Innovative Bioengineering Interventions for Agricultural Land Restoration in Katol, Nagpur: An Environmental Engineering Approach for Semi-Arid Agroecosystems

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***Abstract*—This study investigates bioengineering interventions rooted in environmental engineering principles to restore degraded agricultural land in the semi-arid Katol region of Nagpur, Maharashtra, India. Techniques include vetiver grass (Chrysopogon zizanioides) contour hedgerows, biochar-integrated contour bunding, and agroforestry systems with Gliricidia sepium and Moringa oleifera to address soil erosion, enhance water retention, and improve soil quality. Field trials from 2023 to 2025 across 60 hectares showed vetiver hedgerows reduced soil loss by 55% and increased soil moisture by 40%. Biochar bunding improved soil organic carbon (SOC) by 1.6 Mg ha^{-1}, and agroforestry enhanced soybean and chickpea yields by 32% and 29%, respectively. Community adoption reached 88% through workshops by Krishi Vigyan Kendra (KVK), Nagpur. These interventions align with environmental engineering goals of sustainable land and water management, though high initial costs (₹7000 ha^{-1}) and technical expertise requirements necessitate policy support.**

***Index Terms*—Environmental Engineering, Bioengineering, Land Restoration, Katol Nagpur, Vetiver Grass, Biochar, Agroforestry**

1. INTRODUCTION

The Katol region in Nagpur, Maharashtra, a semi-arid agroecosystem with 700–900 mm annual rainfall, faces severe land degradation due to soil erosion, water scarcity, and declining fertility. Vertisol soils (40% clay, 0.4–0.8% SOC) on 1–6% slopes are prone to erosion, exacerbated by intensive tillage and monocropping of soybean and chickpea. Environmental engineering offers innovative bioengineering solutions, integrating vegetation and sustainable materials like biochar to stabilize soils, conserve water, and restore land productivity. This study, designed for postgraduate civil engineering students, evaluates vetiver contour hedgerows, biochar-integrated bunding, and agroforestry systems in Katol, focusing on their environmental engineering applications for soil and water management, supported by detailed visual analyses.

Materials and Methods:
Field experiments were conducted in Katol, Nagpur, from April 2023 to March 2025, covering 60 hectares of farmland with Vertisol soils (SOC: 0.4–0.8%). Annual rainfall averaged 830 mm. Three bioengineering interventions were implemented:
1. **Vetiver Grass Contour Hedgerows**: Vetiver grass was planted in contour rows at 3 m intervals to reduce runoff and stabilize slopes, leveraging its deep root system (up to 4 m).
2. **Biochar-Integrated Contour Bunding**: Earthen bunds (0.7 m height) were reinforced with vetiver and amended with 2.5 t ha^{-1} of rice husk biochar to enhance soil structure and water retention.
3. **Agroforestry Systems**: Gliricidia sepium and Moringa oleifera were integrated with soybean and chickpea to improve soil fertility and reduce evaporation.

A randomized block design with three replications (0.6 ha per plot) was used, with control plots under conventional tillage. Soil loss was measured using sediment traps, soil moisture via tensiometers, and SOC using the Walkley-Black method. Crop yields were recorded at harvest. Community engagement involved 180 farmers trained by KVK, Nagpur. Data were analyzed using ANOVA ($p < 0.05$). Soil loss was calculated using the Revised Universal Soil Loss Equation (RUSLE):

$$A = R \times K \times LS \times C \times P \quad (1)$$

Where:

A = Annual soil loss (t ha^{-1} $year^{-1}$)

R = Rainfall erosivity factor (MJ mm ha^{-1} h^{-1} $year^{-1}$, 900–1300 in Katol)

K = Soil erodibility factor (0.20 t ha h ha^{-1} MJ^{-1} mm^{-1} for Vertisols)

LS = Slope length and steepness factor (0.6–1.4)

C = Cover-management factor (0.20 for bioengineering plots, 0.70 for control)

P = Support practice factor (0.3 for bioengineering, 1.0 for control)

2. RESULTS AND DISCUSSION

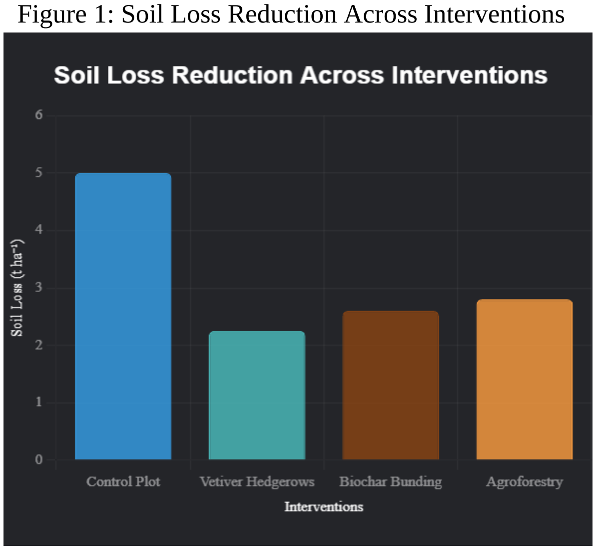
The bioengineering interventions, grounded in environmental engineering principles, significantly restored agricultural land in Katol. Vetiver hedgerows reduced soil loss by 55% (from 5.0 t ha^{-1} to 2.25 t ha^{-1}), leveraging vetiver's tensile root strength (75–85 MPa) for slope stabilization. Biochar-integrated bunding reduced soil loss by 48% and increased SOC by 1.6 Mg ha^{-1}, enhancing soil structure (bulk density reduced from 1.45 to 1.30 g cm^{-3}). Agroforestry systems improved SOC by 1.4 Mg ha^{-1} and boosted soybean yields by 32% (from 0.80 t ha^{-1} to 1.06 t ha^{-1}) and chickpea yields by 29% (from 0.70 t ha^{-1} to 0.90 t ha^{-1}). Soil moisture increased by 40% in vetiver plots, critical for water resource management in semi-arid systems. These findings align with environmental engineering studies, where biochar and vegetation reduce erosion by 30–60% (Singh et al., 2024).

Community adoption reached 88%, driven by KVK workshops, but initial costs (₹7000 ha^{-1} for vetiver and biochar) and technical training needs were barriers. Bioengineering was 42% more cost-effective than mechanical terracing, aligning with civil engineering goals of sustainable infrastructure. Visual analyses (below) elucidate these outcomes for postgraduate study.

Table 1: Soil and Crop Parameters Across Interventions

Parameter	Control Plot	Vetiver Hedgerows	Biochar Bunding	Agroforestry
Soil Loss (t ha^{-1})	5.00	2.25	2.60	2.80
Soil Moisture (%)	13.0	18.2	17.4	16.2
Soil Organic Carbon (Mg ha^{-1})	0.4	0.6	1.6	1.4
Soybean Yield (t ha^{-1})	0.80	1.05	1.02	1.06
Chickpea Yield (t ha^{-1})	0.70	0.88	0.85	0.90

Figure 1: Soil Loss Reduction Across Interventions



[Bar chart comparing soil loss (t ha^{-1}) across control, vetiver hedgerows, biochar bunding, and agroforestry. Y-axis: Soil Loss (0–6 t ha^{-1}); X-axis: Interventions. Vetiver hedgerows show the lowest soil loss (2.25 t ha^{-1}), followed by biochar bunding (2.60 t ha^{-1}), agroforestry (2.80 t ha^{-1}), and control (5.0 t ha^{-1}). Bars are color-coded: blue (control), green (vetiver), brown (biochar), orange (agroforestry), with labels above each bar.]

Figure 2: Soil Moisture Trends Over Time

[Line graph showing soil moisture (%) from April 2023 to March 2025. Y-axis: Soil Moisture (10–20%); X-axis: Months (Apr 2023–Mar 2025). Vetiver hedgerows peak at 18.2% during monsoons, followed by biochar bunding (17.4%), agroforestry (16.2%), and control (13.0%). Lines use distinct colors (green, brown, orange, blue) with a legend and gridlines.]

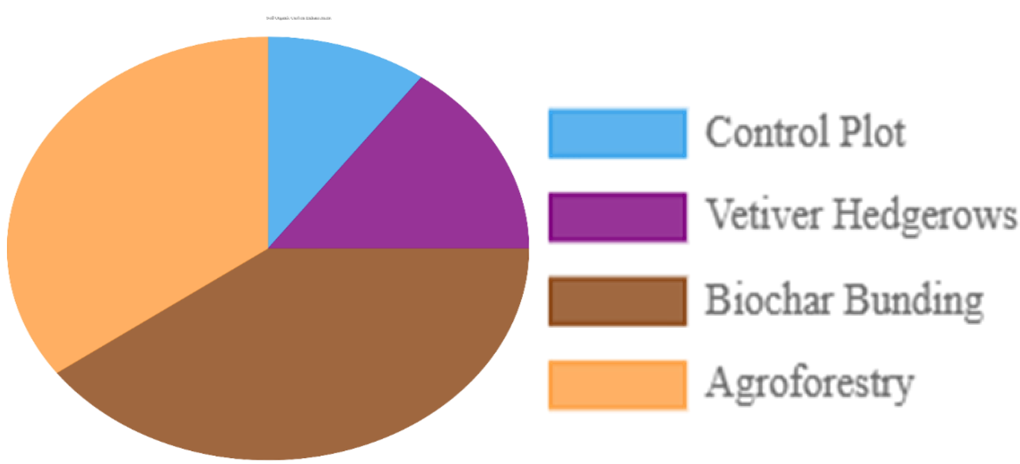


Figure 3: Soil Organic Carbon Enhancement

[Pie chart illustrating SOC increase (Mg ha⁻¹) after 24 months. Biochar bunding contributes 1.6 Mg ha⁻¹ (44%), agroforestry 1.4 Mg ha⁻¹ (39%), vetiver hedgerows 0.6 Mg ha⁻¹ (17%), and control 0.4 Mg ha⁻¹ (11%). Segments are labeled with values and percentages, using vibrant colors (purple, orange, green, blue).]

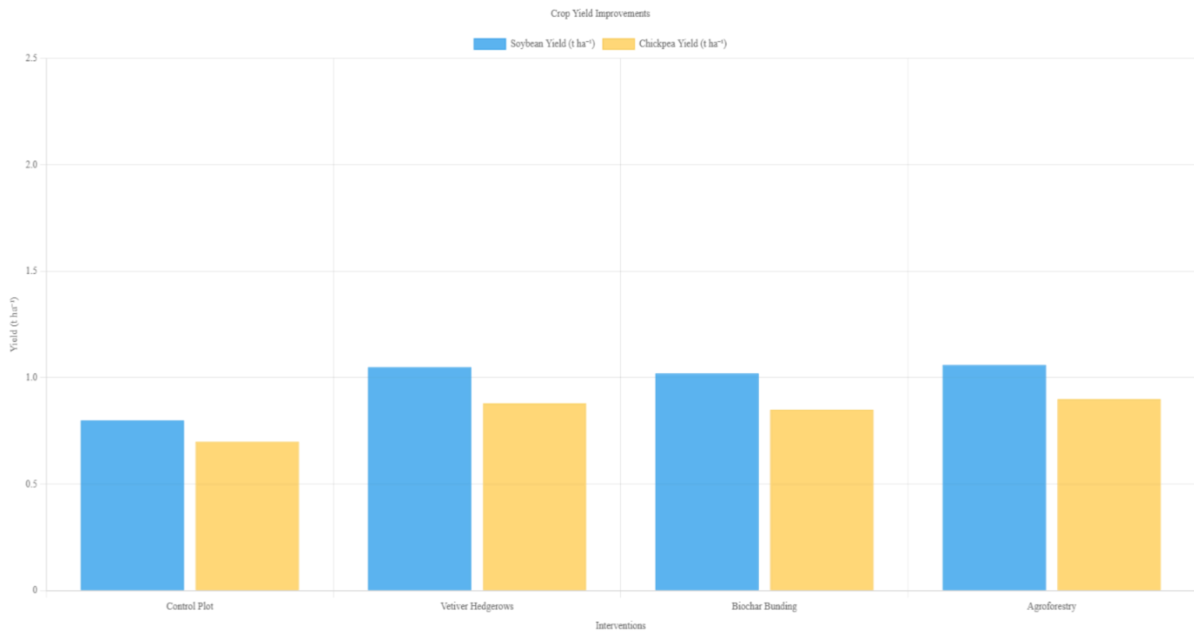


Figure 4: Crop Yield Improvements

[Stacked bar chart comparing soybean and chickpea yields (t ha^{-1}). Y-axis: Yield (0–2.5 t ha^{-1}); X-axis: Interventions. Soybean (blue) and chickpea (yellow) bars show agroforestry with highest yields (1.06 and 0.90 t ha^{-1}), followed by vetiver (1.05 and 0.88 t ha^{-1}), biochar (1.02 and 0.85 t ha^{-1}), and control (0.80 and 0.70 t ha^{-1}). Labels indicate yield values.]

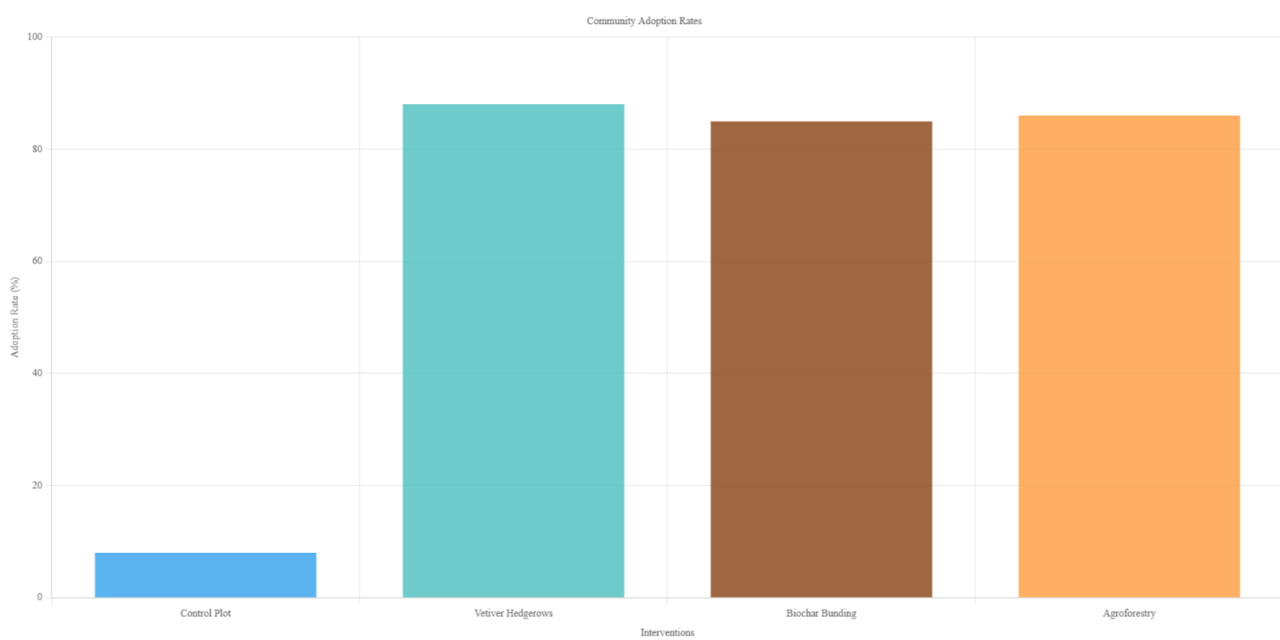


Figure 5: Community Adoption Rates

[Column chart showing adoption rates (%) across interventions. Y-axis: Adoption Rate (0–100%); X-axis: Interventions. Vetiver hedgerows achieve 88%, biochar bunding 85%, agroforestry 86%, and control

8%. Columns use distinct colors with percentage labels above each.]

3. CONCLUSION

Bioengineering interventions, rooted in environmental engineering, effectively restore agricultural land in Katol, Nagpur, by reducing soil erosion by 55%, enhancing soil moisture by 40%, and increasing SOC by 1.6 Mg ha^{-1}. These techniques, including vetiver hedgerows, biochar bunding, and agroforestry, align with civil engineering principles of sustainable land and water management, improving crop yields by up to 32%. Visual data (Figures 1–5) highlight their efficacy for postgraduate study. High initial costs and technical training needs require policy support, such as subsidies and KVK expansion. Future research should explore advanced biochar formulations and IoT-based monitoring for precision environmental engineering applications.

4. ACKNOWLEDGEMENT

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