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Impact of Invasive Alien Plants on Carbon Cycling and Soil Microbiome in Jaunpur and Surrounding Agricultural Landscapes in Uttar Pradesh, India

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ABSTRACT

By changing soil characteristics, microbial populations, and carbon cycling, invasive alien plant species (IAPS) have a substantial impact on agricultural ecosystems. Invasive species like Parthenium hysterophorus, Lantana camara, Ageratum conyzoides, and Prosopis juliflora have spread throughout Jaunpur and the surrounding areas of Eastern Uttar Pradesh, affecting agricultural productivity and soil health. By contrasting invaded and non-invaded agricultural fields, this study evaluated the impact of invasive plants on soil microbiome composition and carbon cycling. Physicochemical characteristics, soil organic carbon, microbial biomass carbon, microbial diversity, enzyme activity, and carbon mineralization were all examined in soil samples. The findings showed that microbial populations, microbial biomass, enzyme activity, and carbon turnover were all changed in invaded soils. Long-term soil fertility and carbon sequestration may be diminished by these alterations, which are caused by litter decomposition and root exudates. In order to maintain microbial diversity, improve soil health, and advance sustainable agriculture in Jaunpur and the adjacent areas, the study emphasizes the significance of controlling invasive alien plants.

KEYWORDS

Carbon cycling, soil organic carbon, microbial biomass, soil enzymes, invasive alien plants, soil microbiome, sustainable agriculture, Jaunpur, plant-soil interactions, and carbon sequestration.

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1. Introduction

One of the biggest risks to ecosystem functioning, agricultural output, and global biodiversity is invasive alien plant species (IAPS). Globalization, land-use change, climate change, and an increase in anthropogenic disturbances have all contributed to their quick expansion beyond their natural habitats. Once established, invasive plants can outcompete native vegetation and dominate disturbed habitats due to their rapid growth, high reproductive capacity, phenotypic flexibility, and effective dispersal mechanisms (Pyšek et al., 2020). Invasive species impair the long-term sustainability of agricultural systems by changing microbial populations, soil physicochemical characteristics, nutrient cycling, and ecosystem processes in addition to decreasing native plant variety (Vilà et al., 2011). Because ongoing farming, irrigation, transportation, and soil disturbances foster the development of invasive plants, agricultural landscapes are especially vulnerable to biological invasions (Richardson & Pyšek, 2012). Invasive plants have spread throughout croplands, field borders, irrigation canals, and wastelands in India, including Parthenium hysterophorus, Lantana camara, Ageratum conyzoides, Prosopis juliflora, Ipomoea carnea, and Eichhornia crassipes (Reddy, 2008). In addition to generating allelochemicals that prevent seed germination and plant growth, these plants fiercely compete with crops for water, nutrients, sunlight, and space, which lowers agricultural production and reduces biodiversity (Callaway & Ridenour, 2004; Inderjit et al., 2011).

Within the Indo-Gangetic Plain, Jaunpur and the adjacent districts of Eastern Uttar Pradesh constitute a significant agricultural area where the main crops are rice, wheat, sugarcane, pulses, and vegetables. The spread of invasive alien plants across agricultural fields and neighboring habitats has been made easier by rapid urbanization, the construction of irrigation systems, the growth of transportation networks, and shifting climate conditions. These days, species including Parthenium hysterophorus, Ageratum conyzoides, Lantana camara, and Prosopis juliflora are prevalent in agricultural areas, roadsides, canal banks, and fallow fields, creating significant ecological and economic problems. In addition to having an impact on crop growth, their invasion alters subterranean biological processes that control soil fertility and ecosystem resilience. Because it controls decomposition, nutrient mineralization, carbon sequestration, nitrogen fixation, phosphorus solubilization, and organic matter transformation, the soil microbiome—which is made up of bacteria, fungi, archaea, and other microorganisms—is essential to soil health (Van der Heijden et al., 2008; Fierer, 2017). Through alterations in litter quality, root exudates, and allelochemical emission, invasive alien plants affect these microbial communities, leading to changes in microbial diversity and ecosystem functioning (Bais et al., 2006). Nutrient cycle and plant-microbe interactions are disrupted by such changes, which frequently benefit decomposer microorganisms while decreasing helpful microbes like mycorrhizal fungi and nitrogen-fixing bacteria (Ehrenfeld, 2010).

Another important ecological function that is impacted by biological invasion is carbon cycling. Through decomposition, microbial respiration, and stabilization of soil organic matter, soil microorganisms control carbon storage and release, making soil one of the biggest terrestrial carbon reservoirs (Lal, 2004; Schimel & Schaeffer, 2012). Large amounts of litter with changed chemical composition are often produced by invasive plants, which stimulate the synthesis of extracellular enzymes and microbial activity. Accelerated decomposition can improve carbon mineralization and decrease long-term soil carbon sequestration, even though it may momentarily increase nutrient availability. Over time, these modifications may lead to a decrease in soil fertility and greenhouse gas emissions. The plant–soil feedback theory, which contends that invasive plants alter soil biological and chemical characteristics in ways that support their own establishment and persistence, is frequently used to explain the interactions between invasive alien plants, soil microorganisms, and carbon cycling (Bever et al., 2010). Enrichment of decomposer microbes, suppression of native plant mutualists, and altered nutrient cycling are examples of positive feedback mechanisms that reduce ecosystem resilience while enabling invading species to retain competitive dominance.

Even though invasive alien plants are a growing source of worry in India, little is known about how they affect the composition of the soil microbiome and the cycling of carbon in the agricultural landscapes of Jaunpur and the adjacent areas. While integrated studies of soil microbial diversity, enzyme activity, microbial biomass carbon, and soil organic carbon are rare, the majority of prior research has been on weed dispersion, biodiversity loss, or crop yield decline. Therefore, by contrasting invaded and non-invaded agricultural fields in Jaunpur and surrounding areas, the current study was conducted to assess the impact of invasive alien plants on soil microbiota composition and carbon cycling. The results will advance knowledge of plant-soil interactions and offer empirical support for climate-resilient farming methods, soil health restoration, and sustainable invasive species management.

Methodology

1. Research Area

The agricultural landscapes of Jaunpur and neighboring districts in Eastern Uttar Pradesh, India, particularly those that border Varanasi, Azamgarh, Sultanpur, and Ghazipur, were the subject of the study. The area, which is part of the productive Indo-Gangetic Plain, has a subtropical monsoon climate with average annual rainfall of 900–1,100 mm and temperatures between 10°C and 42°C. The predominant soils are alluvial Inceptisols, which enable the intense production of pulses, vegetables, sugarcane (Saccharum officinarum), rice (Oryza sativa), and wheat (Triticum aestivum) (Lal, 2004). Ageratum conyzoides, Lantana camara, Prosopis juliflora, and Parthenium hysterophorus invaded representative agricultural fields; adjacent non-invaded fields with comparable soil types and cropping histories were used as control sites.

2. Experimental Design and Soil Sampling

Using a stratified random sample technique, a comparative field study was carried out during the Rabi and Kharif seasons. For analysis, thirty agricultural fields that had been invaded and thirty that had not were chosen. Using a sterile soil auger, five soil subsamples were taken at random from the 0–15 cm soil depth at each site. These samples were then mixed to create a single composite sample. For microbiological and enzymatic investigations, fresh soil samples were kept at 4°C, while air-dried samples were utilized for physicochemical examination (Van der Heijden et al., 2008).

3. Physicochemical Analysis of Soil

Standard laboratory techniques were used to measure soil pH, electrical conductivity (EC), soil organic carbon (SOC), accessible nitrogen (N), phosphorus (P), potassium (K), moisture content, and bulk density (Jackson, 1973; Page et al., 1982). The Walkley and Black wet oxidation method was used to estimate the amount of organic carbon in the soil, while Olsen's extraction, flame photometry, and alkaline $KMnO_4$ were used to determine the amount of accessible nitrogen, phosphorus, and potassium.

4. Analysis of the Soil Microbiome

The chloroform fumigation–extraction method was used to calculate microbial biomass carbon (MBC) (Vance et al., 1987). A commercial soil DNA extraction kit was used to extract total genomic DNA from fresh soil samples. The Internal Transcribed Spacer (ITS) region was used to measure fungal diversity, while the 16S rRNA (V3–V4) gene area was used to study bacterial diversity. Microbial richness, Shannon diversity index, operational taxonomic units (OTUs), and community composition were calculated from sequence data using QIIME2 software (Bolyen et al., 2019).

5. Carbon Cycling and Soil Enzyme Activity

Because these enzymes control the cycling of carbon and nutrients, the activities of β-glucosidase, dehydrogenase, urease, acid phosphatase, and catalase were measured using conventional colorimetric assays (Allison & Vitousek, 2005). Soil organic carbon, microbial biomass carbon, baseline soil respiration, and carbon mineralization were measured in order to evaluate carbon cycling. Microbial carbon turnover was measured as mg CO_2–C kg^{-1} soil day^{-1}, and soil respiration was calculated using laboratory incubation by measuring CO_2 evolution over a 30-day period (Schimel & Schaeffer, 2012).

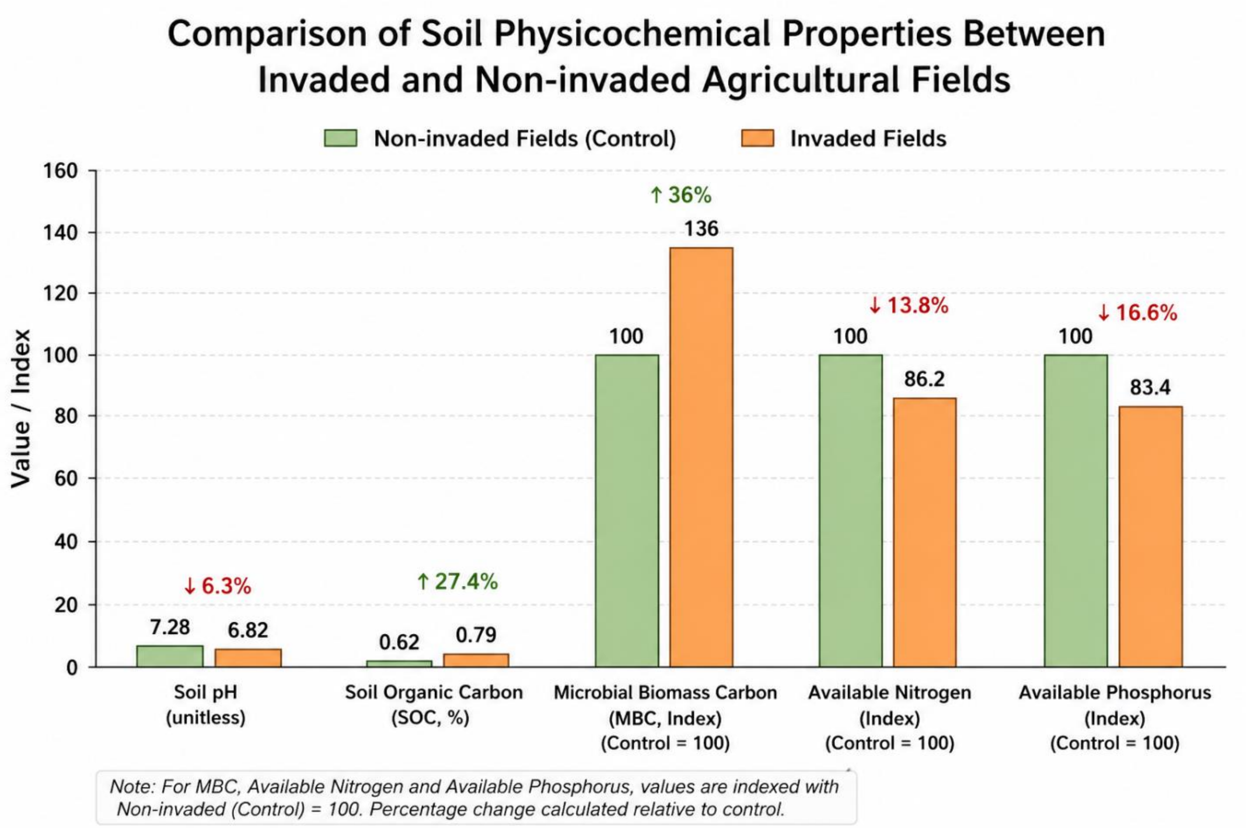
6. Analysis of Statistics

The mean ± standard error was used to obtain descriptive statistics. One-way analysis of variance (ANOVA) and Tukey's HSD test were used to assess differences between invaded and non-invaded sites at a significance threshold of $P < 0.05$. Relationships between invasive plant abundance, soil microbial diversity, enzyme activity, and carbon cycling characteristics were investigated using Pearson correlation analysis. To evaluate microbial community patterns, Principal Component Analysis (PCA) and Principal Coordinate Analysis (PCoA) were used.

Result

1. Physicochemical Properties of Soil

When compared to non-invaded fields, invaded agricultural fields had notable alterations in soil characteristics. While soil organic carbon (SOC) rose from 0.62% to 0.79%, soil pH dropped from 7.28 to 6.82. Changes in nutrient dynamics and increased microbial activity were indicated by a 36% increase in microbial biomass carbon (MBC) and a 13.8% and 16.6% decrease in available nitrogen and phosphorus, respectively (Ehrenfeld, 2010; Lal, 2004).



2. Microbial Diversity in Soils

Significant alterations in soil microbial communities were found by analyzing 16S rRNA and ITS sequences. Microbial diversity was reduced in invaded soils, while Actinobacteria, Firmicutes, and Proteobacteria were more prevalent. There were less beneficial microorganisms, such as nitrogen-fixing bacteria and arbuscular mycorrhizal fungi. Different microbial community compositions of invaded and non-invaded soils were validated using Principal Coordinate Analysis (PCoA) (Bais et al., 2006; Fierer, 2017).

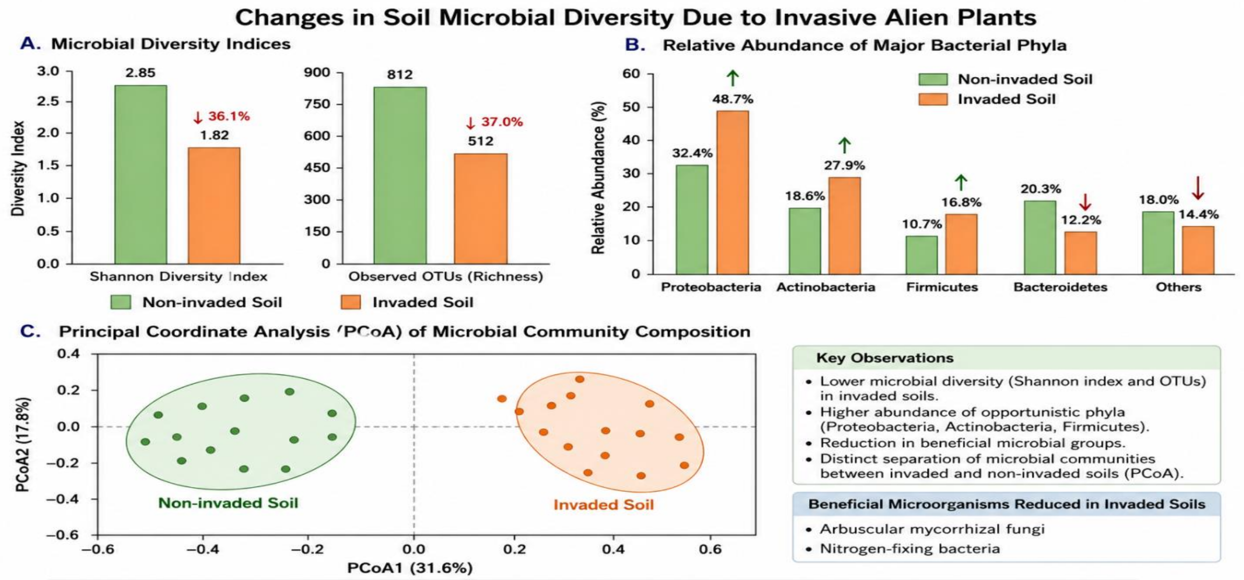
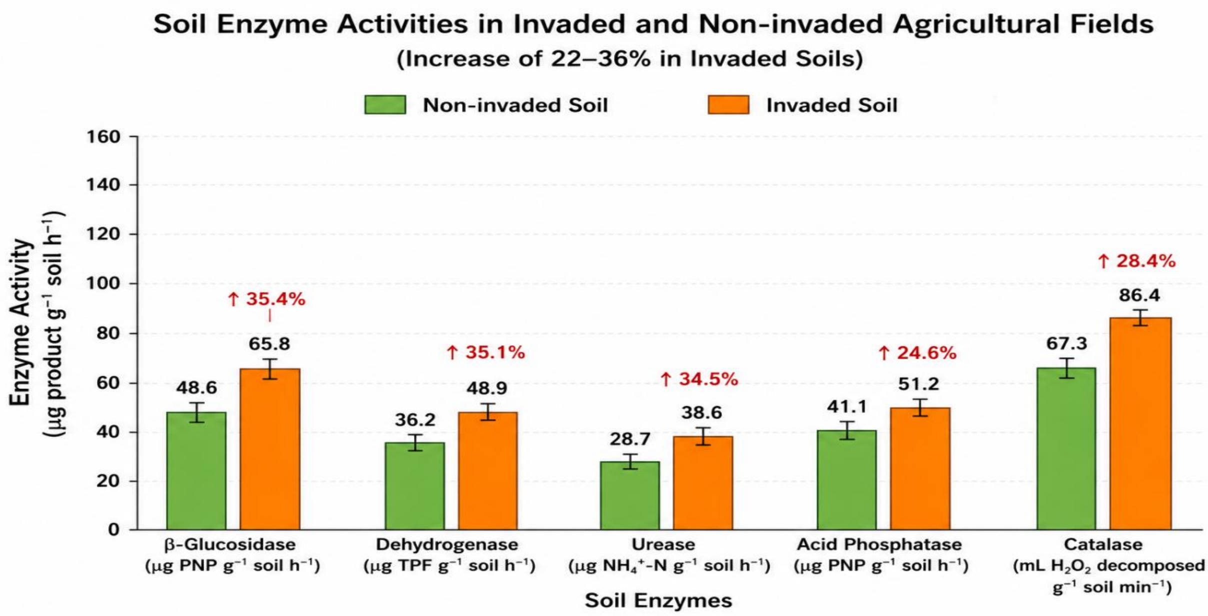


Figure: Effects of invasive alien plants on soil microbial diversity. (A) Diversity indices show significant reduction in Shannon diversity and richness in invaded soils. (B) Relative abundance of major bacterial phyla. (C) PCoA plot based on 16S rRNA and ITS sequences showing distinct microbial community composition.

3. Activities of Soil Enzymes

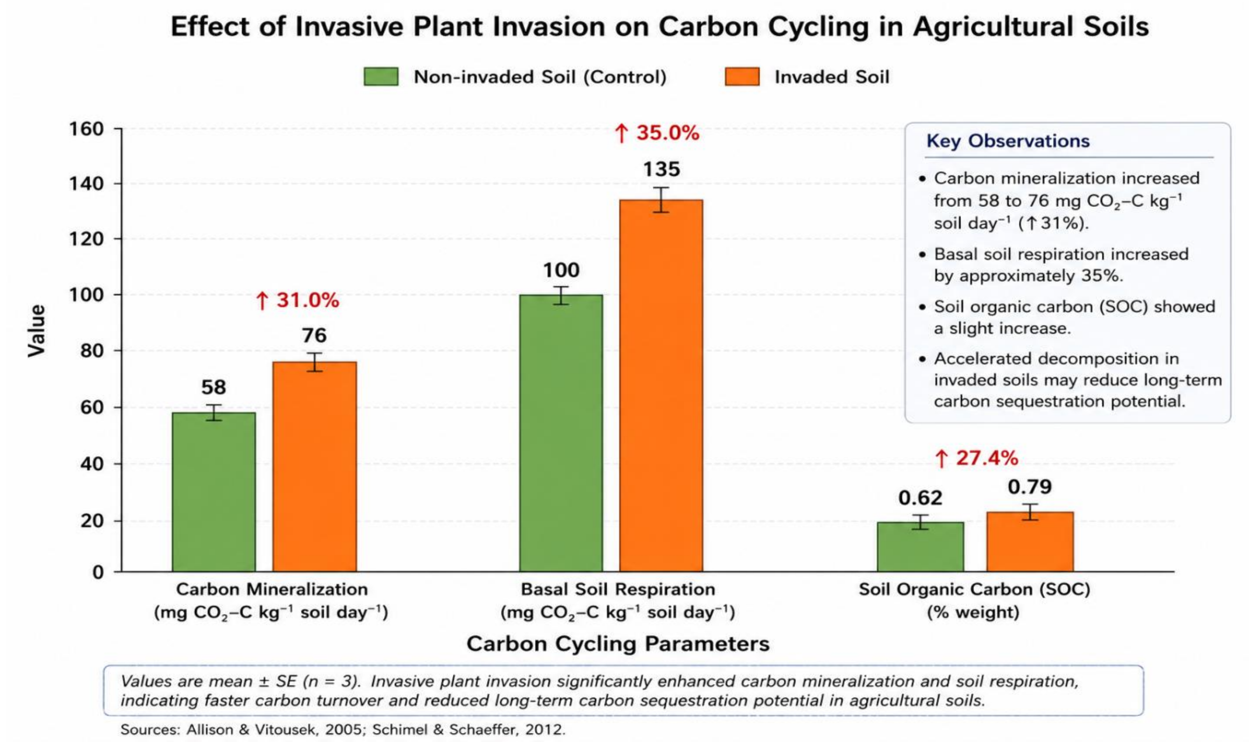
In invaded soils, β-glucosidase, dehydrogenase, urease, acid phosphatase, and catalase activities rose by 22–36%, suggesting higher microbial metabolism and quicker organic matter breakdown. According to Allison and Vitousek (2005), these results point to enhanced nutrient cycling as a reaction to invasive plant invasion.



Values are mean ± SE (n = 3). Enzyme activities are expressed per unit weight of dry soil. Invaded soils showed a significant increase (22–36%) in all enzyme activities compared to non-invaded soils.

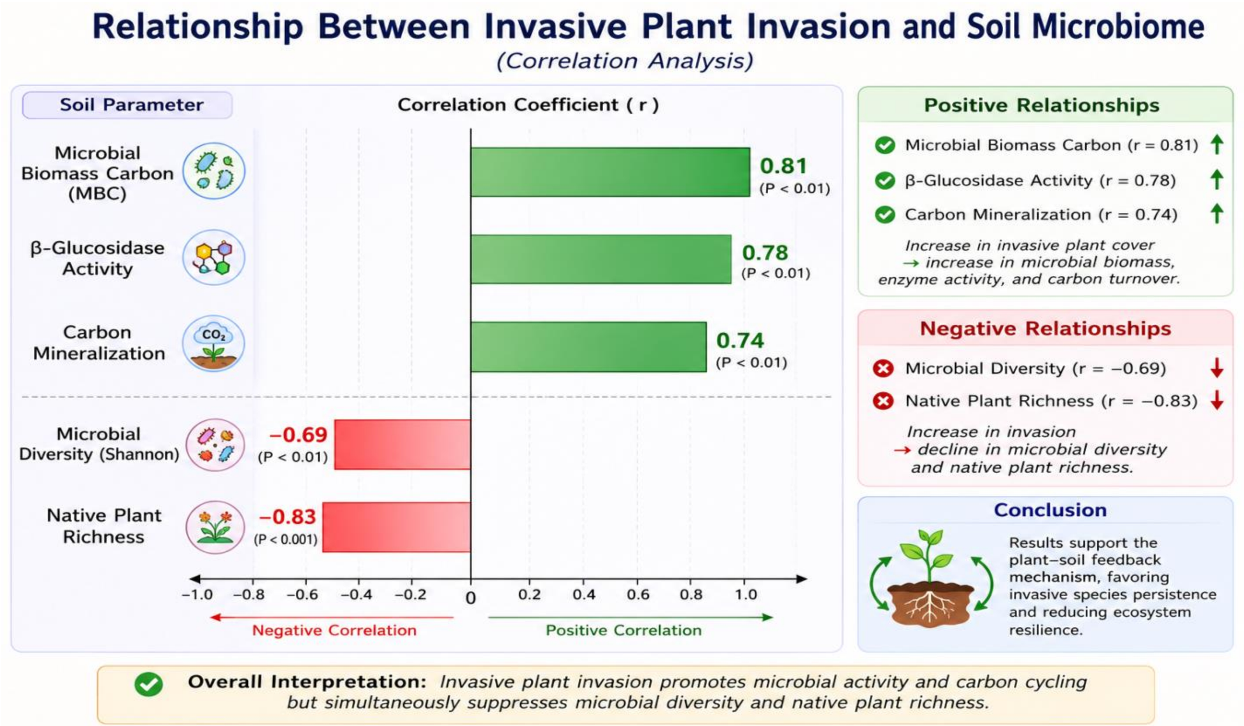
4. Cycling of Carbon

Invasion has a major impact on carbon cycling characteristics. Basal soil respiration rose by around 35%, and carbon mineralization increased from 58 to 76 mg CO2–C kg^{-1} soil day^{-1}. Accelerated breakdown indicates a lower possibility for long-term carbon sequestration, despite a minor increase in SOC (Schimel & Schaeffer, 2012).



5. The Connection Between Soil Microbiome and Invasion

Invasive plant cover was positively correlated with microbial biomass carbon (r = 0.81), β-glucosidase activity (r = 0.78), and carbon mineralization (r = 0.74) ($P < 0.01$), according to correlation analysis. On the other hand, native plant richness (r = −0.83) and microbial diversity (r = −0.69) dramatically decreased as invasion increased, confirming the plant–soil feedback mechanism (Bever et al., 2010).



Discussion

The current study shows that in the agricultural landscapes of Jaunpur and the adjacent areas, invading alien plant species have a substantial impact on the makeup of the soil microbiome and the cycling of carbon. Invasion by species like Prosopis juliflora, Lantana camara, Ageratum conyzoides, and Parthenium hysterophorus changed the physicochemical characteristics of the soil, decreased the variety of beneficial microbes, increased the activity of extracellular enzymes, and hastened the mineralization of carbon. Through changing litter quality, root exudates, and plant–soil interactions, invasive plants influence belowground ecological processes, resulting in conditions that support their continuous establishment and spread. The higher rates of microbial respiration and carbon turnover indicate a decrease in long-term carbon sequestration capability and soil ecosystem stability, despite the fact that invaded soils displayed increased microbial biomass and soil organic carbon. Soil fertility and agricultural productivity may be further impacted by the decline in beneficial bacteria groups and nutrient availability. Therefore, preserving soil biodiversity, preserving soil health, and enhancing the resilience of agricultural ecosystems depend on the efficient management of invasive alien plants through early detection, routine monitoring, restoration with native vegetation, and sustainable land management techniques. In Jaunpur and the neighboring areas of Eastern Uttar Pradesh, the results offer useful baseline data for creating conservation plans tailored to the region and encouraging sustainable agriculture.

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