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Original Article

ENHANCEMENT OF KENAF PLANT (*Hibiscus cannabinus* L.) TO UPTAKE HEAVY METALS THROUGH SOIL AMENDMENT WITH BIOCHAR AND MULCHING

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ABSTRACT

Environmental pollution (soil, water, and air) is a growing global concern with serious public health impacts, motivating the development of effective mitigation strategies. This study evaluated soil amendment and phytoremediation by cultivating kenaf (*Hibiscus cannabinus* L.) with biochar and wheat straw mulch. Field experiments were conducted at two sites in Erbil Governorate (Grdarasha and Gwer), where soils may be contaminated by industrial and agricultural activities. The objectives were to assess pollution levels at both locations, determine how to reduce heavy-metal concentrations in soil, and examine whether biochar and mulch enhance kenaf uptake of heavy metals. At Grdarasha, the control treatment showed the highest leaf accumulation of Pb, Cu, Ni, and Cr (0.07, 0.07, 0.09, and 0.05), ppm respectively, supporting kenaf's phytoremediation potential. At Gwer, applying 150 g/m^2 biochar without mulching produced the highest leaf accumulation of Cu, Ni, Cr, and Fe (0.06, 0.08, 0.03, and 4.50), ppm respectively. Overall, biochar and wheat straw mulch reduced soil heavy metals, likely by chelation and altering metal mobility, while generally improving kenaf's capacity for heavy-metal uptake.

Keywords: Kenaf, Biochar, Mulching, Phytoremediation, Heavy Metals.

1. INTRODUCTION

Kenaf (*Hibiscus cannabinus* L.) is a tall annual dicotyledonous herb that has garnered a significant interest for its prospective applications in various industries, including meals and drinks, medicine, and beauty products, as well as its financial and agronomic significance (Vayabari et al., 2023). Kenaf, a warm-weather annual species, is native to tropical Africa and relates to the Malvaceae family (Corinzia et al., 2022). The selection of raw materials for industrial applications is crucial, additionally not only are the fibers valuable as raw materials, but the leaves and seeds also offer various benefits and uses (Salih et al., 2022).

Phytoremediation is a developing technology that uses specially selected metal accumulating plants to clean heavy metals and crude oil contaminated soils (Ahmed & Hussain, 2025; Ashraf et al., 2019). Crops with high biomass production and ability to cultivate under different soil settings having non-food purposes like kenaf could be an environmentally friendly approach to remediate polluted soils owing to its high tolerance to heavy metals and possible for phytoremediation (Chen et al., 2021; Luo et al., 2023; Pan et al., 2023). Kenaf has been utilized for phytoremediation in tropical regions, serving the dual aim of biomass production to augment the ecological and economic value of degraded landscapes (Arbaoui et al., 2013). Biochar is a carbon-Rich product, similar to charcoal material produced as an outcome of the thermal processing (pyrolysis, which occurs at 350–700 °C) of organic substances or biomass in an oxygen-starved or depleted oxygen condition (Basak et al., 2022). It possesses the capacity to enhance soil quality and
agricultural yield (Bolan et al., 2022). Researchers started investigating biochar substances as an effective method for reducing soil pollution (Ibrahim et al., 2022). It aids reduce production cycle, diminished greenhouse gas and ammonia emissions, enhanced nutritional value and humification, and a lesser threat to the environment concerning heavy metals and Antibiotics in comparison with traditional compost usage (Zhou et al., 2023). Biochar is utilized to improve the soil's condition in terms of its physical, chemical, and biological qualities, instead of recovery of polluted ground (Nguyen et al., 2023). Kenaf stem biochar has an effective ability to absorb heavy metals such as Cu and Pb (Choi et al., 2024).

The application of organic mulch is a prevalent technique utilized in gardening, forestry, and agriculture. Organic mulch is characterized as organic material derived from agricultural waste, wood, paper, and animal excrement, utilized as a surface layer over bare soil. Mulching is a significant nature-based method employed to mitigate runoff and erosion. Korkanç and Şahin (2021) reported that mulching can be utilized to regulate soil moisture and temperature, mitigate nutrient loss, and manage salt. Plant cover has historically been regarded as a means to diminish metal bioaccumulation, for instance, by inhibiting metals in soils. There is increasing evidence that mulch may raise the availability and consequently the hazards of some metals in plants (Golia, 2023). The presence of heavy metal (HM) ions in soil poses considerable environmental risks, including contamination of water and soil, ecosystem breakdown, and the accidental discharge of potentially harmful compounds into the surroundings (Li et al., 2023). Extraction methods for copper, zinc, lead, manganese,

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and iron, widely employed in manufacturing, are now recognized as significant drivers to land poisoning (Zheng et al., 2021). Based on specific studies, the accumulation of heavy metals in soil may lead to a decline in soil quality, a reduction in soil fertility and crop production, and potentially pose risks to the health of people and animals (Alengebawy et al., 2021).
This study examines the capacity of the kenaf plant, biochar, and organic mulching to reduce heavy metal accumulation in the soil. It supposed that the application of biochar and wheat straw mulch at varying rates will affect plant development and the sorption capacity of heavy metals in the soil. It also hypothesizes that kenaf plant has ability in mitigating heavy metal contamination in soil.

2. MATERIALS AND METHODS

Study Site:

The experiment was conducted simultaneously at two distinct sites: Grdarasha Research Station, affiliated with the Department of Field Crops and Medicinal Plants, College of Agricultural Engineering Sciences, Salahaddin University-Erbil, located in the Erbil governorate, Kurdistan/Iraq (Latitude 36° 00’ 16” N and Longitude 44° 01’ 24” E). The alternate location was Shamamar (Gwer Road) field in the Erbil governorate (Latitude 36° 07’ 47” N, Longitude 43° 42’ 33” E). Figure 1 illustrates the location of the Grdarasha and Gwer fields.

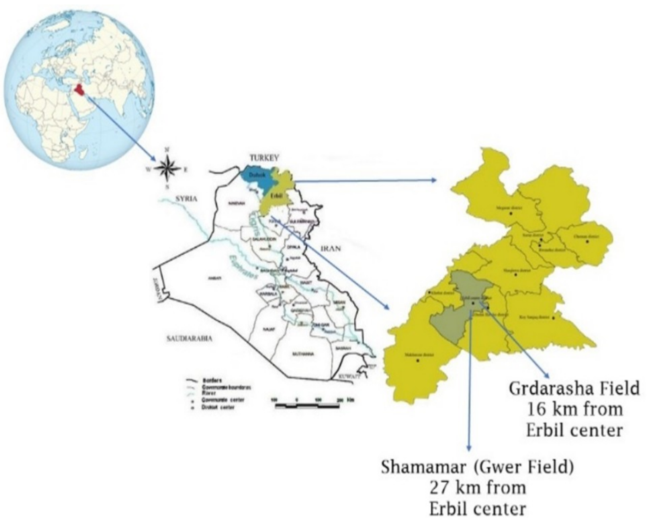

Figure 1: The location of Grdarasha and Gwer fields in Erbil Governorate, Kurdistan, Iraq.

Experimental Design:

A Factorial Randomized Complete Block Design (RCBD) with three replicates was applied in both study sites. Each field were divided to 27 plots on 3 various replications by 9 treatments. The first factor was Kenaf Stem Biochar (KSB) at the rates of (0, 150 and 300) g plot^{-1}, and the second factor was Wheat Straw Mulch (WSM) at the rates of (0, 200 and 400) g plot^{-1}, which were added to soil surface before cultivating kenaf plant. Each plot was 1 m^2 and total field was 7 m wide and 27 m long. Kenaf seeds (FH 952 var.) were planted in 24th at Grdarasha and 26th May at Gwer. This variety chose due to capability to grow and yield significantly in Erbil city and adapt to climate stress (Salih et al., 2023). Then, each plot was divided to 3 lines that contained 10 small holes to sow 3-5 seeds per hole. The seeds were started to germinate at early June according to the treatments. Then, in early July, first thinning of plants in both fields were done, in which only 10 plants per line was remained to avoid competition to resources. Drip irrigation was practiced in both fields.

Data Collection:

Determination of Heavy Metals in Leaf:

Leaf samples were collected in each plot On December 23rd, 2024. Then, it was air-dried in room temperature, next which was grind to make leaf powder. After that, 50 grams of leaf sample (powder) from each experimental unit were stored in a small bag. In March, each of Lead (Pb), Mercury (Hg), Cadmium (Cd), Chromium (Cr), Cobalt (Co), Copper (Cu), Nickle (Ni), Arsenic (As), Zinc (Zn) And Iron (Fe) heavy metals were determined in the Agricultural Testing Laboratory/ Duhok city.

Determination of Heavy Metals in Soil:

During field preparation, the soil sample was taken, which was only pure soil without treatment or planting named as (Base) to be used as a source of original field soil and comparing with other samples to detect the changes. after harvesting on December 26th, 2024, other 500 g samples were taken in each plot from the depth of (15-30 cm) according to (Shaheen & Iqbal, 2018). because it balances representing historical, long-term pollution and avoiding surface-level irregularities. Then, graded and stored in bags, to estimate the same elements estimated in leaves.

Soil Analysis:

Chemical and physical properties of the soil were taken from both study sites (Grdarasha and Gwer). The first soil samples were taken randomly from several places in the farm before it was divided into plot treatments in the soil depth (0-30 cm). while other soil samples were collected from the plot treatments (biochar, wheat straw mulch and interactions), which were done after harvesting the plants. Then, the samples were air- dried and sieved through a (2 mm) pore size sieve. Finally, physicochemical parameters and heavy metals (HMs) were determined in the Agricultural Testing Laboratory/ Duhok city. It is necessary to give the detail of the procedure for determination of heavy metals in soil samples and kenaf plant leaf which was (ICP-Thermo Fisher model (iCAP-7000 plus series ICP-OES atomic emission spectrometer) according to (Baika et al., 2016). Also, physiochemical tests of soil detected in same laboratory by specific methods for each of them. For example Available Nitrogen (N) was determined by extracting the soil samples with KCl 2M using micro-Kjeldahl method according to (Mukherjee et al., 2025). Available Phosphorous (P) determined at (882 nm) using a spectrophotometer equipment, (EMC-LAB Germany v-1100 DIGITAL) using ascorbic acid methods as mentioned by (Olsen & Sommers, 1982). And soil PH determined by pH meter with combined electrode, standard buffers. Soil electrical conductivity (EC) was determined in a soil-water extract using a conductivity meter calibrated with standard EC solutions. Exchangeable potassium (K) was extracted with 1 M ammonium acetate and measured using a flame photometer (or atomic absorption spectrophotometer). as described by (Estefan et al., 2013). Calcium Carbonate ($CaCO_3$)% determined by The calcimine method was used in determination the percentage of CaCO3 in the soil using HCl 1N as explained by (Loeppert & Suarez, 1996). Soil Organic matter was determined by the Walkly and Black method through oxidizing organic carbon using $K_2Cr_2O_7$ (1N) and titrated the excess Cr_2O_7 with $FeSO_4$ according to (Sisay & Feleke, 2024). Cation Exchange Capacity (CEC) The cations exchange capacity was determined using sodium acetate (1N) and ammonium acetate (1N) according to (Silva et al., 2010). Soil Bulk Density was determined using core method according to (Jabro et al., 2020). Also, soil texture test have been done in Hydrometer Method (Beretta et al., 2014). Table 1 shows several physical and chemical soil characteristics at both study sites. While, heavy metals were shown in the table 4 in the section of results and discussion.

Table 1: Several physical and chemical tests of soil at Grdarasha and Gwer Fields.

Parameters	**Grdarasha Field**	**Gwer Field**
Chemical properties		
Nitrogen (mg Kg^{-1})	72	70
Phosphorous (mg Kg^{-1})	5.12	5.67
Potassium (mg Kg^{-1})	15.2	17.89
$CaCO_3$ (%)	15.7	15.4
Organic matter (%)	1.73	2.12
pH	8.04	7.78
Physical properties		
Bulk density (g/cm^3)	1.03	0.98
EC (dS m^{-1})	0.19	0.95
CEC (meq $100g^{-1}$ soil)	22.39	15.72
Soil texture	**Silty clay loam**	**Silty loam**
Sand (%)	16.28	18.78
Silt (%)	49.24	64.24
Clay (%)	34.47	16.97

Data Analysis:

Analysis of data were done by Analysis of Variance (ANOVA) by using SPSS Statistics (IBM SPSS Statistics 21). Least Significant Difference (LSD) at $P \leq 0.05$ was used to perform the mean comparison.

3. RESULT AND DISCUSSION

Effect of Biochar and Wheat Straw Mulch on Heavy Metals Uptake by Kenaf Leaves:

Results in table 2 shows that applying biochar has adverse effect on heavy metal accumulation in leaf only, in which in some cases it causes non-significant rise of heavy metals like (Co and As) by (0.019 and 0.010), at (B1 and B2), respectively. Additionally, Fe increased significantly to (2.527), when biochar was added at the level (B1). Biochar consistently diminished the average amounts of heavy metals in plant tissue relative to plants cultivated in soils devoid of biochar (Chen et al., 2018). Biochar can sequester heavy metals by adsorption and ion exchange, rendering it a promising, cost-effective, and sustainable material for the remediation of contaminants in water and soil (Wang et al., 2022). On the other hand, the effects of wheat straw mulch were more and opposite to biochar, though any significant was not found between treatments. Although the differences were not statistically significant, numerical increases in heavy metal accumulation were observed under straw mulch treatments.

Table 2: Table 2: Effects of biochar and wheat straw mulch on heavy metal accumulation in leaves at Grdarasha Field.

Treatments	**Pb (ppm)**	**Hg (ppm)**	**Cr (ppm)**	**Co (ppm)**	**Cu (ppm)**	**Ni (ppm)**	**As (ppm)**	**Zn (ppm)**	**Fe (ppm)**
Biochar (B) (g/m^2)									
B0	0.058^{a}	0.030^{a}	0.028^{a}	0.011^{a}	0.059^{a}	0.063^{a}	0.007^{a}	0.178^{a}	1.550^{b}
B150	0.056^{ab}	0.026^{ab}	0.022^{ab}	0.019^{a}	0.048^{a}	0.053^{a}	0.009^{a}	0.152^{b}	2.527^{a}
B300	0.043^{b}	0.019^{b}	0.016^{b}	0.008^{a}	0.047^{a}	0.047^{a}	0.010^{a}	0.148^{b}	1.657^{b}
Wheat straw mulch (M) (g/m^2)									
M0	0.049^{a}	0.024^{a}	0.028^{a}	0.014^{a}	0.052^{a}	0.060^{a}	0.009^{a}	0.151^{a}	1.557^{a}
M200	0.050^{a}	0.026^{a}	0.020^{a}	0.014^{a}	0.053^{a}	0.056^{a}	0.007^{a}	0.158^{a}	2.346^{a}
M400	0.058^{a}	0.024^{a}	0.018^{a}	0.009^{a}	0.048^{a}	0.048^{a}	0.010^{a}	0.169^{a}	1.833^{a}

Means followed by the same letter for each factor separately within columns are not significant different at ≤ 0.05 according to the least significant differences (LSD).

Table 3 shows the effects of biochar and straw wheat mulch on (HMs) in leaf detected in Gwer Field. Although the effects were not statistically significant but according to those data the effect of B1 on Cr, Co, Cu, Ni, Zn and Fe have higher concentrations were consistently observed compared with the other treatments, suggesting a possible tendency of biochar to influence heavy metal accumulation in kenaf leaves. Whereas, B2 has affected Pb. Unlike biochar, which showed relatively consistent numerical increases for some elements, straw mulch treatments exhibited inconsistent and mostly non-significant variations in heavy metal concentrations. Straw has long been believed to reduce metal bioaccumulation by immobilizing metals in soils. Nonetheless, there is increasing evidence that straw return may potentially augment bioavailability and hence elevate the dangers (i.e., food safety) of some metals in crops (Su et al., 2021). Through, this and many recent researches, show that straw mulch in some cases causes capturing HMs in it according to its composition stage, metal types and soil properties. Also sometimes encourage metal accumulation in plant. Generally, the results from this present study may belongs to the difference in physical and chemical characteristics between the two studied sites (Table 1).

Table 3: Table 3: Effects of biochar and wheat straw mulch on heavy metal accumulation in leaves in Gwer Field.

Treatments	**Pb (ppm)**	**Hg (ppm)**	**Cr (ppm)**	**Co (ppm)**	**Cu (ppm)**	**Ni (ppm)**	**As (ppm)**	**Zn (ppm)**	**Fe (ppm)**
Biochar (B) (g/m^2)									
B0	0.013^{a}	0.030^{a}	0.014^{a}	0.002^{a}	0.040^{a}	0.036^{a}	0.010^{a}	0.108^{a}	1.134^{a}
B150	0.013^{a}	0.024^{b}	0.017^{a}	0.006^{a}	0.049^{a}	0.052^{a}	0.007^{b}	0.139^{a}	2.211^{a}
B300	0.016^{a}	0.030^{a}	0.012^{a}	0.001^{a}	0.040^{a}	0.044^{a}	0.010^{a}	0.103^{a}	1.246^{a}
Wheat straw mulch (M) (g/m^2)									
M0	0.017^{a}	0.030^{a}	0.018^{a}	0.006^{a}	0.048^{a}	0.052^{a}	0.010^{a}	0.114^{a}	2.296^{a}
M200	0.011^{b}	0.024^{b}	0.011^{a}	0.002^{a}	0.040^{a}	0.040^{a}	0.010^{a}	0.112^{a}	1.092^{b}
M400	0.014^{ab}	0.030^{a}	0.014^{a}	0.001^{a}	0.041^{a}	0.040^{a}	0.007^{b}	0.123^{a}	1.203^{b}

Means followed by the same letter for each factor separately within columns are not significant different at ≤ 0.05 according to the least significant differences (LSD).

Effect of Interaction of Biochar and Wheat Straw Mulch on Heavy Metals Uptake by Leaves:

The interaction effect of biochar and wheat straw mulch on HMs accumulation in kenaf leaves is shown in (Figure 2). It clarifies that interaction between both factors; biochar and wheat straw mulch, were significantly affected HMs rates in leaf from both locations. Focusing on the B0M0 and B1M2 treatments, Pb accumulation in kenaf leaves at the Grdarasha field reached the highest values (approximately 0.07 ppm). These treatments were not significantly different from each other ($p > 0.05$), but they showed significantly higher Pb accumulation compared with the B2M0 treatment. This indicates that kenaf has the potential to accumulate Pb under both untreated conditions and specific biochar– straw mulch combinations. Kenaf could be suggested as a Phyto accumulator for the remediation of soil Pb contamination (Mani et al., 2018). While, the highest amount of Pb accumulation in kenaf leaves was noted in the treatments of (B1M0 and B2M0) by (0.02 ppm) at Gwer field. As the newest research found that corn straw biochar has potential to repair the soil polluted with cadmium and lead (Rehman et al., 2023).

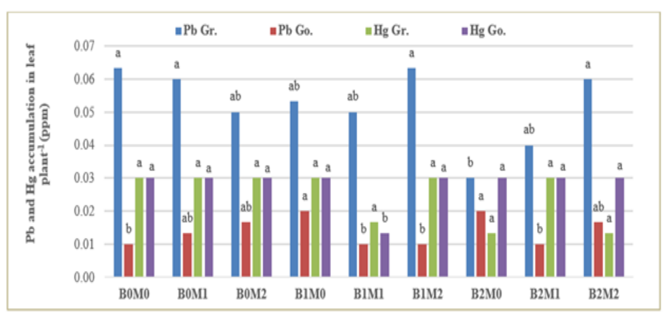

Figure 2: Interaction effects between biochar and wheat straw mulch on accumulation of Pb and Hg in kenaf leaves at Gradarasha and Gwer Fields.

From figure 3, the interaction effect of biochar and wheat straw mulch were detected on Co and Cu accumulation in kenaf leaves. Accumulation of Co was raised non-significantly in the treatment (B1M1) from (0.02 ppm) to (0.03 ppm), in Grdarasha field, while the highest amount was noted in the treatment (B1M0) at Gwer, same as for Cu in the same place, it was increased nearly to (0.07 ppm). As reported in the previous study, the optimal soil pH was the main factor, which was caused to improve soil properties, and then growth parameters in sugarcane at Grdarasha field (Salih & Abdullah, 2025). These results may refer to the pH level since acidic soils (low pH) increase the solubility and mobility of heavy metals (Table 1). The results from this present study, were supported by (Zhang et al., 2023). Acidic soils increase the solubility of heavy metal ions. Despite that, the highest amount of copper (Cu) accumulation in the kenaf leaves at Grdarasha field was found in the control treatment (B0M0) by above of (0.07 ppm). This is evidence of kenaf plant ability to uptake heavy metals from contaminated soils.

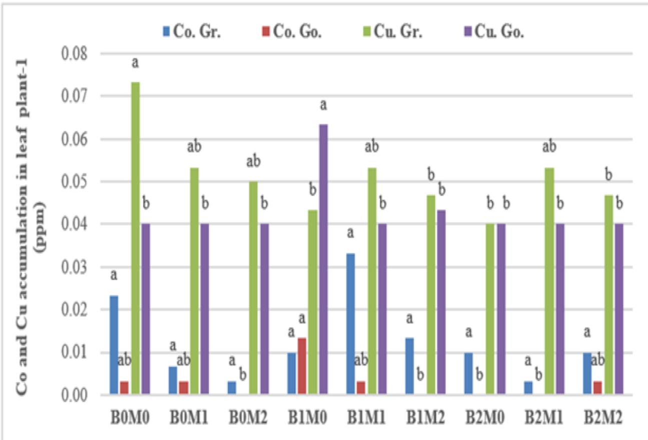

Figure 3: Interaction effects of biochar and wheat straw mulch on accumulation of Co and Cu in kenaf leaves at Gradarasha and Gwer Fields.

Figure 4 presents the interaction effects of biochar and straw mulch on Ni and As accumulation in kenaf leaves at Grdarasha and Gwer fields. kenaf plant had showed ability to uptake HMs like Ni and As, which mean that in the control treatment (B0M0) without biochar and wheat straw mulch. Thus, the biggest value for Ni was more than (0.09 ppm) at Grdarasha. While, the highest amount of Ni at Gwer was noted in the interaction (B1M0), which was almost to (0.08 ppm). This present study confirmed by the result found by (Meera & Agamuthu, 2012), whose stated that kenaf is usefull in removing heavy metals like As from the contaminated soil.

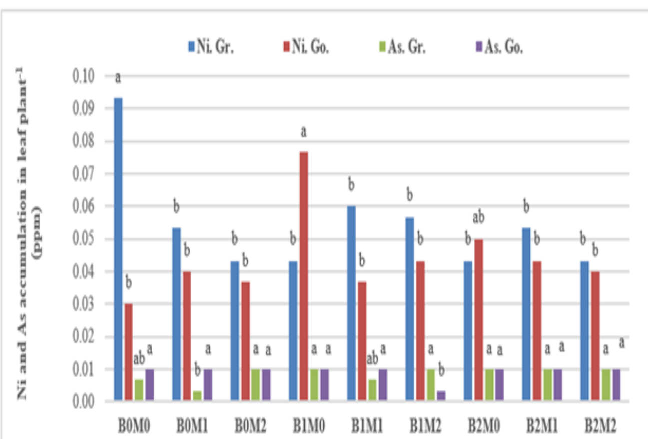

Figure 4: Interaction effects of biochar and wheat straw mulch on accumulation of Ni and As in kenaf leaves at Gradarasha and Gwer Fields.

Figure 5 displays the significant effect between interactions at both locations on Zn and Fe accumulation in kenaf leaves. Zn was increased from (0.07 ppm) in control to (0.18 ppm) in (B1M0) treatment at Gwer field. Whereas, Fe significantly raised from (0.79 ppm) in the control treatment (B0M0) to (3.17 ppm) in the treatment of (B1M1) at Grdarasha field. It was increased significantly from (1.13 ppm) to (4.43 ppm) in the treatments (B0M0 and B1M0), respectively at Gwer field.

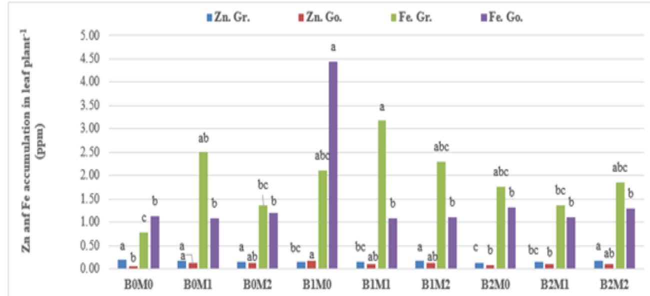

Figure 5: Interaction effects of biochar and wheat straw mulch on accumulation of Zn and Fe in kenaf leaves at Gradarasha and Gwer Fields.

Chromium (Cr) accumulation in kenaf leaves was significantly changed between treatments at both locations. The highest values were (0.05 and 0.03) ppm, respectively in the interaction treatment (B0M0) and (B1M0), at Grdarasha and Gwer field (Figure 6). The finding from the current research was confirmed by previous research carried out by Pan et al. (2025), who is reported that cultivating kenaf plants to absorb chromium and applying kenaf biochar to immobilize the heavy metal. This approach forces kenaf's capability to withstand and accumulate chromium (phytoremediation), while the biochar's had benefit of reducing chromium's availability in the soil by forming complexes and altering soil chemistry.

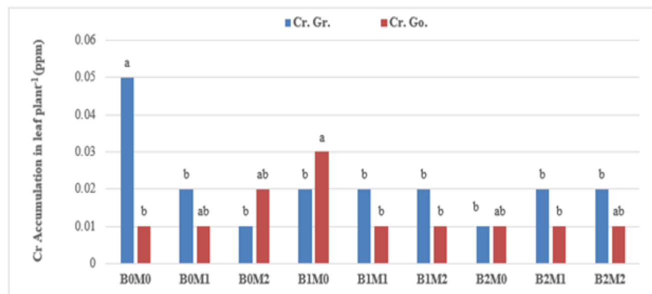

Figure 6: Interaction effects of biochar and wheat straw mulch on accumulation of Cr in kenaf leaves at Gradarasha and Gwer Fields.

Through those data, it could be observed that Gwer field had more HMs pollution. and up taking in some cases from Grdarasha and Gwer. It may have returned to external factors especially in Gwer, for example the pollution of water that used for irrigation and also air pollution due to locating numerous industries such as petroleum field and factors around the region which surely causes to promote CO_2 concentration in air. Münzel et al. (2023) stated that soil contaminants are transported into rivers, resulting in water pollution. Deforestation induces erosion of soil, releases stored contaminants, and produces dust that escapes in air. Air, water, and soil contamination accounts for a minimum of 9 million fatalities yearly. It means that pollution is a circle and can be transferred from one site to another. The increasing concentrations of atmospheric carbon dioxide (CO_2) have emerged as a substantial ecological issue in the past few years (Anwar et al., 2020). The increase in atmospheric CO_2 levels is mostly attributed to the burning of petroleum and gas for power generation, forest loss, and crop production activities (Nunes, 2023). Kenaf thrives in regions with elevated CO_2 levels and increased CO_2 markedly enhances its development and fiber output. Kenaf employs the C3 photosynthetic process, which has a strong responsiveness to elevated CO_2 concentrations (Mahdi et al., 2014). Figure 7 shows the difference between each field in control. It is obvious that image (A) which was related to Grdarasha field, that the plants were weak, thinned stem, pale and less foliated. While, in (B) which related to Gwer field, the plants were vigorous, thick stem, dark green and more foliated that shows better growth through more CO_2 concentration area. This observation agrees with open-field evidence that elevated CO_2 can enhance growth of C3 plants under natural conditions (Ainsworth & Long, 2021).

Figure 7: Difference between kenaf growth in the control treatment (A) at Grdarasha Field; (B) Gwer Field.

Upon that information which detects that kenaf aids to HMs uptake from soil, can also say that biochar and mulch help kenaf to be able for taking up metals well because they promote kenaf to grow much vigorously. Additionally, they reduce pests, enhance soil characteristics, augment biodiversity in soil, suppress weed growth, boost the integrity of the soil, facilitate nutrients in the soil cycling, and conserve humidity in the soil (Akhtar et al., 2023; Shahzadi et al., 2024). On the other hand, the differences can be noticed in biochar or mulch applied plots compared to control plot in (Figure 8).

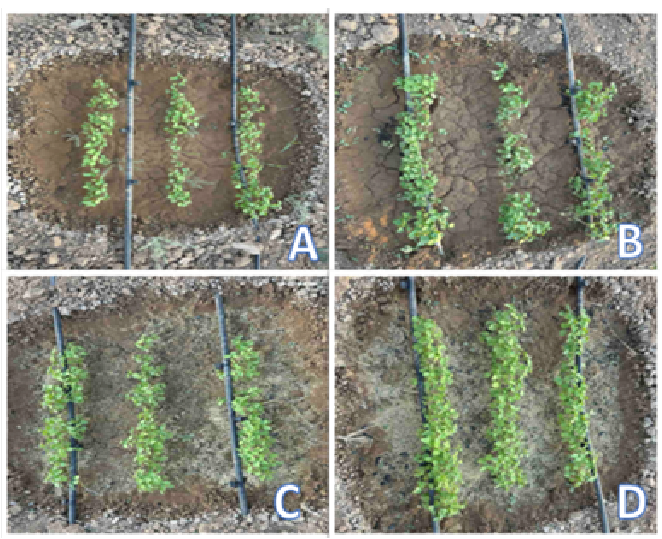

Figure 8: Difference between biochar and wheat straw mulch on plant growth at Grdarasha field (A) control (B0M0); (B) when biochar added to plot (B1M0); (C) when biochar and wheat straw mulch added in small rate (B1M1); (D) interaction of biochar and wheat straw mulch in more rate (B1M2).

From the above figure, the impact of biochar and wheat straw mulch alone or when combined clearly appear on plant growth and additionally on having weeds; (A) when biochar added to plot (B1M0); (B) interaction between biochar and wheat straw mulch in small rate (B1M1); (C) control treatment without adding any organic sources to the plot, that was weak and more weed grew; (D) great result of growth and density of plant with less weed growing by using interaction of biochar and wheat straw mulch in more rate (B1M2). Generally, in this study, other important view-points were recorded that caused HMs accumulation in kenaf leaves for example; biochar reduces HMs accumulation in plants more effectively in acidic soils because The liming effect of biochar increases soil pH, which generally reduces the bioavailability of cationic metals, although the behaviour of anionic metals such as arsenic may differ depending on soil chemistry, though its effectiveness can be influenced by the specific metal and biochar properties. Also, calcium carbonate ($CaCO_3$) reduces HMs uptake by plants by increasing soil pH such as in Gwer field with a pH value of (7.78) according to laboratory tests of soil physical properties (Table 1). Soil Electrical Conductivity (EC) is positively correlated with HMs uptake by plants because higher EC values indicate greater total dissolved salts and ionic contaminants, which can increase HMs bioavailability in the soil solution, making them more accessible for plant absorption. Nitrogen plays a crucial role in plant growth and metabolism, which can indirectly influence heavy metal uptake. Even though soil N content was similar in Grdarasha (72 mg/kg) and Gwer (70 mg/kg) fields, the slight difference, combined with the plant's N use efficiency, may have contributed to enhanced growth in kenaf. Increased growth leads to greater root biomass and metabolic activity, which can facilitate higher uptake of HMs from the soil. On the other hand, a high soil cation exchange capacity (CEC) decreases HMs uptake by binding metal ions, making them less available for plant absorption, while a low CEC increases metal availability and plant uptake (Cui et al., 2021). So, according to the table in Grdarasha (22.39 meq/100g soil) was high but in Gwer (15.72 meq/100g soil) it was low to medium. Sometimes soil texture could be the other factor influences in the process of retain and mobility of HMs. Here, Grdarasha field soil was silty clay loam that have a high capacity to adsorb and retain HMs, which reduces the risk of the metals leaching into groundwater or being absorbed by plants. The fine particles of clay and the presence of organic matter create more surface area and binding sites for HMs compared to coarser soils. Compared to Gwer field soil, it was silty loam that has a moderate capacity to retain HMs, but this varies based on specific soil conditions like pH, organic matter content, and the specific metal involved. Compared to sandy soils, silty loam was much better at retaining HMs, but it was not as effective as clay-rich soils.

Effect of Kenaf Plant, Biochar and Wheat Straw Mulch on Heavy Metal Rates in Soil:

As mentioned previously, the soil samples were collected to determine the heavy metals (HMs) rates before sowing, which was named as (Base), and after plant harvesting in both sites Grdarasha and Gwer (Tables 4 and 5). These data display crucial information about how treatments of applying biochar, straw mulch and also kenaf plants affect HMs rates in the soil, and how each of them binds heavy metals and acted as a soil amendment technique in contaminated areas. According to table 4, generally kenaf plant had high ability to reduce HMs in the soil (phytoremediation), without using any other factors (biochar and wheat straw mulch), which was noted when the base soil sample was compared to control treatment. As scientifically known that those HMs are hazardous. All treatments effectively decreased HMs in soil in general, but each of (B0M2 and B1M2) showed the best results for that purpose. On the other hand, it could be said that biochar caused to chelate and lower bioavailability of HMs and then bind them. Additionally, adverse of that wheat straw mulch had increased HMs uptake by plant due to wheat straw mulch composition, organic matter, save soil humidity, less weed and pest to compete on sources and more proper soil properties, which that caused to drop HMs rates in soil. Also, it can bind metals tightly to itself. While, in Gwer field in the treatment of (B0M1), could said that all heavy metals dramatically declined and removed in the soil, this again confirmed the impact of mulch in soil cleaning (Table 5). As Jang et al. (2005) reported that mulch would be effective for removing heavy metals. Previous studies had also demonstrated the effectiveness of mulching for the removal of HMs from contaminated soils. Straw mulching can be used as an effective measure to control heavy metal contaminated soil which poses a pollution risk to the environment (Rao et al., 2016).

Table 4: Heavy metals (HMs) concentration under different treatments at Grdarasha Field.

HMs Treatments (g/m^2)	Pb (ppm)	Hg (ppm)	Cd (ppm)	Cr (ppm)	Co (ppm)	Cu (ppm)	Ni (ppm)	As (ppm)	Zn (ppm)	Fe (ppm)
Base	1.67	0.16	0.25	29.89	0.08	4.58	47.56	3.53	12.71	5415.92
B0M0	1.88	0.23	0.14	22.86	0.04	3.49	1.171	3.07	10.17	4382.96
B0M200	1.88	0.21	0.22	32.31	0.06	5.01	0.808	3.81	14.94	5945.08
B0M400	1.30	0.10	0.13	20.39	0.05	3.10	11.44	2.53	10.05	3816.15
B150M0	1.63	0.17	0.12	21.89	0.05	3.12	4.046	2.59	10.45	3921.71
B150M200	1.40	0.09	0.20	31.37	0.08	4.17	46.28	3.40	14.19	4647.95
B150M400	0.74	0.01	0.11	19.15	0.04	2.86	1.846	2.47	10.03	3410.29
B300M0	1.75	0.19	0.19	32.65	0.06	5.07	53.12	3.36	16.87	5505.33
B300M200	1.96	0.25	0.16	26.84	0.05	3.85	51.57	2.53	11.84	4533.34
B300M400	2.09	0.25	0.13	23.02	0.04	3.25	47.27	2.62	13.61	4024.81

Table 5: Effect of biochar and wheat straw mulching on heavy metals of soil planted with kenaf at Gwer Field.

HMs Treatments (g/m^2)	Pb (ppm)	Hg (ppm)	Cd (ppm)	Cr (ppm)	Co (ppm)	Cu (ppm)	Ni (ppm)	As (ppm)	Zn (ppm)	Fe (ppm)
Base	1.82	0.21	0.12	24.29	0.06	3.62	32.35	2.88	10.79	4171.16
B0M0	2.58	0.36	0.35	37.44	0.12	7.04	29.25	4.80	25.45	7792.51
B0M200	0.84	0.01	0.10	21.86	0.04	3.17	12.97	2.57	9.11	3266.42
B0M400	1.36	0.12	0.15	27.65	0.07	4.39	36.17	3.65	11.42	4134.99
B150M0	2.31	0.29	0.22	30.72	0.06	4.94	15.24	2.49	13.88	4673.53
B150M200	1.02	0.03	0.26	37.92	0.09	5.65	6.566	4.08	16.25	5332.77
B150M400	1.35	0.12	0.12	26.67	0.05	3.52	38.18	2.72	10.11	3843.52
B300M0	1.39	0.15	0.17	24.46	0.06	4.01	17.26	3.09	13.36	4710.38
B300M200	2.15	0.29	0.38	34.88	0.17	6.92	59.16	4.37	20.76	7044.59
B300M400	1.28	0.08	0.15	29.67	0.06	4.04	0.035	2.72	12.03	3917.36

CONCLUSION

This study determined the effect of kenaf plant, kenaf stem biochar (KSB), and wheat straw mulch on heavy metals uptake by plant and using them as soil bioremediation to minimize soil pollution. Results showed that, kenaf (FH 952 var.) was very able to uptake heavy metals in polluted soil. Also, biochar was able to reduce some hazardous HMs in soil by binding them and lowering their mobility. Additionally, wheat straw mulch effected kenaf plant to uptake HMs and minimizing rates in soil, that technique was economic and environmentally friendly. It is recommended to plant kenaf in Kurdistan due to its capability to grow in and handing best yield, also to be used as phytoremediation for polluted areas that even causes job opportunity to many agronomists. Unfortunately, Kurdistan region is not exempt from environmental pollution due to ongoing war, economic situation and less chance to focus on environmental sectors and still have serious problems to be solved among health and environment. That is why it is recommended to pay attention about those researches that investigate on contaminated areas and reduce risks of those places that faces pollution especially chemical weapons as Halabja, Balisan and Sheikh Wasan.

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R. F. S. carried out the conception and design of the study, while O. A. O. collected and analyzed the data and drafted the manuscript.

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