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Engineered Biochar–Nanocomposites Enhanced Vetiver Growth and Nickel Uptake in Ni-Elevated Ultramafic Soils

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INTRODUCTION & AIM

Biochar, a carbon-rich material produced from biomass, improves soil quality and immobilizes heavy metals, while nanomaterials such as nano-silica, nano-calcium, and nano-chitosan offer high reactivity for metal binding. When combined, these materials form a biochar-nanocomposite that enhances both soil stability and plant growth.

This study explores the **synergistic effect of biochar and nanomaterials** on the phytoremediation capacity of vetiver grass (Vetiveria zizanioides) in chromium-contaminated ultramafic soil, providing a sustainable and efficient approach to rehabilitate metal-polluted environments.

METHODOLOGY

1. Soil collection and characterization

Ultramafic soil from the top 0–20 cm of a mining-impacted site was air-dried, sieved (2 mm), and homogenized before analysis. Initial soil characterization included:

- Soil texture
- pH (H_2O)
- Electrical conductivity (EC)
- Organic matter (loss on ignition)
- Total Cr and Cr (VI) (via alkaline digestion and ICP-OES analysis)
- Cation exchange capacity (CEC)

Land-use Rice fields Coordinates: N15°46'38.1" E119o56'14.1"
Slope Gradient: Nearly Level
Parent Material: Alluvium deposit
Soil Moisture: Regime Ustic
Elevation: 11.5 meters above sea level
Vegetation: Barren, previously rice

(**Figure 1.** Cross-section of the soil in the area at 1 meter depth.)

2. Preparation of biochar and nanomaterials

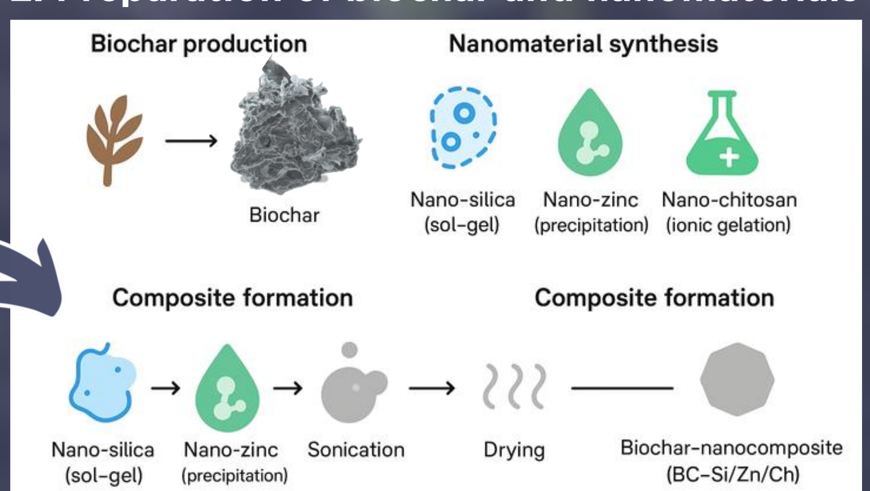

Figure 2. Schematic diagram of the Preparation of biochar and nanomaterials.

Rice husk biochar was produced through pyrolysis at 500°C. Nano-silica, nano-zinc, and nano-chitosan were synthesized using sol-gel, precipitation, and ionic gelation methods, respectively. These nanoparticles were then combined with biochar through sonication and mild heating to form a stable biochar–nanocomposite (BC–Si/Zn/Ch).

3. Experimental design

Table 1. Experimental design and description of treatments

Treatment	Description	Description
T1	Control	Soil only, no plant
T2	Vetiver only	Vetiver planted without any
T3	Vetiver + Biochar	2% (w/w) biochar added to soil
T4	Vetiver + Nanoparticles	Combined nano-silica, nano-zinc, and nano-chitosan
T5	Vetiver + Biochar–Nanocomposite	2% (w/w) biochar loaded with nanoparticles

- Design: Randomized Complete Block Design (RCBD)
- Replicates: 4 per treatment
- Soil per pot: 4 kg (5 L capacity)
- Planting: Vetiver slips (20 cm length) after soil equilibration
- Duration: 90 days
- Conditions: Outdoor shade with regular irrigation to field capacity

4. Chemical and biological analyses

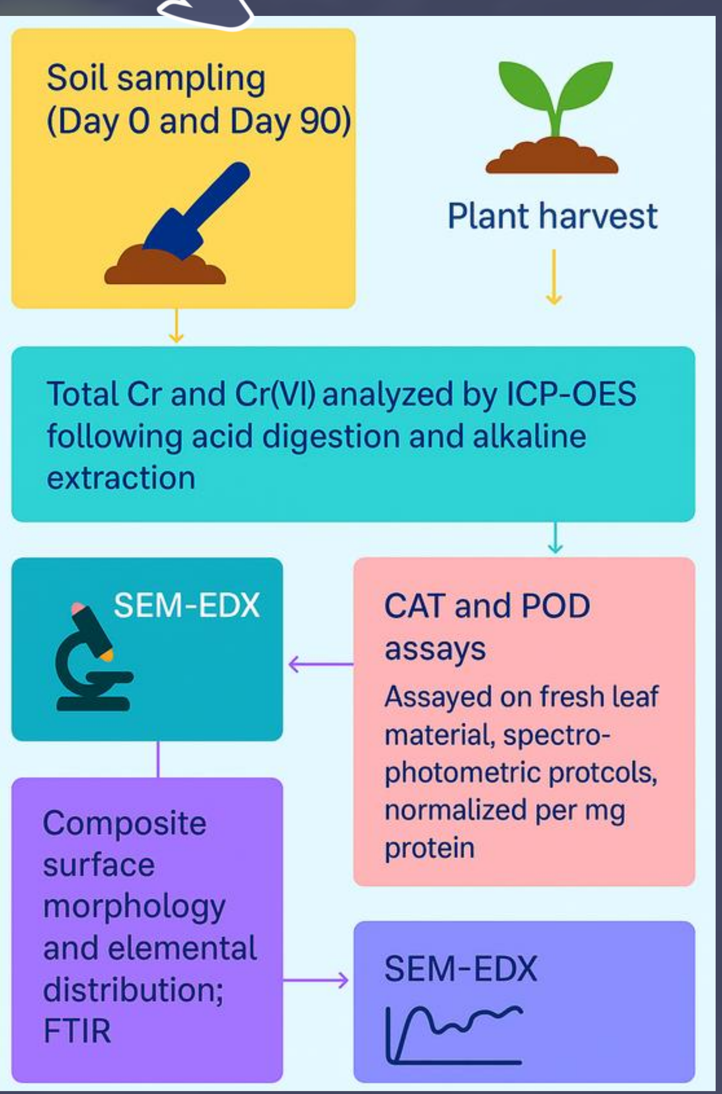

Figure 3. Schematic diagram of the chemical and biological analyses

- Soil samples were collected at day 0 and day 90.
- Total Cr and Cr(VI) were analyzed by ICP-OES following acid digestion and alkaline extraction, respectively.
- Plant shoots and roots were harvested, washed, oven-dried at 60°C, and digested in HNO_3/H_2O_2 for tissue Cr analysis.
- Antioxidant enzyme assays (catalase (CAT) and peroxidase (POD)) were conducted on fresh leaf material using spectrophotometric protocols and normalized per mg protein.
- SEM–EDX examined composite surface morphology and elemental distribution.
- FTIR identified functional groups involved in adsorption.

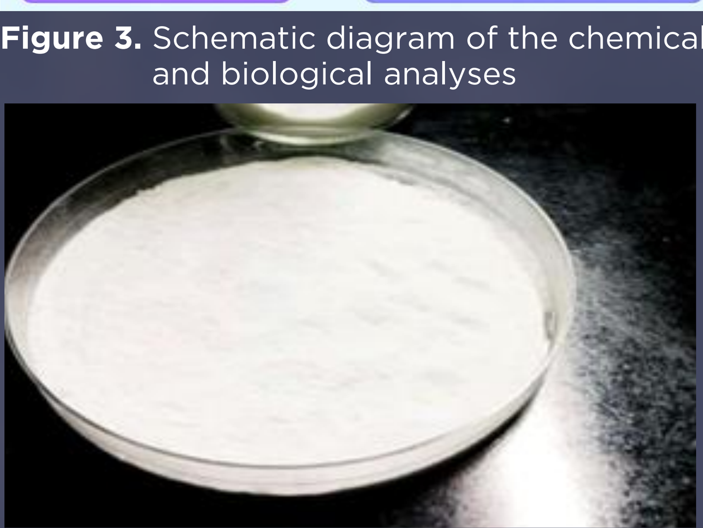

Figure 4. Synthesized silica Nanoparticles from crushed rice hull biochar.

5. Data Analysis

- Data were expressed as mean ± standard deviation (SD).
- One-way ANOVA was used to determine significant differences among treatments.
- Tukey's post-hoc test was applied for multiple comparisons at α = 0.05.
- Bioconcentration Factor (BCF) and Translocation Factor (TF) were computed as:

$$\mathrm{BCF} = \frac{\text{Cr concentration in root or shoot}}{\text{Total Cr concentration in soil}}$$

$$\mathrm{TF} = \frac{\text{Cr concentration in shoot}}{\text{Cr concentration in root}}$$

RESULTS & DISCUSSION

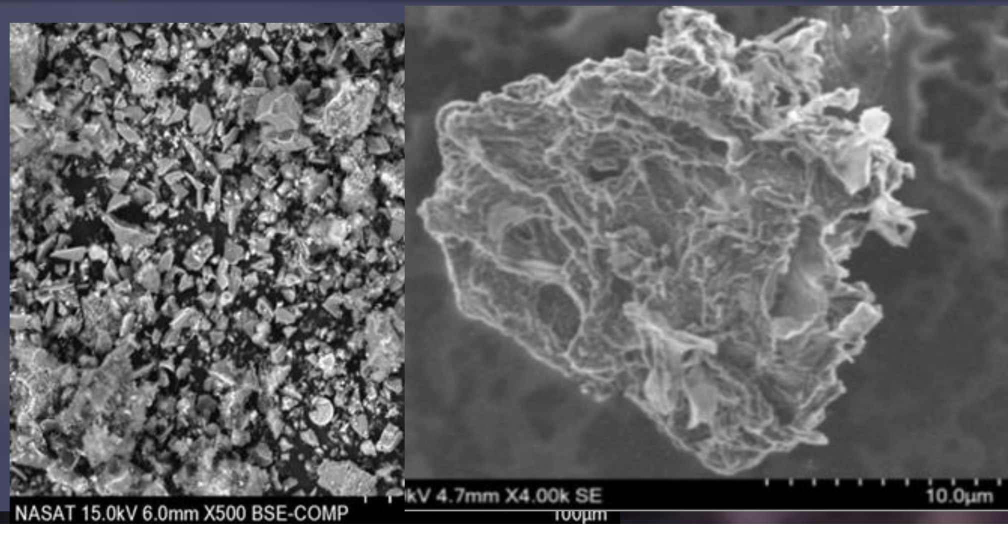

Figure 5. Scanning electron microscope (SEM) of synthesized rice husk **biochar** at 100µm (left) and at 10µm (right).

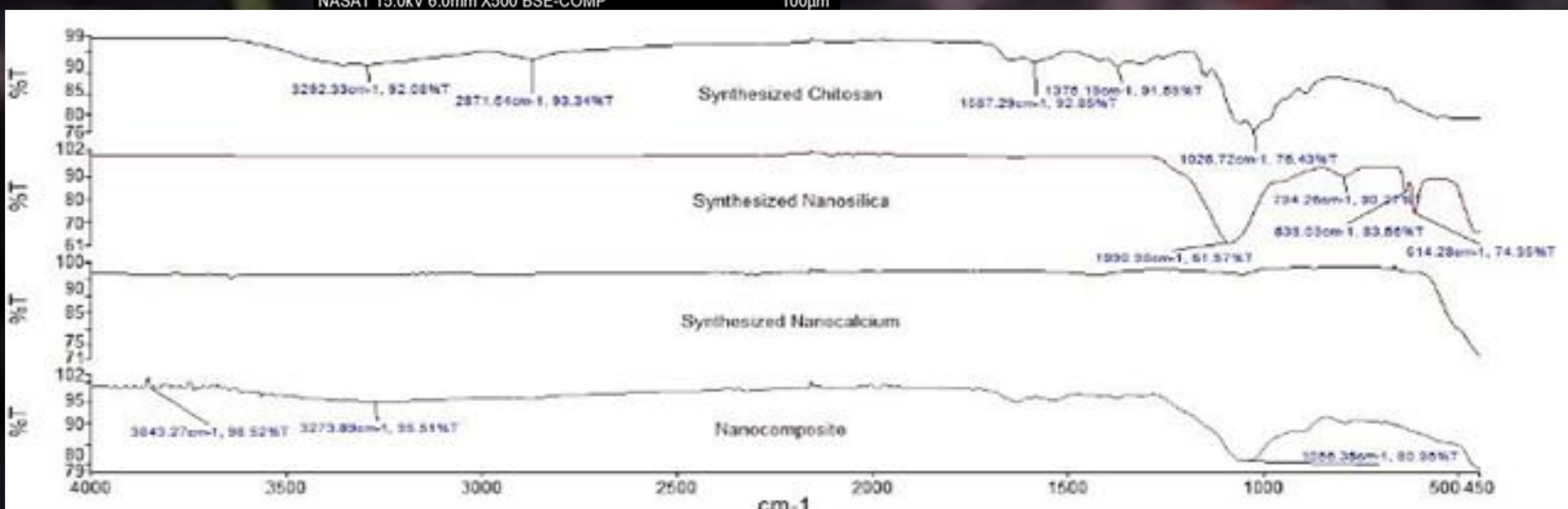

Figure 6. Overlay spectra of the synthesized nano silica, nano calcium, nano chitosan and nanocomposites.

Table 2. Plant parameters of vetiver

TREATMENTS	PLANT PARAMETER					
	Height	Tiller Number	Tiller Diameter	Shoot Weight	Root Weight	Total Biomass
T1 - Control	133.13	30*d*	7.04*c*	130.25*d*	61.33*d*	191.58*e*
T2 – Biochar Alone	139.75	31*d*	7.77*c*	131.23*cd*	153.42*bc*	284.64*cd*
T3 – Nanocomposite Alone	137.75	34*bcd*	9.59*bc*	127.81*d*	111.96*c*	239.78*de*
T4 – Biochar + nano silica	140.5	34*bcd*	15.52*a*	184.98*a*	284.99*a*	469.97*a*
T5 – Biochar + nano calcium	136.88	38*ab*	12.02*ab*	156.07*bc*	183.02*b*	339.09*b*
T6 – Biochar + nano chitosan	139.5	38*ab*	13.04*ab*	163.32*b*	108.47*b*	343.80*bc*
T7 – Biochar + nanocomposite	142.12	42*a*	5.84*c*	146.60*c*	185.14*b*	331.74*bc*
Tukey's HSD value(1%)	ns	7	4.04	2.52	49.32	48.81
cv %	3.99	8.39	17.1	9.1	12.73	6.65

*Mean values w/in a column and factor denoted by the same letter has no significantly at 5% level by HSD

The combination of biochar and nanocomposite enhanced the tillering ability of vetiver, though increased tiller numbers resulted in smaller diameters. This improvement may be attributed to the higher surface area and reactivity of the nanocomposite (Benzon et al., 2015). Silicon nanoparticles further support plant growth by enhancing photosynthesis, tissue strength, and water regulation (Ma & Takahashi, 2002; Rastogi et al., 2019).

Among treatments, biochar + nanosilica showed the highest absorption efficiency (0.2531%), likely due to increased Cr solubility linked to slight pH elevation (Alaboudi et al., 2019), consistent with findings where biochar + chitosan reduced Cr(VI) by 55% (Mandal et al., 2017). However, overall, biochar–nanocomposite application showed limited improvement in vetiver's chromium absorption efficiency.

Table 3. Chromium (Cr) and Nickel (Ni) Absorption Efficiency and Soil Concentration Difference of Vetiver under Different Treatments

Treatment	Cr Absorption Efficiency (%)	Ni Absorption Efficiency (%)	Difference in Soil Cr ($g\cdot kg^{-1}$)	Difference in Soil Ni ($g\cdot kg^{-1}$)
T1 – No Application	0.0852	0.0432	256.11	42.53
T2 – Biochar Alone	0.1256	0.0983	159.54	-138.1
T3 – Nanocomposite Alone	0.0837	0.0999	256.6	57.96
T4 – Biochar + Nano Silica	0.2531	0.1912	437.09	137.96
T5 – Biochar + Nano Calcium	0.1477	0.107	418.75	120.11
T6 – Biochar + Nano Chitosan	0.1608	0.1237	336.83	38.19
Tukey's HSD Value	1.1781	0.1117	402.32	103.68

*computed based on means.

Vetiver applied with Treatment 6 (Biochar + nano chitosan) had lowest difference in terms soil Ni. The result is in contrast with the study of Hadi (2012) and Heidari et al. (2014) wherein Ni bioavailability in soil was reduce, as well as lowered the biological accumulation of Ni in roots and shoots, and Ni transfer to leaves.

CONCLUSION

The study concluded that nano-silica, nano-calcium, and nano-chitosan were successfully synthesized and characterized. The nanomaterials were applied to test the phytoremediation potential of vetiver grass, where biochar + nano-silica produced the highest biomass yield. However, biochar–nanocomposites did not enhance metal absorption, and results highlighted the risk of heavy metal translocation to harvestable plant parts.

FUTURE WORK / REFERENCES

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