soil, as well as the growth and physiological characteristics of crops. The contamination of agricultural lands with toxic metals is a significant environmental concern in Europe and globally. Approximately 28% of European soils are reported to be polluted (Toth et al., 2016), while China faces considerable challenges in safeguarding its soil from contamination due to rapid industrialization and urbanization in the past three decades (Zhou et al., 2023). Some of the heavy metal contaminated arable lands are still being farmed (Zhou et al., 2022). The urgent need to address the heavy metal contamination in these agricultural regions is of paramount importance. Undoubtedly, the farmers are unable to relinquish their land. Moreover, in both Greece and China there are several untapped mining sites contaminated with heavy metals and metalloids, which can be utilized to generate supplementary income for farmers and explore fresh business prospects.

As part of the FORTE project, the efficacy and application of phytoremediation are being examined and enhanced for contaminated areas. Flax, industrial hemp and kenaf are fiber crops classified in the families of Linaceae, Cannabaceae and Malvaceae respectively. Furthermore, these crops are recognized for their potential in phytoremediation and for their multiple uses and industrial applications.

The main goal of the FORTE project is to grow these three fast- growing fiber crops on contaminated mining and agricultural lands. The project aims to achieve two objectives: remediating the soil and producing biomass for industrial purposes. For this specific study, the focus will be on presenting the results obtained from the Lavrion site in Greece.

2. Materials & Methods

2.1. Soil sampling and characterization

The experiment took place in a field (0.5 ha) situated in Lavreotiki peninsula, 60 km SE from Athens. Soil samples from ten distinct points were collected from the field, air-dried and sieved through a 2-cm sieve. Standard procedures outlined in the FAO soil protocol (Motsara et al., 2008) were followed to determine the selected soil properties. Table 1, displays the range values observed among the sampling points.

Table 1. Physical and chemical properties of the soil.

Physical	
Clay (%)	22-35
Silt (%)	25-34
Sand (%)	31-53
Texture	CL
Conductivity (μS/cm)	109-264
Chemical	

pH	7.8-8.2
Organic matter (%)	1.57-3.73
Equal carbonate (%)	11.76-15.56
Total Nitrogen (g/kg)	0.10-0.22
Available P_2O_5(g/kg)	7.5-16.9

Heavy metals and metalloids in soil were determined using *aqua regia* digestion and quantified by an ICP-OS. The findings showed that the soil contamination with heavy metals was up to: Cd (25 mg/kg), Pb (10797.7 mg/kg), Zn (4958.5 mg/kg), Ni (172.1 mg/kg), Cu (138.0 mg/kg), and with metalloids up to: As (590.0 mg/kg), and Sb (92.0 mg/kg).

2.2. Experimental set-up

A field experiment spanning three years (2021-present) was conducted in Greece, and two experimental fields were established: one in the heavily contaminated multi-metal site in Lavrion, Attica, and another in a non-contaminated control site in Aliartos, Boeotia. Each crop was subjected to testing using two different varieties, all of which are specifically cultivated for fiber production, along with three irrigation doses (I0: 108.6 mm-precipitation only, I1: 50% of ET- 421.1 mm, I2: 100% of ET- 733.5mm) and three fertilization levels (N0: no urea addition, N1:30 kg urea /ha, N2: 60 kg urea/ha). The influence of mycorrhizal fungi (M) was also investigated. Given that flax is a winter crop, irrigation was not utilized as a factor during its cultivation. The varieties that were tested for each crop are shown in Table 2. At the time of harvest, various parameters, such as plant height and dry weights, as well as the concentrations of heavy metals and metalloids in the above- ground biomasses were determined.

Table 2. Tested varieties per crop

	Flax	Ind. Hemp	Kenaf
Var.1	Calista	Futura 83	HC3
Var.2	Jan	Futura 75	HC95

3. Results

Calista for flax, Futura 83 for industrial hemp and HC3 for kenaf exhibited superior performance not only in the control field but also in the contaminated field. These three crops, demonstrated increased effectiveness in yield production, when higher doses of water and fertilization were applied. However, the presence of heavy metals and metalloids in the soil had a detrimental effect on the plants, leading to inhibited growth when compared to the plants in control field. As a result, there was a notable decline in biomass production. The determined biomass yields and reductions for flax, industrial hemp and kenaf can be found in Table 3.

Table 3. Best biomass yields, corresponding treatments and reductions in tested crops at Alliartos and Lavreotiki.

Location	Plant	Treatment	Yield (tn/ha)	Reduction (%)
Alliartos	Flax	N1 &M	5.77	8.5
Lavrio	Flax	N1	5.28	
Alliartos	Ind.hemp	I1&N2	24.2	84.3
Lavrio	Ind.hemp	I2&N2	3.80	
Alliartos	Kenaf	I2&N2	32.23	59.2
Lavrio	Kenaf	I2&N2	13.16	

According to the data presented in Fig. 1, in the aerial biomass of industrial hemp higher concentrations of Ni, Cu, Pb and Sb were determined. Kenaf exhibits higher concentrations of heavy metals in the cases of Cd and Zn. Conversely, flax demonstrates the lowest levels of contaminants concentrations among the three crops.

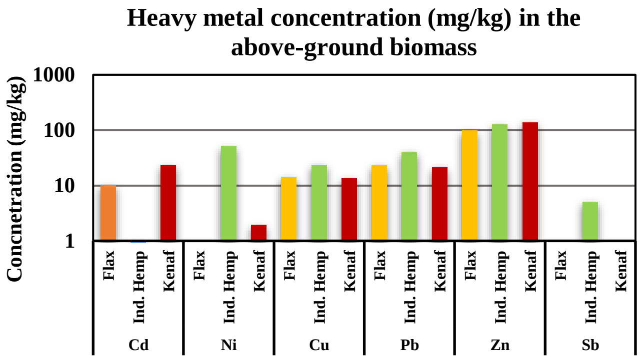

Figure 1. Heavy metal concnetration (mg/kg) in flax, industrial hemp and kenaf.

More specific, industrial hemp exhibited contaminant concentrations up to 0.12 mg/kg for Cd, 51.85 mg/kg for Ni, 23.78 for Cu, 39.93 mg/kg for Pb, 127.23 mg/kg for Zn and 5.04mg/kg for Sb. In kenaf, the measured concentrations in the above- ground biomass were up to 23.58 mg/kg for Cd, 1.94 mg/kg for Ni, 13.58 mg/kg for Cu, 21.19 mg/kg for Pb and 137.96 mg/kg for Zn, while Sb was below the detection limit. In the case of flax, the corresponding concentrations in the aerial biomass reached up to 10.09 mg/kg for Cd, 14.38 mg/kg for Cu, 23.22 mg/kg for Pb, and 99.08 mg/kg for Zn, with Ni and Sb levels below the detection limit.

In summary of the project's findings, at the Alliartos site, the most effective treatment combinations were identified as N1&M for flax, I1&N2 for industrial hemp, and I2&N2 for kenaf. Meanwhile, at the Lavrion site, the optimal treatment combination for industrial hemp and kenaf was determined to be I2&N2, while N1 was found to be the best treatment for flax. In terms of soil contaminant release, the order of uptake for Cd and Zn was kenaf> flax> ind. hemp, while for Pb and Cu, it was kenaf> ind. hemp> flax. Higher levels of Ni and Sb were observed in industrial hemp, followed by kenaf and flax.

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