**The Transformative Effects of Coconut Shell Biochar on Heavy Metal Bioavailability in Soil, Phytotoxicity and Yield in French Bean**

**Abstract**

* In a controlled pot experiment using a Completely Randomized Design (CRD) conducted at UAS, GKVK, Bangalore, India, soil was artificially contaminated with different concentrations of four types of heavy metals (Cd, Cr, Pb and As). French Bean (*Phaseolus vulgaris* L.) crop was grown to assess the remediation caused by varying levels of coconut shell biochar. It was found that the biochar was capable of causing a reduction ranging from 68.1- 90.1 per cent in the bioavailability of heavy metals with reductions peaking at 5% application (e.g., 87.5–90.1% for Pb). Soil health parameters (pH, nutrient status, microbial activity) also improved with maximum yield improvement at 5 per cent application rate. Phytotoxic symptoms were not observed in the plants.

**Keywords**

Coconut shell biochar, Heavy metals, Bioavailability, Phytotoxicity, Yield

**Introduction**

Soil pollution is a silent threat beneath our feet that erodes the foundation of life, compromises food security and endangers ecosystems worldwide. Heavy metal contamination which is one of the forms of soil pollution has become a significant challenge due to increasing industrialization and urbanization. Unlike organic pollutants, heavy metals are persistent toxins that cannot be broken down. They are non-degradable, mobile and toxic in nature (Adnan *et al.* 2022). Even a small amount of exposure can disrupt the body's normal metabolic processes. Nineteen elements come under the category of heavy metals which are defined as elements having a high atomic mass number (> 20) and a density greater than 5 grams per cm3 of volume. Biologically, they are called heavy metals because their small quantities are more toxic to plants and animals (Rascio and Navariizzo, 2011).

Worldwide, there are five million polluted sites covering around 500 million hectares area. These soils are contaminated by various heavy metals or metalloids, with current concentrations exceeding geo-baseline or regulatory levels (Liu *et al.*, 2018). Several attempts are being made to search for the potential solutions to this problem. The *in-situ* as well as *ex-situ* technologies are the two main categories of remediation strategies (Gomes *et al.*, 2013). The *in-situ* techniques involve the management of pollutants at the site itself while *ex-situ* techniques comprise excavating the soil for treatment. Out of the two techniques, *in-situ* is considered to be more economical (Song *et al.*, 2017). One of those *in-situ* techniques is the use of biochar for the remediation of polluted sites.

 Biochar is a highly porous product produced by pyrolysis of crop residues like coconut shells, rice husk, maize straws, *etc*. It is produced at various temperatures like 300, 450 and 600 degrees Celsius. It consists of a highly condensed aromatic structure, including several classes of polycyclic aromatic hydrocarbons (Schmidt and Noack, 2000). These properties of biochar make it suitable for heavy metals remediation (Oni *et al.* 2019). The use of biochar is becoming popular as an effective treatment for the removal of metals (Inyang *et al*., 2015). Furthermore, due to its highly microporous structure, it is also used for carbon capture and improving soil quality (Liu *et al.,* 2022).

An experiment was conducted with the purpose of assessing the efficacy of Coconut shell Biochar in the remediation of heavy metal-contaminated soil. For this, the test crop selected was French Bean (*Phaseolus vulgaris* L.) which is a legume crop. It is highly sensitive to soil conditions, making it an excellent indicator of soil health and nutrient availability. The study holds great importance with respect to the increasing threat of soil health degradation.

**Experimental methodology**

**Experimental design and treatments**

A pot culture experiment was conducted following the Completely Randomized design (CRD). Fourteen treatments were planned with three replications. The treatment details are mentioned in Table 1.

**Table 1: Treatment details of the experiment**

|  |  |  |  |
| --- | --- | --- | --- |
| T1 | Absolute control | T8 | RDF+ FYM+ CSB @ 1% + HM @ 30 mg kg-1 |
| T2 |  RDF + FYM | T9 | RDF+ FYM+ CSB @ 3% + HM @ 10 mg kg-1 |
| T3 | RDF+ FYM+ HM @ 10 mg kg-1 | T10 | RDF+ FYM+ CSB @ 3% + HM @ 20 mg kg-1  |
| T4 | RDF+ FYM+ HM @ 20 mg kg-1 | T11 | RDF+ FYM+ CSB @ 3% + HM @ 30 mg kg-1 |
| T5 | RDF+ FYM+ HM @ 30 mg kg-1 | T12 | RDF+ FYM+ CSB @ 5% + HM @ 10 mg kg-1 |
| T6 |  RDF+ FYM+ CSB @ 1% + HM @ 10 mg kg-1  | T13 | RDF+ FYM+ CSB @ 5% + HM @ 20 mg kg-1 |
| T7 | RDF+ FYM+ CSB @ 1% + HM @ 20 mg kg-1 | T14 | RDF+ FYM+ CSB @ 5% + HM @ 30 mg kg-1 |

\*RDF- Recommended dose of fertilizers (63:100:75 kg ha-1 (N: P2O5: K2O)

 FYM- Farm yard Manure (25 t ha-1), HM- Heavy metals and CSB- Coconut shell Biochar

**Artificial contamination of soil**

The soil was collected from the agroforestry-based Integrated farming system field, GKVK, UAS, Bangalore and analyzed for various parameters. The initial status of heavy metals in the soil was found to be negligible. The soil was air-dried and 7 kg of soil was filled in pots with a capacity of 10 kg. The initial properties of soil were determined using the standard procedures. For the artificial contamination of soil with heavy metals (Cd, Cr and Pb), solutions of 500 ml were prepared using the salts of these heavy metals and Arsenic standard solution was used. These solutions were mixed into the soil 20 days before the sowing of the crop.

**Table 2: Heavy metals used for soil contamination**

|  |  |  |
| --- | --- | --- |
| Heavy metals | Chemicals used | The amount used for 10, 20 and 30 mg L-1 respectively |
| Cadmium | Cadmium nitrate tetrahydrate AR (Finar) | 192.5, 385 and 577.5 mg |
| Chromium | Chromium sulphate basic LR (Sigma-Aldrich) | 245, 490 and 735 mg |
| Lead | Lead nitrate AR (SDFCL) | 112, 224 and 336 mg |
| Arsenic | Arsenic standard solution (Sigma-Aldrich) | 5, 10 and 15 ml |

**Table 3: Initial properties of the collected soil and Coconut shell Biochar**

|  |  |  |
| --- | --- | --- |
| **Parameter** | **Collected soil** | **Coconut Shell Biochar** |
| Sand (%) | 59.90 | - |
| Silt (%) | 21.71 | - |
| Clay (%) | 18.39 | - |
| Textural class | Sandy loam | - |
| Bulk Density (Mg m-3) | 1.34 | 0.7 |
| Maximum water holding capacity (%) | 36.46 | 67.22 |
| pH (1:2.5 for soil and 1:10 for biochar) | 6.73 | 8.97 |
| Electrical Conductivity (1:2.5 for soil and 1:10 for biochar) (dS m-1) | 0.37 | 1.98 |
| Carbon (Organic Carbon for Soil and Total Carbon for biochar) (%) | 0.54 | 76 |
| Cadmium | ND | 0.15 mg kg-1 |
| Chromium | ND | 0.52 mg kg-1 |
| Lead | ND | 3.16 mg kg-1 |
| Arsenic | ND | 2.23 mg kg-1 |
| Primary nutrients | 294.76, 46.26, 214.2 kg ha-1 (N: P2O5: K2O) | 0.32, 0.26, 0.76 % (N, P, K) |
| Secondary nutrients | 5.5, 4.3 c mol p+ kg-1 (Exch. Ca, Mg), 14.14 mg kg-1 Available S | 0.17, 0.11, 0.06 % (Ca, Mg. S) |
| Micronutrients (mg kg-1) (Zn, Cu, Fe, Mn) | 2.38, 2.8, 18.76, 8.6 | 21.67, 36.06, 448.56, 278.11 |

 \*ND-Not detected

**Application of Coconut shell biochar**

Coconut shell biochar was used for the experiment because large amounts of coconut shells are generated as agri-waste in the Karnataka region. Coconut shell biochar was procured from Kalpatharu Products, Tiptur Taluk, Tumkur district, Karnataka, India. 15 days before sowing of the test crop, the soil was mixed with biochar at different concentrations of 70, 210 and 350 grams which is equivalent to 1, 3 and 5 per cent of biochar for 7 kg soil. Water was added to maintain the field capacity of the soil.

**Test crop**

Five seeds per pot of Arka Komal variety of French Bean (*Phaseolus vulgaris* L.) released by the Indian Institute of Horticultural Research, Bangalore were sown in the pots in December 2023. Plant protection measures were followed to maintain the crop. For example, leaf minor infestation was removed by clipping out the infected leaves. Irrigation was provided at regular intervals. The crop was harvested at maturity after two months.

**Laboratory analysis**

Soil was collected from pots at the vegetative stage of the crop. At harvest, soil samples were collected along with the pods and haulm of the test crop. Soil samples were dried, processed and analyzed for different parameters using standard procedures. Plant samples were oven dried, powdered and analyzed for different parameters. The standard methods followed for laboratory analysis have been mentioned in Table 4.

**Table 4: Standard methods followed for plant and soil analysis**

|  |  |  |
| --- | --- | --- |
| **Parameter** | **Method** | **Reference** |
| **Plants** |
| Nitrogen (%) | Kjeldahl digestion and distillation | Piper (1966) |
| Heavy metal in plants (mg kg-1) | Atomic absorption spectroscopy | Lindsay and Norwell (1978) |
| **Soil** |
| Soil pH | Potentiometry | Jackson (1973) |
| Electrical conductivity (dS m-1) | Conductometry | Jackson (1973) |
| Organic carbon (%) | Wet oxidation method | Walkley and Black (1934) |
| Available Nitrogen (kg ha-1) | Alkaline Potassium permanganate | Subbiah and Asija (1956) |
| Available P2O5 (kg ha-1) | Olsen’s method | Jackson (1973) |
| Available K2O (kg ha-1) | Ammonium acetate extraction and Flame photometry | Jackson (1973) |
| DTPA-extractable heavy metals (mg kg-1) | Atomic absorption spectrophotometry | Lindsay and Norwell (1978) |
| Dehydrogenase activity (μg TPF g-1 soil) | 2,3,5-Triphenyl tetrazolium chloride (TTC) reduction method | Casida *et al.* (1964) |
| Urease activity (μg-NH4+ g-1 soil) | Titration method | Tabatabai and Bremner (1970) |
| Microbial Biomass Carbon (μg g-1 soil) | Chloroform fumigation technique | Jenkinson and Powlson (1976) |

**Statistical analysis**

The data obtained was analyzed using OPSTAT software using the method of analysis of variance (ANOVA) for completely randomized design (CRD) as given by Fisher and Yates (1963). Whenever the F-test was found significant for comparing the means of two treatments, the critical difference (C.D. at 5%) was worked out. Duncan’s multiple range test was done to compare the treatment means of the bioavailability of heavy metals in the soil using the Grapesstat web application.

**Results and Discussion**

**Effect of application of different levels of Coconut shell Biochar on soil pH and EC**

The results indicated that the application of biochar significantly improved the pH and EC of soil. The alkaline nature of biochar increased the soil pH from 6.74 in the control to 7.43 and 7.47 in T12 (RDF+ FYM+ CSB @ 5% + HM @ 10 mg kg-1) at the vegetative and harvest stage of the crop, respectively. It was observed that with the increasing rates of application of biochar, i.e. from 1 per cent to 5 per cent, soil pH increased. Due to the presence of basic cations and high ash content along with various functional groups (Herlambang *et al.* 2019, Chintala *et al.* 2014), biochar is capable of increasing the soil pH.

As reported by Bakshi *et al.* 2018, heavy metal cations saturate or supersaturate the cation exchange sites which leads to the displacement of protons. This causes a decrease in soil pH. A decrease in soil pH was observed in the treatments where artificial contamination of heavy metals was carried out without biochar application.

High ash content and heavy metal salts increased the electrical conductivity of the soil. The electrical conductivity showed a decrease from the vegetative to the harvest stage of the crop, which might have occurred due to the uptake of cations by the plant. Similar findings have been reported by Lu *et al.* 2014 and Karimi *et al.* 2020.

**Fig. 1. Effect of different levels of Coconut shell Biochar on soil pH at different crop stages**

**Fig. 2. Effect of different levels of Coconut shell Biochar on soil EC at different crop stages**

**Effect of application of different levels of Coconut shell Biochar on organic carbon**

 The soil organic carbon got improved due to the porous nature, high cation exchange capacity (CEC) and large surface area of biochar. Song *et al.* 2019 and Demise *et al.* 2014 found that microbial activity gets improved by the application of biochar with FYM, which aids in the improvement of soil organic carbon. In T12 (RDF+ FYM+ CSB @ 5% + HM @ 10 mg kg-1) organic carbon increased from 0.51 in control to 0.72 and 0.78 per cent at the vegetative and harvest stages respectively.

**Effect of application of different levels of Coconut shell Biochar on soil macronutrient status**

Available primary nutrients (N, P2O5, K2O) showed an increasing trend with the increasing rates of the application of coconut shell biochar. In T12 (RDF+ FYM+ CSB @ 5% + HM @ 10 mg kg-1) the highest amount of nutrients was observed. This might have been the result of slow release of nitrogen (Bhattacharjya *et al.*2015) and reduction in N2O-N emission (Fan *et al.* 2017) that improved the soil nitrogen status. The change in pH caused by the biochar application enhanced the solubility of phosphorus, moreover, the porous nature of biochar created a favourable environment for mycorrhizal fungi (Gul and Whalen, 2016) which might have secreted phosphorus-solubilising organic acids. Soil potassium status might have improved due to the high ash content of the biochar. Additionally, increased soil pH might have reacted with the strongly attached potassium ions on clay minerals (Oram *et al.* 2014) and that increased the soil potassium level.

 After the harvest of the crop, these nutrients showed a decrease as compared to the vegetative stage due to nutrient uptake by crop. However, the trend of increase with the increasing rates of biochar application was intact.

 The secondary nutrients (exchangeable Ca, Mg) showed a similar increasing trend where the maximum concentrations were found where 5 per cent biochar application was done. The increase in concentration can be explained by the nature of biochar i.e. its high CEC, presence of basic cations, large surface area, *etc.* Interestingly, biochar showed a non-significant effect on the concentration of available sulphur in soil. As pH variation does not show its effect on available sulphur content, the biochar application could not pose any significant effect on it. Only a slight increase in the concentration was seen which might have been caused by the mineralization of organic sulphur carried out by biochar (Deluca *et al.* 2015).

**Effect of application of different levels of Coconut shell Biochar on soil micronutrient status**

As there was an increase in pH observed with the biochar application, the availability of soil micronutrients decreased. This can be ascertained also from the large surface area of the biochar which immobilizes the micronutrients (Park *et al.* 2011). Whereas, copper availability showed an increase despite the increase in pH with the application of coconut shell biochar. As copper metal has a high tendency to chelate with organic carbon, with the application of coconut shell biochar the copper status of soil improved. Manganese concentration did not vary significantly with the different treatments applied. Similar findings have been reported by Bramarambika *et al.* 2021.

**Effect of application of different levels of Coconut shell Biochar on the bioavailability of heavy metals in soil**

The bioavailability of heavy metals in the soil was found to decrease with the application of different rates of biochar. The maximum extent of reduction was observed in the treatments where 5 per cent biochar was applied. The concentration of cadmium reduced from 10 to 1.99 and 1.39 mg kg-1 at the vegetative and harvest stages respectively in T12 (RDF+ FYM+ CSB @ 5% + HM @ 10 mg kg-1).

 Similarly, the bioavailability of other applied heavy metals was found to decrease to the maximum extent in T12 (RDF+ FYM+ CSB @ 5% + HM @ 10 mg kg-1). The remediation ability of coconut shell biochar can be understood by its high adsorption capacity. The large number of functional groups and porous nature provide it with the affinity to adsorb heavy metal cations (Cao and Harris 2010, Uchimiya *et al.* 2011). Other mechanisms responsible for the reduction of bioavailability of heavy metals might have been the formation of metal complexes with the various functional groups (carbonates, hydroxides, *etc.*) present on the surface of biochar.

**Effect of application of different levels of Coconut shell Biochar on the soil biological properties (dehydrogenase activity, urease activity, microbial biomass carbon)**

Biochar is known to increase the organic carbon status of soil which helps to enhance the microbial activity of soil (Gasco *et al.* 2016). The large number of pores present in biochar provides habitat to the soil microbes which helps in the proliferation of microbes (Zhang *et al.* 2021). Additionally, enhanced nutrient status and reduced toxicity of heavy metals also contribute to improving the biological properties of soil (Salazar *et al.*2011).

 T12 (RDF+ FYM+ CSB @ 5% + HM @ 10 mg kg-1) showed a dehydrogenase activity of 40.60 and 41.20 µg-TPF g-1 soil at the vegetative and harvest stages respectively while control (T1) showed the minimum activity of 11.77 and 13.57 µg-TPF g-1 soil at both the crop stages respectively.

 Likewise, the hydrolysis of urea was accelerated by the presence of oxidizing microbes which enhanced soil urease activity as also reported by Du *et al.* 2014. By enhanced soil organic matter, microbial biomass carbon also increased (Yuan and Yue 2012). Urease activity and microbial biomass carbon also followed the same trend as soil dehydrogenase activity.

**Effect of application of different levels of Coconut shell Biochar on the phytotoxicity of heavy metals**

The application of coconut shell biochar at different levels along with RDF and FYM led to a decrease in the phytotoxicity of cadmium in pods as well as haulm of the crop. T12 (RDF+ FYM+ CSB @ 5%+ HM @ 10 mg kg-1) showed the lowest content of cadmium with a concentration of 1.14 and 0.27 mg kg-1 in haulm and pods, respectively, among the contaminated treatments, which might have been the result of the remediation caused by biochar. The highest content was seen in T5 (RDF+ FYM+ HM @ 30 mg kg-1) which received no biochar and the highest concentration of heavy metals i.e. 30 mg kg-1. The same trend was observed for other applied heavy metals. The plants at harvest did not show any visible toxicity symptoms.

**Fig. 3. Effect of different levels of Coconut shell Biochar on soil available primary nutrients (N, P2O5, K2O) at different crop stages (VS-Vegetative stage, HS-Harvest stage)**

**Fig. 4. Effect of different levels of Coconut shell Biochar on soil secondary nutrients (exchangeable Ca and Mg) at different crop stages (VS-Vegetative stage, HS-Harvest stage)**

**Table 5: Effect of different levels of Coconut shell Biochar on soil organic carbon**

|  |  |  |
| --- | --- | --- |
| **Treatments** | **Organic carbon (VS)** | **Organic carbon (HS)** |
| T1 | 0.507 ± 0.038g | 0.483 ± 0.032g |
| T2 | 0.567 ± 0.021ef | 0.587 ± 0.021f |
| T3 | 0.520 ± 0.026fg | 0.500 ± 0.026g |
| T4 | 0.503 ± 0.023g | 0.480 ± 0.017g |
| T5 | 0.480 ± 0.020g | 0.470 ± 0.020g |
| T6 | 0.600 ± 0.026de | 0.620 ± 0.026def |
| T7 | 0.570 ± 0.026ef | 0.600 ± 0.026ef |
| T8 | 0.560 ± 0.017ef | 0.580 ± 0.017f |
| T9 | 0.660 ± 0.036bc | 0.690 ± 0.036abc |
| T10 | 0.640 ± 0.044cd | 0.670 ± 0.044bcd |
| T11 | 0.630 ± 0.026cd | 0.650 ± 0.026cde |
| T12 | 0.720 ± 0.036a | 0.740 ± 0.036a |
| T13 | 0.703 ± 0.032ab | 0.723 ± 0.032a |
| T14 | 0.693 ± 0.031ab | 0.710 ± 0.036ab |

**(Values represent mean ± standard deviation) (VS-Vegetative stage, HS-Harvest stage)**

**(Treatments with the same letters are not significantly different)**

**Table 6: Effect of different levels of Coconut shell Biochar on the bioavailability of Cadmium and Chromium**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Treatments** | **Cadmium (VS)** | **Cadmium (HS)** | **Chromium (VS)** | **Chromium (HS)** |
| T1 | 0.136 ± 0.010g | 0.082 ± 0.006i | 0.134 ± 0.010h | 0.122 ± 0.009i |
| T2 | 0.144 ± 0.005g | 0.072 ± 0.003i | 0.152 ± 0.006h | 0.164 ± 0.006i |
| T3 | 7.346 ± 0.389c | 6.560 ± 0.347c | 5.690 ± 0.301d | 4.192 ± 0.222d |
| T4 | 11.974 ± 0.522b | 11.462 ± 0.500b | 10.294 ± 0.449b | 9.270 ± 0.404b |
| T5 | 19.806 ± 0.907a | 17.046 ± 0.781a | 18.258 ± 0.837a | 15.832 ± 0.726a |
| T6 | 3.224 ± 0.148e | 2.637 ± 0.121f | 2.194 ± 0.101g | 1.952 ± 0.090g |
| T7 | 5.125 ± 0.235d | 4.742 ± 0.217d | 3.672 ± 0.169f | 3.276 ± 0.150e |
| T8 | 7.541 ± 0.199c | 6.122 ± 0.162c | 6.356 ± 0.168c | 5.986 ± 0.159c |
| T9 | 2.309 ± 0.122f | 1.966 ± 0.104g | 2.164 ± 0.115g | 1.344 ± 0.071h |
| T10 | 3.178 ± 0.222e | 2.684 ± 0.188f | 2.390 ± 0.167g | 2.080 ± 0.145fg |
| T11 | 5.222 ± 0.188d | 4.427 ± 0.160de | 4.728 ± 0.170e | 4.150 ± 0.149d |
| T12 | 1.985 ± 0.105f | 1.392 ± 0.074h | 1.924 ± 0.101g | 1.192 ± 0.063h |
| T13 | 3.480 ± 0.152e | 2.804 ± 0.122f | 3.350 ± 0.146f | 2.450 ± 0.107f |
| T14 | 4.762 ± 0.218d | 4.130 ± 0.189e | 4.536 ± 0.208e | 3.550 ± 0.162e |

 **(Values represent mean ± standard deviation) (VS-Vegetative stage, HS-Harvest stage)**

**(Treatments with the same letters are not significantly different)**

**Table 7: Effect of different levels of Coconut shell Biochar on the bioavailability of Cadmium and Chromium**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Treatments** | **Lead (VS)** | **Lead (HS)** | **Arsenic (VS)** | **Arsenic (HS)** |
| T1 | 0.104 ± 0.007j | 0.098 ± 0.007j | 0.063 ± 0.006k | 0.053 ± 0.006h |
| T2 | 0.192 ± 0.007j | 0.134 ± 0.005j | 0.143 ± 0.006k | 0.120 ± 0.000h |
| T3 | 5.200 ± 0.275d | 4.700 ± 0.249d | 6.310 ± 0.335d | 5.830 ± 0.308c |
| T4 | 12.362 ± 0.539b | 11.570 ± 0.504b | 13.213 ± 0.572b | 12.113 ± 0.529b |
| T5 | 15.624 ± 0.716a | 15.134 ± 0.693a | 16.480 ± 0.753a | 15.620 ± 0.714a |
| T6 | 2.266 ± 0.104gh | 1.850 ± 0.085h | 3.547 ± 0.163fg | 3.197 ± 0.143f |
| T7 | 3.974 ± 0.182ef | 3.630 ± 0.167e | 4.633 ± 0.208e | 3.990 ± 0.183e |
| T8 | 6.254 ± 0.166c | 5.340 ± 0.141c | 6.940 ± 0.185c | 6.130 ± 0.159c |
| T9 | 1.956 ± 0.103h | 1.536 ± 0.081h | 2.363 ± 0.127ij | 1.827 ± 0.095g |
| T10 | 2.670 ± 0.187g | 2.520 ± 0.177g | 3.140 ± 0.219gh | 2.757 ± 0.195f |
| T11 | 4.240 ± 0.153e | 3.736 ± 0.134e | 4.987 ± 0.175e | 4.673 ± 0.169d |
| T12 | 1.350 ± 0.071i | 0.990 ± 0.052i | 2.253 ± 0.121j | 1.707 ± 0.091g |
| T13 | 2.288 ± 0.100gh | 1.948 ± 0.085h | 2.813 ± 0.119hi | 2.157 ± 0.099g |
| T14 | 3.574 ± 0.164f | 2.964 ± 0.136f | 3.740 ± 0.173f | 2.883 ± 0.132f |

**(Values represent mean ± standard deviation) (VS-Vegetative stage, HS-Harvest stage)**

**(Treatments with the same letters are not significantly different)**

**Fig. 5. Effect of different levels of Coconut shell Biochar on soil micronutrients (Copper, Zinc, Iron) at different crop stages (VS-Vegetative stage, HS-Harvest stage)**

**Fig. 6. Effect of different levels of Coconut shell Biochar on total uptake (pod + haulm) of heavy metals by the crop**

**Fig. 7. Effect of different treatments on soil dehydrogenase activity (T1- Control, T3- RDF+FYM+HM@10mgkg-1, T6-RDF+FYM+CSB@1%+HM@10mgkg-1, T9-RDF+FYM+CSB@3%+HM@10mg kg-1andT12 RDF+FYM+CSB@5%+HM@10mg kg-1)**

**Fig. 8. Effect of different treatments on soil urease activity (T1- Control, T3- RDF+FYM+HM@10mgkg-1, T6-RDF+FYM+CSB@1%+HM@10mgkg-1, T9-RDF+FYM+CSB@3%+HM@10mg kg-1andT12 RDF+FYM+CSB@5%+HM@10mg kg-1)**

**Fig. 9. Effect of different treatments on soil microbial biomass carbon (T1- Control, T3- RDF+FYM+HM@10mgkg-1, T6-RDF+FYM+CSB@1%+HM@10mgkg-1, T9-RDF+FYM+CSB@3%+HM@10mg kg-1andT12 RDF+FYM+CSB@5%+HM@10mg kg-1)**

**Effect of application of different levels of Coconut shell Biochar on the productivity of French Bean**

Biochar application improved soil nutrient status, reduced metal toxicity and improved microbial activity in soil. All these factors summed up to improve the productivity of the crop. The maximum yield was observed inT12 (RDF+ FYM+ CSB @ 5%+ HM @ 10 mg kg-1) which signifies that 5 per cent rate of application improved the productivity potential to the maximum.

 Plant growth parameters like plant height, number of pods per plant and number of branches were observed to be the best where 5 per cent biochar application was done. This was followed by 3 and 1 per cent of biochar application. Heavy metals contamination without any remediation led to a decline in the productivity potential of the crop.

**Relationship between soil chemical, biological properties and bioavailability of heavy metals in soil**

Pearson correlation analysis was done to analyze the relationship between different soil properties and the bioavailability of heavy metals in soil. Organic carbon (0.958), available N (0.900), available K₂O (0.895), exchangeable Mg (0.904) and dehydrogenase activity (0.941) showed a high positive correlation with soil pH. This suggests that as pH increases, these parameters also increase. Whereas, there was a negative correlation of soil pH with DTPA-extractable micronutrients (Zn, Fe, Mn) and heavy metals (Cd, Cr, Pb, As).

**Bioconcentration factor of heavy metals in plants**

The bioconcentration factor is a parameter which is used to assess the accumulation of heavy metal in the plants with reference to the concentration present in the soil. It is the measure of the extent to what the heavy metals accumulate in the edible portion of plants. It can be calculated by the formula mentioned below (Dowdy and McKone 1997)-

 Concentration of heavy metal in plant’s edible portion

Bioconcentration factor = Concentration of heavy metal in soil

The bioaccumulation factor ranged from 0.194 to 0.719 for cadmium, 0.117 to 0.846 for chromium, 0.147 to 0.596 for lead and 0.106 to 0.596 for arsenic among all the artificially contaminated treatments.

**Fig. 10. Effect of different treatments on yield parameters of the crop**

**Fig. 11. Effect of different treatments on height of the crop**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | *pH* | *EC* | *Organic Carbon* | *Available N* | *Available P₂O₅* | *Available K₂O* | *Exch. Ca* | *Exch. Mg* | *Available S* | *DTPA-ext. Zn* | *DTPA-ext. Cu* | *DTPA-ext. Fe* | *DTPA-ext. Mn* | *DTPA-ext. Cd* | *DTPA-ext. Cr* | *DTPA-ext. Pb* | *DTPA-ext. As* | *Dehydro-genase activity* | *Urease activity* | *Microbial Biomass Carbon* |
| pH | 1.000 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| EC | 0.328 | 1.000 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Organic Carbon | 0.958 | 0.226 | 1.000 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Available N | 0.900 | 0.136 | 0.931 | 1.000 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Available P₂O₅ | 0.865 | 0.470 | 0.838 | 0.826 | 1.000 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Available K₂O | 0.895 | 0.236 | 0.975 | 0.935 | 0.824 | 1.000 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Exch. Ca | 0.871 | -0.091 | 0.930 | 0.916 | 0.658 | 0.908 | 1.000 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Exch. Mg | 0.904 | -0.034 | 0.939 | 0.898 | 0.754 | 0.890 | 0.960 | 1.000 |  |  |  |  |  |  |  |  |  |  |  |  |
| Available S | 0.732 | -0.277 | 0.832 | 0.807 | 0.469 | 0.820 | 0.967 | 0.896 | 1.000 |  |  |  |  |  |  |  |  |  |  |  |
| DTPA-ext. Zn | -0.824 | 0.067 | -0.746 | -0.847 | -0.606 | -0.675 | -0.842 | -0.825 | -0.760 | 1.000 |  |  |  |  |  |  |  |  |  |  |
| DTPA-ext. Cu | 0.918 | -0.001 | 0.941 | 0.903 | 0.686 | 0.898 | 0.986 | 0.956 | 0.937 | -0.870 | 1.000 |  |  |  |  |  |  |  |  |  |
| DTPA-ext. Fe | -0.720 | 0.149 | -0.595 | -0.692 | -0.473 | -0.484 | -0.721 | -0.727 | -0.648 | 0.965 | -0.763 | 1.000 |  |  |  |  |  |  |  |  |
| DTPA-ext. Mn | -0.869 | 0.096 | -0.809 | -0.814 | -0.617 | -0.718 | -0.891 | -0.906 | -0.819 | 0.942 | -0.916 | 0.921 | 1.000 |  |  |  |  |  |  |  |
| DTPA-ext. Cd | -0.487 | 0.537 | -0.566 | -0.515 | -0.262 | -0.487 | -0.730 | -0.778 | -0.797 | 0.586 | -0.691 | 0.588 | 0.707 | 1.000 |  |  |  |  |  |  |
| DTPA-ext. Cr | -0.454 | 0.522 | -0.534 | -0.499 | -0.259 | -0.456 | -0.682 | -0.746 | -0.739 | 0.550 | -0.636 | 0.555 | 0.664 | 0.989 | 1.000 |  |  |  |  |  |
| DTPA-ext. Pb | -0.507 | 0.505 | -0.584 | -0.544 | -0.287 | -0.508 | -0.741 | -0.798 | -0.797 | 0.604 | -0.699 | 0.601 | 0.722 | 0.992 | 0.984 | 1.000 |  |  |  |  |
| DTPA-ext. As | -0.507 | 0.503 | -0.583 | -0.522 | -0.267 | -0.499 | -0.740 | -0.791 | -0.802 | 0.589 | -0.703 | 0.594 | 0.725 | 0.991 | 0.979 | 0.995 | 1.000 |  |  |  |
| Dehydrogenase activity | 0.941 | 0.267 | 0.965 | 0.982 | 0.850 | 0.964 | 0.907 | 0.887 | 0.787 | -0.806 | 0.912 | -0.641 | -0.794 | -0.447 | -0.421 | -0.474 | -0.460 | 1.000 |  |  |
| Urease activity | 0.649 | -0.454 | 0.813 | 0.750 | 0.408 | 0.874 | 0.922 | 0.856 | 0.980 | -0.641 | 0.876 | -0.576 | -0.761 | -0.889 | -0.819 | -0.874 | -0.894 | 0.747 | 1.000 |  |
| Microbial Biomass Carbon | 0.903 | 0.342 | 0.942 | 0.964 | 0.863 | 0.968 | 0.857 | 0.830 | 0.730 | -0.724 | 0.855 | -0.536 | -0.703 | -0.353 | -0.333 | -0.381 | -0.364 | 0.989 | -0.362 | 1.000 |

 **Table 8: Correlation of different soil parameters**

**Table 9: Bioconcentration factor of heavy metals**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Treatments | Cadmium | Chromium | Lead | Arsenic |
| T1 | 0.029 | 0.035 | 0.024 | 0.020 |
| T2 | 0.129 | 0.041 | 0.065 | 0.192 |
| T3 | 0.401 | 0.563 | 0.587 | 0.367 |
| T4 | 0.429 | 0.493 | 0.448 | 0.300 |
| T5 | 0.302 | 0.276 | 0.478 | 0.268 |
| T6 | 0.406 | 0.277 | 0.362 | 0.238 |
| T7 | 0.493 | 0.543 | 0.336 | 0.388 |
| T8 | 0.441 | 0.408 | 0.596 | 0.374 |
| T9 | 0.493 | 0.551 | 0.280 | 0.373 |
| T10 | 0.719 | 0.846 | 0.147 | 0.598 |
| T11 | 0.425 | 0.417 | 0.434 | 0.383 |
| T12 | 0.194 | 0.117 | 0.384 | 0.106 |
| T13 | 0.221 | 0.176 | 0.252 | 0.218 |
| T14 | 0.301 | 0.320 | 0.410 | 0.361 |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  |  |  |  |

**Conclusion**

The application of coconut shell biochar showed good results in the management of heavy metal polluted soil. It proves to be a potent soil amendment which can be used to reduce the bioavailability of heavy metals in soil. Moreover, phytotoxicity to the plants also gets reduced and the yield parameters of the crop improved. Biochar application also improved soil properties and nutrient retention. Therefore, we can say that biochar is a very good solution for polluted soil and we can make use of different types of biochar (e.g. rice husk biochar, maize straw biochar, *etc.*) based on the availability of the raw material.

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**2.**

**3.**

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