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Impact of Invasive Alien Plant Species on Nutrient Dynamics and Soil Enzyme Activity in Croplands

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ABSTRACT

Reduced agricultural productivity, soil degradation, and biodiversity loss are all significantly influenced by invasive alien plant species (IAPS). They negatively impact crop performance while favoring their own growth by altering the physicochemical characteristics of the soil, microbial communities, enzyme activity, and nutrient cycling. Invasive plants have a major impact on soil enzymes including β-glucosidase, urease, phosphatase, dehydrogenase, and catalase, which are important markers of soil health and alter the cycle of carbon, nitrogen, and phosphorus. Parthenium hysterophorus, Lantana camara, Ageratum conyzoides, Prosopis juliflora, and Chromolaena odorata are among the invasive species that have spread throughout I This review highlights the implications for sustainable agriculture, soil restoration, and biodiversity conservation by summarizing recent research on the effects of invasive alien plants on soil enzyme activity and nutrient dynamics in croplands.

KEYWORDS
Nutrient cycling, soil fertility, cropland ecosystems, invasive alien plant species, soil enzyme activity, soil microbes, and agricultural sustainabilityndia, interfering with soil biological processes and decreasing soil fertility.

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1. Introduction

Because invasive alien plant species destroy biodiversity, interfere with ecosystem functioning, and lower agricultural productivity globally, biological invasion is a significant ecological concern (Roy et al., 2024). They can spread swiftly, outcompete native flora, and change belowground soil processes, which can have an impact on long-term soil health and agricultural productivity because to their quick growth, high reproductive capacity, and adaptability (Raheem et al., 2024; Zhang et al., 2019).

1. The Basis of Agricultural Ecosystems: Soil

By controlling nutrient availability, water retention, microbial diversity, and ecosystem resilience, healthy soil promotes sustainable agriculture (Raheem et al., 2024). Soil enzyme activity is a trustworthy indication of soil biological health and nutrient cycling because soil microorganisms use extracellular enzymes to drive decomposition and nutrient mineralization (Chen et al., 2025; Zhang et al., 2019).

Key Soil Enzymes consist of:

- **β-glucosidase**: cellulose breakdown and carbon cycling.
- **Urease**: Mineralization of nitrogen.
- **Acid Phosphatase**: Mineralization of organic phosphorus.
- **Alkaline Phosphatase**: availability of phosphorus.
- **Dehydrogenase**: Total microbial activity.
- **Catalase**: detoxification of reactive oxygen species and defense against oxidative stress. By regulating the turnover of carbon, nitrogen, phosphorus, and other vital elements, these enzymes work together to govern soil fertility (Chen et al., 2025).

2. How Invasive Plants Affect Soil Functions

According to recent research, invasive alien plants modify litter quality, root exudates, microbial populations, soil moisture, dissolved organic carbon, and nutrient availability, among other soil processes (Raheem et al., 2024). In addition to limiting native vegetation and lowering crop yield, these modifications increase microbial activity, quicken nutrient cycling, and provide favorable plant–soil feedbacks that encourage invasion (Zhang et al., 2019; Chen et al., 2025; Roy et al., 2024).

3. Activity of Soil Enzymes During Plant Invasion

Soil enzyme activity, a crucial factor in ecosystem functioning, is greatly impacted by invasive plants (Chen et al., 2025). According to a global meta-analysis, invasion caused increases in carbon-acquiring enzymes of 18%, nitrogen-acquiring enzymes of 29%, and phosphorus-acquiring enzymes of 32%. These modifications improve the cycling of nutrients, especially in farmland ecosystems.

4. The Dynamics of Nutrients During Plant Invasion

By speeding up litter decomposition, nutrient mineralization, and microbial activities, invasive alien plants alter the cycling of carbon, nitrogen, and phosphorus (Raheem et al., 2024; Zhang et al., 2019). Over time, decreasing soil fertility and agricultural production result from invasive species using nutrients more effectively than crops, despite an initial boost in nutrient availability (Chen et al., 2025).

5. Alien Invasive Plants in Indian Croplands

Indian croplands are seeing a rapid expansion of invasive alien plants such Parthenium hysterophorus, Lantana camara, Ageratum conyzoides, Chromolaena odorata, and Prosopis juliflora (Roy et al., 2024). Through their alteration of soil biological processes, these species pose a threat to crop productivity in eastern Uttar Pradesh, particularly Jaunpur. However, little is known about how they affect the dynamics of nutrients and soil enzyme activity in this area.

Methodology

1. Research Area

The study was carried out in the agricultural areas of Uttar Pradesh, India's Jaunpur District. Crops including wheat, rice, chickpeas, pigeon peas, and mustard are supported by the region's alluvial soils and subtropical climate. Parthenium hysterophorus, Ageratum conyzoides, Lantana camara, Prosopis juliflora, and Chromolaena odorata are examples of common invasive plants (Chen et al., 2025; Roy et al., 2024).

2. Design of Experiments

Ten invaded (>70% invasive cover) and ten non-invaded agricultural areas with comparable soil and management characteristics were examined using a paired-site design. In each field, five 1 m × 1 m quadrats were positioned at random to collect soil and vegetation samples.

3. Survey of Vegetation

Invasive species richness, density, frequency, abundance, and percentage cover were recorded in order to evaluate the vegetation using the quadrat method. For dominating invasive species, the Importance Value Index (IVI) was computed.

4. Sampling of Soil

Samples of composite soil (0–15 cm depth) were taken between November and January. Samples were separated into fresh soil (4°C) for microbiological and enzyme assays and air-dried soil for physicochemical examination (Myszura-Dymek et al., 2024).

5. Examination of the Physicochemical Characteristics of Soil

To assess soil quality and nutrient status, standard laboratory techniques were used to measure soil pH, electrical conductivity, organic carbon, nitrogen, phosphorus, potassium, moisture, and bulk density.

6. Analysis of Soil Enzyme Activity

Standard biochemical techniques were used to evaluate the activities of β-glucosidase, urease, acid phosphatase, dehydrogenase, and catalase. These enzymes show nitrogen cycling and soil microbial activity (Chen et al., 2025).

7. Analysis of Microbial Biomass

The chloroform fumigation–extraction method was used to measure microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN). Microbial activity and soil biological fertility are reflected in these metrics.

8. Evaluation of Nutrient Dynamics

Nutrient cycling in invaded and non-invaded soils was evaluated by measuring soil organic carbon, dissolved organic carbon, total nitrogen, accessible nitrogen, phosphorus, potassium, and the C:N ratio (Chen et al., 2025).

9. Analysis of Statistics

Descriptive statistics, t-tests, one-way ANOVA, Pearson correlation, Principal Component Analysis (PCA), and Redundancy Analysis (RDA) were used to examine the data. $P < 0.05$ was used to determine statistical significance.

Result

1. Invasive Alien Plant Species Distribution

In the croplands of the Jaunpur area, five major invasive alien plant species were found through field surveys: Parthenium hysterophorus, Ageratum conyzoides, Lantana camara, Chromolaena odorata, and Prosopis juliflora. Ageratum conyzoides and Parthenium hysterophorus had the greatest Importance Value Index (IVI). Strong invasion and dominance in agricultural ecosystems were demonstrated by the significantly higher invasive plant cover (72–91%) in invaded fields compared to non-invaded fields ($P < 0.001$).

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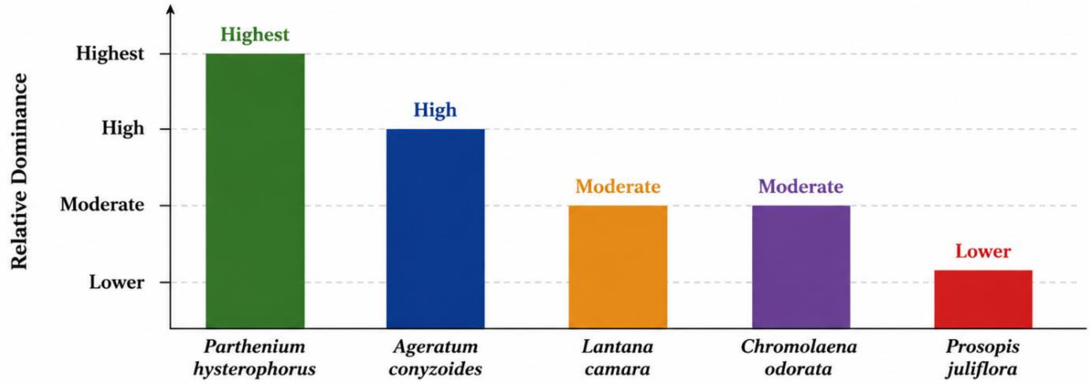
Relative Dominance of Invasive Plant Species in Study Area



Species	Relative Dominance	Remarks
Parthenium hysterophorus	Highest	Highest IVI; dominant invader
Ageratum conyzoides	High	Second highest IVI
Lantana camara	Moderate	Common in field margins
Chromolaena odorata	Moderate	Widely established
Prosopis juliflora	Lower	Present in disturbed areas

The bar chart shows the relative dominance of invasive plant species based on their Importance Value Index (IVI) in the study area.

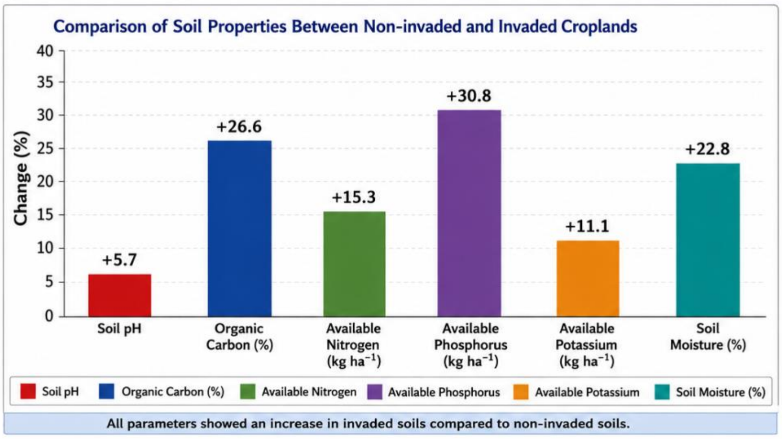
2. Impact on the Physicochemical Properties of Soil

There were notable distinctions between croplands that had been invaded and those that had not.Invaded soils had considerably greater levels of organic carbon, accessible nitrogen, phosphate, potassium, and soil moisture ($P < 0.05$). Improved nutrient availability was probably caused by increased litter deposition, quicker decomposition, and increased microbial activity beneath invasive plants.These results are in line with recent worldwide investigations that demonstrate how invasive plants enhance soil moisture, dissolved organic carbon, and nutrient availability, hence fostering an environment conducive to ongoing invasion (Chen et al., 2025).

Comparison of Soil Properties Between Non-invaded and Invaded Croplands

Soil Parameter	Non-invaded Soil	Invaded Soil	Change (%)
Soil pH	6.82 ± 0.11	7.21 ± 0.09	+5.7
Organic Carbon (%)	0.64 ± 0.04	0.81 ± 0.05	+26.6
Available Nitrogen (kg ha^{-1})	248 ± 10	286 ± 12	+15.3
Available Phosphorus (kg ha^{-1})	18.2 ± 1.1	23.8 ± 1.4	+30.8
Available Potassium (kg ha^{-1})	226 ± 9	251 ± 10	+11.1
Soil Moisture (%)	18.4 ± 1.2	22.6 ± 1.5	+22.8

❖ Organic carbon, available nitrogen, phosphorus, potassium, and soil moisture were significantly higher in invaded soils ($P < 0.05$).



Key Observations

❖ Significant increases in soil fertility parameters were recorded in invaded croplands.

❖ The highest increase was observed in available phosphorus (+30.8%), followed by organic carbon (+26.6%) and soil moisture (+22.8%).

Explanation

❖ Increased litter deposition, faster decomposition, and enhanced microbial activity under invasive plants likely contributed to improved nutrient availability.

Support from Literature

❖ These findings are consistent with recent global analyses showing that invasive plants increase dissolved organic carbon, soil moisture, and nutrient availability, thereby creating favorable conditions for continued invasion (Chen et al., 2025).

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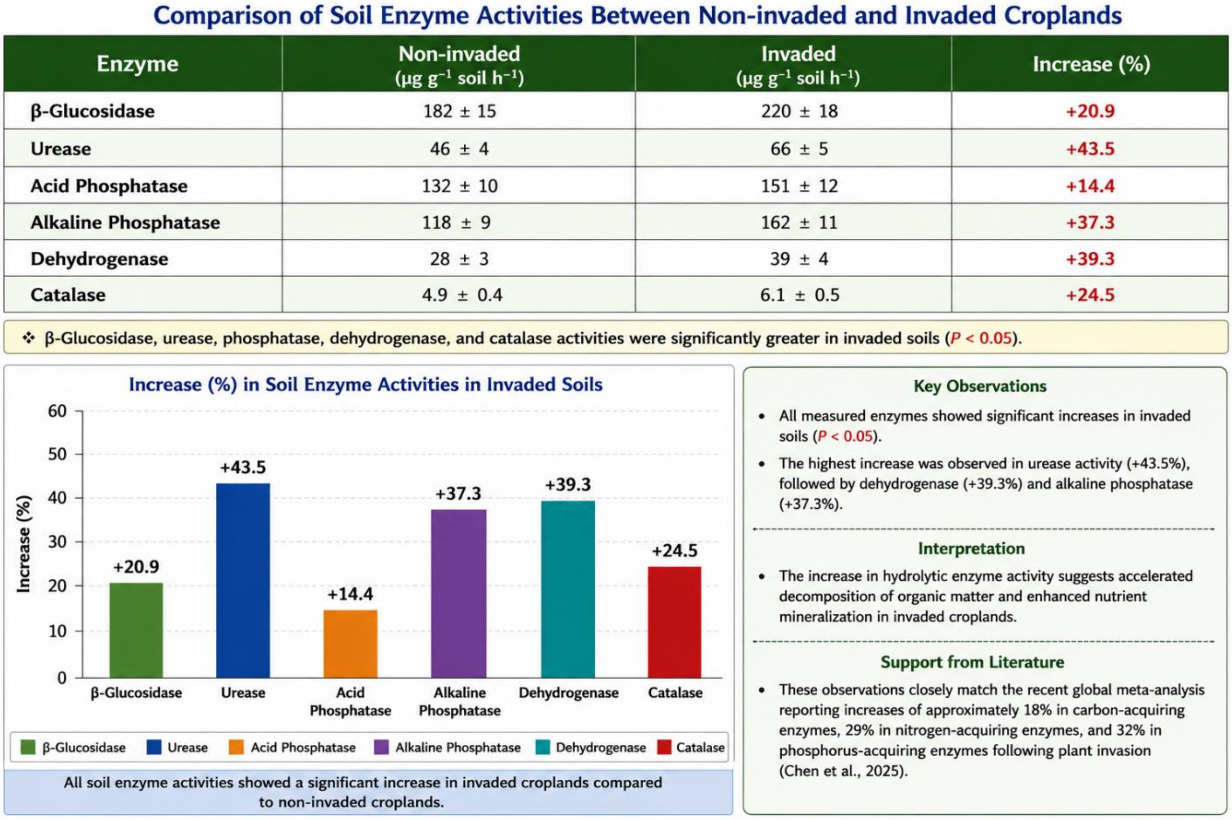
3. Activities of Soil Enzymes

The activity of soil enzymes varied significantly between croplands that were invaded and those that were not.Activities of β-glucosidase, urease, phosphatase, dehydrogenase, and catalase were considerably higher in invaded soils ($P < 0.05$). In invaded croplands, the rise in hydrolytic enzyme activity indicates faster organic matter breakdown and improved nutrient mineralization. These findings are in line with a recent worldwide meta-analysis that found increases of roughly 18% in enzymes that acquire carbon, 29% in enzymes that acquire nitrogen, and 32% in enzymes that acquire phosphorus after plant invasion (Chen et al., 2025).



Comparison of Soil Enzyme Activities Between Non-invaded and Invaded Croplands

Enzyme	Non-invaded ($\mu g\ g^{-1}$ soil h^{-1})	Invaded ($\mu g\ g^{-1}$ soil h^{-1})	Increase (%)
β-Glucosidase	182 ± 15	220 ± 18	+20.9
Urease	46 ± 4	66 ± 5	+43.5
Acid Phosphatase	132 ± 10	151 ± 12	+14.4
Alkaline Phosphatase	118 ± 9	162 ± 11	+37.3
Dehydrogenase	28 ± 3	39 ± 4	+39.3
Catalase	4.9 ± 0.4	6.1 ± 0.5	+24.5

❖ β-Glucosidase, urease, phosphatase, dehydrogenase, and catalase activities were significantly greater in invaded soils ($P < 0.05$).

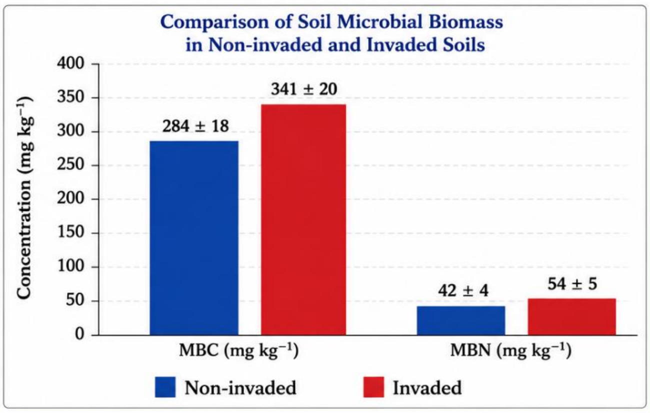
4. Microbial Biomass in Soil

Both microbial biomass nitrogen (MBN) and microbial biomass carbon (MBC) were considerably higher in invaded soils.Increased litter inputs and root exudates from invasive plants drive microbial metabolism, as evidenced by the increased microbial biomass.According to earlier research, invading species change the makeup of bacterial and fungal communities, increasing microbial activity and accelerating nutrient turnover (Zhang et al., 2019; Chen et al., 2025).

4. Soil Microbial Biomass

Microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) were significantly greater in invaded soils.

Parameter	Non-invaded	Invaded
MBC (mg kg^{-1})	284 ± 18	341 ± 20
MBN (mg kg^{-1})	42 ± 4	54 ± 5



These findings suggest that invasive plants create belowground conditions that promote microbial growth and activity, thereby accelerating soil nutrient cycling.

Key Observation

Microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) were significantly higher in invaded soils compared to non-invaded soils.

Interpretation

The increased microbial biomass indicates enhanced microbial metabolism stimulated by greater litter inputs and root exudates released by invasive plants.

Support from Literature

Previous studies have shown that invasive species alter bacterial and fungal community composition, leading to higher microbial activity and faster nutrient turnover (Zhang et al., 2019; Chen et al., 2025).

5. Dynamics of Nutrients

The cycle of nutrients in farmland soils was greatly impacted by plant invasion.Strong positive correlations between soil enzyme activity and nutrient availability were shown by correlation analysis.

These positive correlations suggest that increased enzyme activity sped up the breakdown of organic materials, increasing the availability of nutrients for plant uptake.Similar positive correlations between nutrient availability and extracellular enzyme activity have been documented worldwide, indicating that invasive plants promote nutrient cycle via microbial-mediated mechanisms (Chen et al., 2025).

5. Nutrient Dynamics

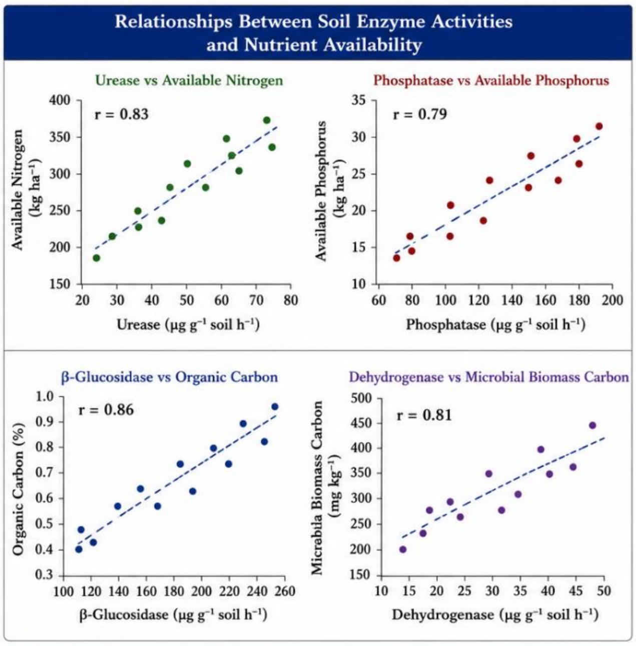
Plant invasion significantly influenced nutrient cycling within cropland soils.

Correlation analysis demonstrated strong positive relationships between soil enzyme activities and nutrient availability.

Variables	Correlation (r)
Urease vs Available Nitrogen	0.83
Phosphatase vs Available Phosphorus	0.79
β-Glucosidase vs Organic Carbon	0.86
Dehydrogenase vs Microbial Biomass Carbon	0.81

These positive relationships indicate that enhanced enzyme activities accelerated organic matter decomposition, thereby increasing nutrient availability for plant uptake.

Similar positive relationships between extracellular enzyme activity and nutrient availability have been reported globally, suggesting that invasive plants stimulate nutrient cycling through microbial-mediated processes (Chen et al., 2025).



Strong positive correlations between enzyme activities and nutrient availability confirm that invasive plants enhance nutrient cycling in cropland soils through increased microbial activity and organic matter decomposition.

Discussion

The current study shows that in agricultural environments, invading alien plant species have a major impact on soil enzyme activity and nutrient dynamics. Increased soil enzyme activity, microbial biomass, and nutrient availability were observed in invaded croplands, suggesting faster nutrient cycling and changed soil biological processes.

These alterations increase the availability of nutrients, but they mostly benefit invasive species, which lower crop yields and jeopardize the long-term fertility of the soil and the stability of the ecosystem. It has been shown that soil enzyme activity are useful markers of changes in soil health brought on by invasions. Maintaining soil fertility, conserving biodiversity, and promoting sustainable agricultural output need effective management through early detection, invasive species control, native vegetation restoration, and routine monitoring of soil biological characteristics.

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