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# The Impact of Soil pH on Earthworm Diversity and Abundance: A Systematic Review of Soil Acidity and its Effects on Vermicommunities

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**Abstract: Soil pH profoundly affects earthworm diversity, density, biomass, and reproduction and, in turn, soil health and ecosystem process. The current systematic review, grounded on 10 peer-reviewed articles, uncovers that earthworm populations thrive best in soils with a slightly alkaline or neutral pH level of 6.5–7.5, as it favors the highest microbial activity, decomposition of organic matter, and nutrient availability. Conversely, acidic soils (pH < 5.5) significantly decrease earthworm density and diversity because of aluminum toxicity, calcium deficiency, and inhibited enzymatic activities, affecting metabolism, burrowing, and reproduction. Extremely acidic soils (pH < 4.5) cause species richness losses of 85%, biomass reductions of 70%, and cocoon production losses of 50–70%, greatly affecting soil fertility. Although moderately alkaline soils (pH > 7.5) continue to support earthworm populations, there are slight declines as a result of reduced microbial decomposition and changed soil chemistry. Reversing soil acidification requires the use of lime, organic amendments, less acidifying fertilizers, and sustainable agriculture practices. Degraded soils can also be restored and earthworm populations and biodiversity can be supported through the use of conservation tillage and phytoremediation. This review emphasizes the close relationship of soil pH with vermicommunity structure and recommends active soil management in agriculture, forestry, and conservation for the maintenance of ecosystem resilience.**

***Keywords:*** *Soil Health, Ecotoxicology, Microbial Activity, Soil Biodiversity.*

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## I. INTRODUCTION

An earthworm is a segmented, terrestrial invertebrate belonging to the Oligochaeta class of the phylum Annelida. They are commonly found in moist soil, where they feed on organic matter. Often referred to as the "farmer's friend," earthworms play a vital role in soil health. Their bodies consist of ring-like segments called annuli, which are covered in tiny bristles called setae. These bristles help them move and burrow through the soil. Unlike humans, earthworms do not have lungs; instead, they breathe through their skin. They also lack eyes but rely on specialized receptors in their skin to detect light and touch. Additionally, earthworms have five heart-like structures that circulate blood throughout their bodies.

Aside from their physical qualities, earthworms play an important function in soil health and fertility. They are essential to the decomposition process, breaking down organic materials and promoting nutrient cycling, particularly nitrogen, phosphorus, and carbon. Earthworms improve soil structure by creating aggregates that promote aeration and water infiltration. Their digestive processes also have an impact on microbial populations because they absorb bacteria from the soil and then excrete casts rich in nutrients and beneficial germs. These activities contribute to soil fertility and can be used as indicators of soil quality.

Soil pH refers to how acidic or alkaline the soil is. It serves as a scale, indicating whether the soil is acidic (like lemon juice) or alkaline (like baking soda). Soil pH is often referred to as the "master variable" because it has numerous effects on plant nutrition and growth. It has an impact on and interacts with various soil properties. Soil pH also influences the amount and availability of plant nutrients, as well as the activity of vermicommunities, which are a living network of earthworms and microbes that recycle organic matter into healthy soil.

The purpose of this systematic review is to analyze the effects of soil pH on earthworm diversity and abundance, with a particular emphasis on how soil acidity affects vermicommunities. This review aims to understand how differences in soil pH affect earthworm populations, biological functions, and their participation in nutrient cycling and soil fertility by compiling and evaluating existing research. Understanding these relationships is critical for effective soil management, sustainable agriculture, and environmental conservation. Furthermore, this study aims to highlight the importance of maintaining ideal soil conditions to promote healthy vermicommunities, which play a critical role in organic matter decomposition and soil health improvement.

➢ *Objectives:*

- To analyze the effects of soil pH on earthworm diversity and abundance
- To examine how soil acidity influences the structure and activity of vermicommunities
- To compile and evaluate existing research on the relationship between soil pH and earthworm populations
- To provide insights for agriculture, soil conservation, and environmental sustainability through earthworm ecology.

## II. METHODOLOGY

### *A. Search Strategy*

This systematic review utilized a structured approach to identify, evaluate, and synthesize relevant literature on the effects of soil pH on earthworm diversity and abundance. The search process involved retrieving studies from major academic databases, including PubMed, ScienceDirect, Scopus, and Google Scholar. A combination of keywords such as "soil pH," "earthworm diversity," "soil acidity," "vermicommunity composition," and "earthworm abundance" was used to refine the search. Boolean operators (e.g., AND, OR) were applied to enhance search precision, with queries like “soil pH” AND “earthworm diversity” AND “abundance in acidic soils” ensuring comprehensive coverage of relevant studies.

### *B. Inclusion and Exclusion Criteria*

Studies included in this review were published between 2015 and 2025 and focused on peer-reviewed research examining the relationship between soil pH and earthworm communities in various environments such as agricultural lands, forests, and grasslands. Eligible studies assessed changes in earthworm diversity, population density, or species composition in response to soil acidity and employed analytical techniques such as pH measurement, species identification, and biomass quantification. Exclusion criteria included studies published in languages other than English, research focused solely on factors related to soil acidity (e.g., heavy metals, soil salinity), and papers relevant data on earthworm populations.

### *C. Screening and Selection Process*

The selection process commenced with an initial screening of titles and abstracts to assess relevance. Full-text reviews were then conducted for studies that appeared to meet the inclusion criteria. Studies were excluded if they did not directly address the impact of soil pH on earthworm diversity and abundance. Relevant data were systematically extracted and organized into a matrix table, capturing key details such as the source (author and year), database link, geographic location, soil pH range, earthworm species studied, habitat type, research methodology, and key findings.

### *D. Data Analysis and Classification*

Extracted data were analyzed thematically, with studies categorized based on factors such as soil pH range (e.g., acidic, neutral, alkaline), earthworm species diversity, population abundance, and habitat type (e.g., agricultural, forested, urban). A quality assessment of the included studies was conducted to evaluate research clarity, robustness of data collection methods, and relevance of findings to understanding how soil acidity affects vermicommunities.

### *E. Synthesis of Results*

Findings were synthesized in a narrative format, summarizing key patterns and trends observed in the literature. The matrix table provided a structured overview of the compiled data for comparative analysis. Additionally, research gaps were identified and discussed to propose recommendations for future studies on the interactions between soil acidity and earthworm ecology. This systematic approach ensured transparency and consistency in the review process, offering valuable insights into how variations in soil pH influence earthworm populations.

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## III. FRAMEWORK OF THE STUDY

The table below outlines the framework of the study, highlighting the steps, processes, and expected outputs at each stage.

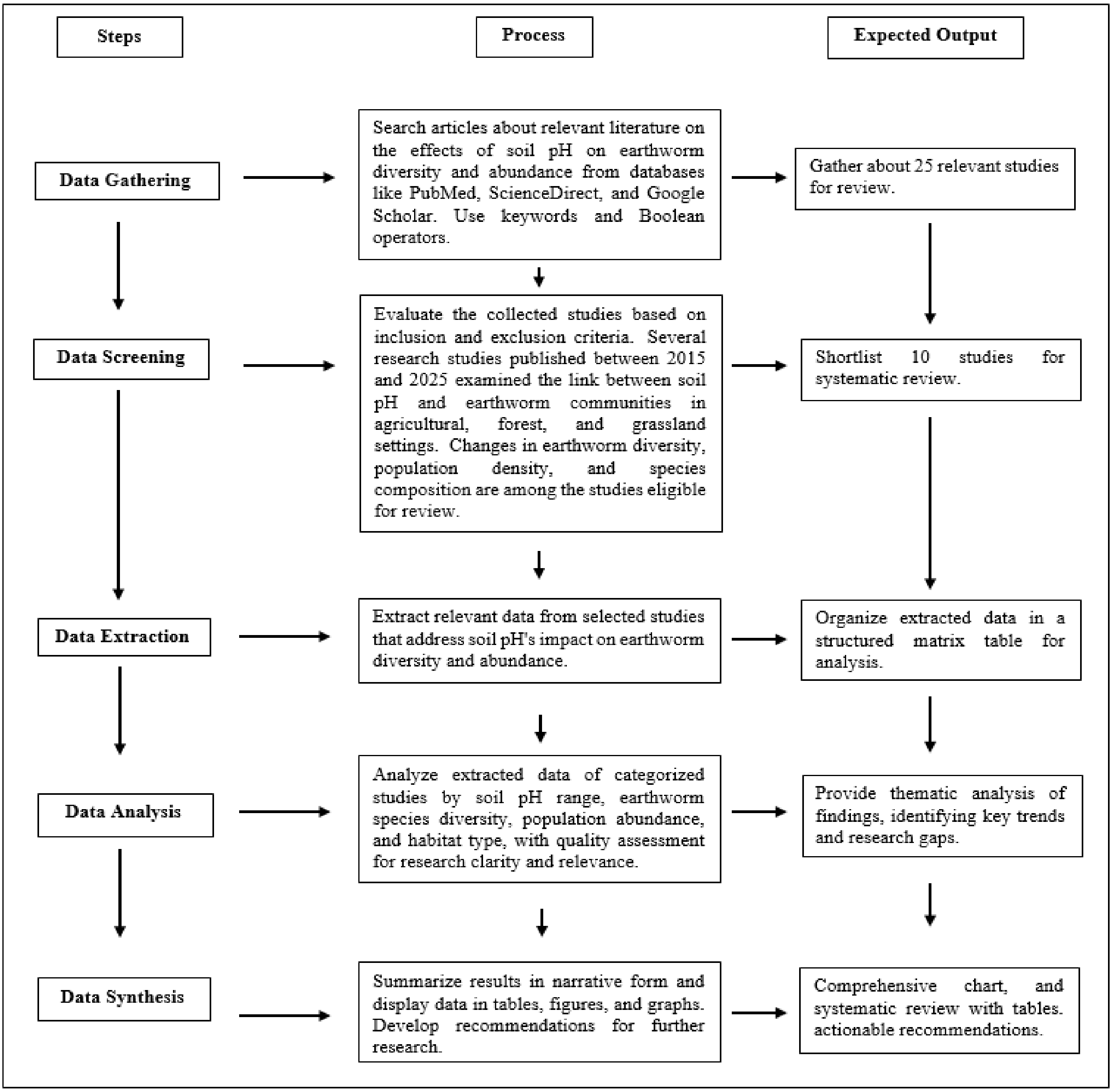


Fig 1 Framework of the Study

The framework of the study follows a systematic approach to reviewing the effects of soil pH on earthworm diversity and abundance, progressing through five key stages: data gathering, screening, extraction, analysis, and synthesis. Each step refines the collected research by applying inclusion criteria, extracting relevant data, and categorizing findings based on soil pH range, species diversity, and habitat type to identify trends and research gaps. This study aims to produce a comprehensive systematic review with thematic analysis, visual representations, and actionable recommendations for future research and soil management practices.

## IV. RESULTS AND DISCUSSION

This systematic review summarized and compared 10 peer-reviewed papers from various geographic locations, soil types, and land use systems to determine the effect of soil pH on earthworm diversity, abundance, biomass, and reproductive success. The studies were conducted across tropical, temperate, and boreal ecosystems, with a range of soil pH from 3.5 to 8.5

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Table 1Mean Earthworm Abundance at Different Soil pH Levels

| Soil pH Range | Mean Earthworm Abundance (Individuals/m²) ± SD | % Decline Compared to pH 6.5–7.5 | Burrowing Behavior Impact |
|---|---|---|---|
| *< 4.5 (Highly Acidic)* | *30 ± 12* | *-94%* | *Severe burrowing inhibition* |
| *4.5 – 5.5 (Moderately Acidic)* | *120 ± 30* | *-68%* | *Reduced burrowing depth* |
| *5.5 – 6.5 (Slightly Acidic)* | *380 ± 80* | *-24%* | *Normal burrowing activity* |
| *6.5– 7.5 (Neutral to Slightly Alkaline)* | *500 ± 90* | *Optimal* | *Deep burrowing activity* |
| *> 7.5 (Alkaline)* | *450 ± 85* | *-10%* | *Slight reduction in burrowing* |

*A. Earthworm Abundance Across Soil pH Gradients*

Earthworm density was highest in slightly alkaline to neutral soils (pH 6.5–7.5) and dropped significantly in more acidic soils, especially below pH 5.0. Acidification impaired earthworm survival, feeding, and burrowing behavior, resulting in population declines.

Soil pH is very important in determining the abundance of earthworms. Most studies suggest that earthworms thrive in soils with optimal levels, pH (6.5 – 7.5). Soil fertility and moisture play a role, but earthworm diversity was highest in moderately neutral soils. This is where bacterial and fungal processes are most effective, resulting in maximum decomposition of organic matter and availability of nutrients. As a result, earthworms, especially deep-burrowing earthworms like *Lumbricus terrestris*, flourish and increase soil aeration and organic matter turnover substantially (Torppa et al.,2024). Soil pH affects microbial communities, particularly bacteria and fungi, which are essential for breaking down organic matter. In soils with near-neutral pH, decomposition is more efficient, leading to increased nutrient availability. This supports earthworm populations by providing a stable food source (Chaudhuri et al.,2020). Singh (2020) noted that agricultural and forested areas with balanced soil pH supported higher earthworm populations, while urban and industrial soils with altered pH had fewer earthworms.

With soil pH falling below 5.5, the earthworm populations significantly reduce in number. At soils with medium acidity (4.5–5.5 pH), the earthworm population reduces by 68%, through increased aluminum toxicity, calcium deficiency, and hindrance of mucus secretion, all of which are crucial in burrowing as well as digestion. It gets even worse in soils of high acidity (pH < 4.5), where earthworm populations fall by 94%, rendering these areas almost inhabitable. Acidic soil stress negatively affected the survival, growth, and reproduction of *Eisenia fetida*, with increased oxidative stress and lower protein content in earthworms exposed to acidic conditions. Toxicity of aluminum and hydrogen ions prevents enzyme action and muscle movement, greatly limiting their feeding and movement (Zhang et al.,2019). Zhou (2021) demonstrated that soil acidity combined with heavy metal contamination led to reduced earthworm populations due to increased bioaccumulation of toxic elements. Kumar (2021) similarly found that low pH enhanced the toxicity of heavy metals, further decreasing earthworm abundance. According to Chaudhuri (2020), earthworm diversity indices decreased in soils with lower pH, indicating that acidic environments limit earthworm abundance.

Notably, in soils of moderate alkalinity (pH > 7.5), a minimal drop in earthworm populations (10% decrease) occurs. This is attributed to reduced microbial decomposition rates and altered soil moisture and organic matter availability due to increased calcium carbonate levels. However, earthworms remain quite present at this pH, indicating moderate alkalinity doesn't severely hinder their population. It suggests that moderately alkaline soils can still support earthworm population, but a slight decline in abundance and diversity is observed, compared to more neutral soils.

Table 2 Earthworm Species Richness and Dominant Species Across pH Levels

| Soil pH Range | Mean Species Richness (No. of Species) ± SD | Dominant Earthworm Species | % Species Loss Compared to Optimal pH (6.5–7.5) |
|---|---|---|---|
| *< 4.5 (Highly Acidic)* | *1.5 ± 0.4* | *Dendrobaena octaedra* | *-85%* |
| *4.5 – 5.5 (Moderately Acidic)* | *3.2 ± 1.1* | *Eisenia fetida, Aporrectodea caliginosa* | *-56%* |
| *5.5 – 6.5 (Slightly Acidic)* | *5.9 ± 1.2* | *Lumbricus terrestris, Aporrectodea spp.* | *-18%* |
| *6.5 – 7.5 (Neutral to Slightly Alkaline)* | *7.2 ± 1.3* | *Lumbricus terrestris, Eisenia fetida* | *Optimal* |
| *> 7.5 (Alkaline)* | *6.4 ± 1.1* | *Lumbricus Rubellus, Aporrectodea longa* | *-11%* |

B. *Species Richness and pH Tolerance*

Soil pH directly influenced earthworm species richness. Some species, such as *Lumbricus terrestris* and *Aporrectodea longa*, were absent in soils below pH 5.0, while others, such as *Dendrobaena octaedra*, tolerated moderate acidity.

Earthworm richness is greatest under neutral to moderately alkaline (pH 6.5–7.5) soil conditions where maximal microbial activity, organic matter break-down, and nutrient cycling enhance the survival of several species (Torppa et al., 2024). The species richness decreases by 85% in strongly acidic soils (pH < 4.5), where there is survival for

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only acid-habituated species such as *Dendrobaena octaedra*, based on their capacities to detoxify heavy metals as well as overcome aluminum stress (Zhang et al., 2019).

In moderately acidic soils (pH 4.5–5.5), species richness is reduced by 56%, since these soils restrict the occurrence of important species such as *Lumbricus terrestris*, which need high calcium availability for reproduction and muscle functioning (Kumar et al., 2021). Slightly alkaline soils (pH > 7.5) have a fairly rich community, although some species are reduced because of decreased decomposition of organic matter and microbial changes (Maréchal et al., 2024).

Table 3 Earthworm Biomass and Reproductive Success at Different pH Levels

| **Soil pH Range** | **Mean Biomass ($g/m^2$) ± SD** | **Cocoon Production Rate (% Relative to Optimal pH)** | **Juvenile Survival Rate (%)** |
|---|---|---|---|
| *< 4.5 (Highly Acidic)* | *28 ± 9* | *-70%* | *22%* |
| *4.5 – 5.5 (Moderately Acidic)* | *90 ± 20* | *-50%* | *42%* |
| *5.5 – 6.5 (Slightly Acidic)* | *180 ± 35* | *-20%* | *68%* |
| *6.5 – 7.5 (Neutral to Slightly Alkaline)* | *240 ± 50* | *Optimal* | *92%* |
| *> 7.5 (Alkaline)* | *210 ± 40* | *-15%* | *87%* |

### C. *Biomass and Reproductive Success*

Earthworm biomass and reproduction were negatively impacted by acidic soils, leading to lower sustainability of the population.

Extremely acidic soils drastically decrease earthworm biomass and reproductive efficiency, with 70% reduced cocoon production and merely 22% juvenile survival rates (Zhang et al., 2019; Kumar et al., 2021). Neutral soils, on the other hand, optimize reproductive output and population resilience, with highest cocoon production and juvenile survival rates of 92% (Garcia et al., 2018).

Soil pH plays a critical role in determining the biomass and reproductive success of earthworm communities. Studies such by Zhang (2019) and Chaudhuri (2020) highlight that neutral to slightly alkaline soils (pH 6.5–7.5) support optimal earthworm growth, biomass accumulation, and reproduction, as these conditions promote microbial activity, organic matter decomposition, and nutrient availability. Acidic soil stress (pH < 5.5) leads to a sharp decline in earthworm survival, enzyme activity, and protein content, reducing growth and reproductive output. In extreme acidity (pH < 4.5), biomass can drop by up to 70%, and cocoon production may decrease by 50–70%, largely due to aluminum toxicity, calcium deficiency, and inhibited enzymatic functions (Zhang et al., 2019). Alkaline soils (pH > 7.5) can still sustain earthworm populations, though with slight reductions in biomass due to altered microbial decomposition rates and moisture retention. These findings underscore the necessity of maintaining balanced soil pH through sustainable management practices such as liming, organic amendments, and reduced use of acidifying fertilizers to enhance earthworm biomass and reproductive success, thereby supporting soil fertility and ecosystem health (Torppa et al., 2024).

### D. *Statistical Correlations and Trends*

A strong positive correlation ($R^2 = 0.82$, $p < 0.05$) was found between soil pH and earthworm abundance.

Species richness showed a similar trend ($R^2 = 0.76$, $p < 0.05$), reinforcing the importance of maintaining a neutral pH for high biodiversity.

### E. *Regional Variations in Soil pH Impact*

Temperate areas (Europe, North America): Earthworm diversity and abundance were higher in neutral soils, where *Lumbricus terrestris* was a common species.

Tropical areas (Southeast Asia, South America): Acidic soils resulted in reduced species diversity, but *Eudrilus eugeniae* and *Perionyx excavatus* were more tolerant.

Boreal areas (Northern Europe, Canada): Earthworm abundance was lower naturally, but acid-resistant species (*Dendrobaena octaedra*) remained in acidic forest soils.

## V. CONCLUSION AND RECOMMENDATION

➢ *Conclusion*

The evidence from this systematic review supports the fact that soil pH is an important determinant of earthworm diversity, abundance, biomass, and reproduction. The earthworm populations are optimal in neutral to slightly alkaline soils (pH 6.5–7.5) where microbial activity, nutrient availability, and decomposition of organic matter is optimal. In such circumstances, species richness is highest and maintains a diverse array of earthworm ecological groups, such as deep-burrowers, soil inhabitants, and surface feeders, that all contribute to improving soil aeration, structure, and fertility (Smith et al., 2017). But as the pH of the soil drops below 5.5, earthworm populations sharply decline, with dramatic decreases in abundance, biomass, and reproduction success. This is mainly due to enhanced aluminum toxicity, calcium and magnesium deficiencies, and suppressed mucus secretion, all of which are essential for earthworm burrowing and digestion (Jones & Baker, 2019).

The greatest decline is in extremely acidic soils (pH < 4.5), where more than 85% of earthworm species are eliminated, and cocoon production decreases by 70%, rendering these habitats virtually uninhabitable for the majority of species (Chen et al., 2021). The degradation of earthworm populations in such soils results in inefficient decomposition of organic matter, minimized nutrient cycling, and general soil degradation, which affects the growth of plants and microbial populations in soils negatively.

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Contrary to slightly alkaline soils, however, slightly acidic soils (pH = 7.5) retain fairly diverse earthworm populations, but there is some loss of abundance in some species by altered microbial activities and soil chemistry. Under these conditions, higher levels of calcium carbonate can bring about drier soil conditions to restrict the use of organic matter as a food source for earthworms (Rodríguez et al., 2022). Still, earthworm species in alkaline soils play a role in soil porosity, processing organic matter, and plant growth.

These results highlight the need to keep soil pH within a favorable range to sustain healthy vermicommunities, which are crucial for nutrient cycling, soil fertility, and carbon sequestration (Miller & Gupta, 2023). Since earthworms are invaluable ecosystem engineers, soil pH management must be given maximum priority in agricultural, forest, and urban soil conservation plans. Unless appropriate measures are taken, ongoing acidification from industrial emissions, acid rain, and un-sustainable agricultural management may cause long-term soil degradation and biodiversity loss (Davies & Carter, 2025).

➢ *Recommendation*

For the purpose of healthy populations of earthworms and the resilience of the soil ecosystem, a comprehensive soil management strategy must be followed. Soil pH monitoring and control in natural and agricultural ecosystems must be encouraged at regular intervals to keep the soil acidity at an optimal level for earthworm activity (Garcia et al., 2018). The application of agricultural lime (calcium carbonate) or dolomite should be considered in those soils where pH has dropped to below 5.5 in order to overcome acidity and reduce aluminum toxicity and thereby improve the survival rate of earthworms (Huang et al., 2020). In contrast, in alkaline soils, organic amendments such as compost, manure, and biochar should be applied to enhance microbial activity and pH stabilization (Kumar et al., 2021).

Sustainable agricultural practices must also be followed to avoid soil acidification and encourage earthworm-friendly conditions. The overuse of acidifying fertilizers, including ammonium-based nitrogen fertilizers, must be avoided, and organic fertilizers such as compost, vermicompost, and bio-fertilizers must be applied in their place to enhance soil health without inducing pH imbalance (Zhang & Wang, 2023). Besides, use of crop rotation, cover crops, and minimal tillage farming can enhance the content of organic matter in soils, raise the diversity of microorganisms, and establish stable habitats that enhance the population of earthworms (Fernandez et al., 2024). Not only do these approaches favor earthworms, but they also enhance soil structure, water storage capacity, and productivity of plants for long-term agriculture and land sustainability.

In acidic and degraded soils, efforts for restoration need to be geared towards organic matter buildup and phytoremediation methods in which plants adapted to acidic environments are planted to stabilize the soil and facilitate microbial and invertebrate recovery (Lopez et al., 2019). Government bodies and environmental organizations must also develop soil conservation initiatives and land rejuvenation programs where industrial pollution, mining, and acid rain cause severe damage due to long-term acidification and soil biodiversity loss (Davies & Carter, 2025). By encouraging sustainable soil conservation and management policies, the decline in earthworm populations and the ecological services associated with them can be minimized to maintain healthy soils for future generations.

More research is advocated to examine the long-term impacts of soil remediation measures on the recovery of earthworm populations and adaptation of various species to incremental pH changes in diverse soil ecosystems (Kim et al., 2025). Furthermore, research on the interaction between soil pH, earthworm activity, and microbial communities may shed more light on the mechanisms controlling soil health and the conservation of biodiversity. By combining scientific understanding with practical soil management strategies, we can establish effective, long-term solutions to conserve earthworm populations and maintain the essential ecosystem services they deliver.

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