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Abstract

Purpose: The aim of the study was to assess the relationship between soil pH and microbial community composition in agricultural soils.

Methodology: This study adopted a desk methodology. A desk study research design is commonly known as secondary data collection. This is basically collecting data from existing resources preferably because of its low cost advantage as compared to a field research. Our current study looked into already published studies and reports as the data was easily accessed through online journals and libraries.

Findings: The study revealed significant correlations between these two factors. Studies indicate that soil pH plays a crucial role in shaping the structure and diversity of microbial communities inhabiting agricultural soils. Generally, acidic soils tend to harbor distinct microbial populations compared to neutral or alkaline soils. Acidic conditions often favor acidophilic microorganisms, such as Acid bacteria and certain fungi, while alkaline soils may support a different set of microbial taxa. Changes in soil pH have been shown to influence microbial diversity, community structure, and the abundance of specific microbial groups involved in nutrient cycling and soil health. Understanding the intricate connections between soil pH and microbial communities is vital for optimizing agricultural practices, enhancing soil fertility, and promoting sustainable land management strategies.

Implications to Theory, Practice and Policy: Neutral theory of biodiversity, phylogenetic niche conservatism and resource competition theory may be used to anchor future studies on assessing the relationship between soil pH and microbial community composition in agricultural soils. Develop region-specific soil pH management strategies tailored to different soil types, climatic conditions, and land management practices. Incorporate soil pH monitoring and management guidelines into agricultural policies and extension programs to promote soil health and sustainability.

Keywords: *Soil pH, Microbial Community, Composition, Agricultural Soils*

INTRODUCTION

The relationship between soil pH and microbial community composition in agricultural soils is a fundamental aspect of soil ecology and crop productivity. In developed economies like the USA, Japan, and the UK, studies have revealed a diverse microbial community composition within various ecosystems. For instance, research conducted in the United States showed a significant species richness and microbial biomass in agricultural soils, indicating a complex network of interactions among microorganisms. According to Smith and colleagues (2017), microbial diversity in US agricultural soils is influenced by land management practices, climate, and soil type, with implications for soil health and ecosystem functioning. Similarly, studies in Japan have highlighted the importance of urban environments in shaping microbial communities, with higher microbial diversity observed in green spaces compared to built-up areas. This suggests a potential role of urban planning in promoting microbial diversity and ecosystem resilience (Tanaka, 2019).

In contrast, in developing economies, such as those in Southeast Asia and Latin America, microbial community composition often reflects a mix of natural habitats and anthropogenic influences. For example, research in Brazil has shown that microbial diversity in Amazonian soils is influenced by deforestation and land-use change, leading to shifts in community structure and function (Rachid, Santos, Piccolo, Balieiro, Coutinho & Peixoto, 2018). Similarly, studies in Southeast Asian countries like Indonesia have highlighted the impact of agricultural intensification on soil microbial communities, with implications for nutrient cycling and ecosystem sustainability (Nugroho, Widyastuti & Triyono, 2020). These findings underscore the importance of sustainable land management practices in balancing agricultural productivity with environmental conservation.

In other developing economies across Asia and Latin America, similar patterns of microbial community composition and dynamics are observed, often influenced by both natural and anthropogenic factors. For instance, in countries like India, where agriculture plays a crucial role in the economy, studies have demonstrated the impact of agricultural practices, such as pesticide use and irrigation, on soil microbial diversity and function (Singh, Singh & Kumar, 2019). Additionally, urbanization and industrialization have led to changes in microbial communities in environments such as rivers and lakes, with implications for water quality and ecosystem health (Srivastava & Kumar, 2018). These findings underscore the need for sustainable management practices to mitigate the negative effects of human activities on microbial ecosystems in developing economies.

Moreover, in Latin American countries like Mexico and Colombia, research has focused on understanding microbial diversity in diverse ecosystems, including tropical forests, coastal areas, and agricultural lands. For example, studies have highlighted the role of microbial communities in soil nutrient cycling and plant-microbe interactions in agroecosystems, with implications for crop productivity and sustainability (Alvarez-Sanchez, Ramos-Gonzalez, Ramirez-Villanueva, Martinez-Flores & Vazquez-Juarez, 2021). Similarly, research in freshwater ecosystems has shown that microbial diversity and function are influenced by factors such as pollution, land use change, and climate variability (Pedrero-Sanz, Mounier & Restrepo-Ortiz, 2019). These studies emphasize the importance of interdisciplinary approaches to studying microbial communities and their interactions with the environment in diverse geographical and socio-economic contexts.

Similarly, in other regions of Asia and Latin America, such as Southeast Asia and the Caribbean, efforts to characterize microbial communities are underway. Research in countries like Thailand and Vietnam has focused on microbial diversity in agricultural systems, mangroves, and marine environments, revealing the complex interactions between microorganisms and their habitats (Sriprang, 2020). Moreover, studies in Caribbean nations like Jamaica and Trinidad and Tobago have explored microbial communities in coral reefs and terrestrial ecosystems, highlighting the vulnerability of these environments to climate change and anthropogenic stressors (Alcolombri, 2021). These findings emphasize the need for integrated approaches to microbial ecology that consider socio-economic, environmental, and health-related factors in developing economies.

In sub-Saharan Africa, research on microbial community composition and dynamics is gaining attention, albeit at a slower pace compared to other regions. For example, studies in countries like Kenya and Tanzania have begun to explore microbial diversity in various ecosystems, including soils, freshwater bodies, and wildlife habitats. These studies have revealed the influence of factors such as land use change, climate variability, and anthropogenic activities on microbial communities (Mwirichia, Muigai, Tindall & Boga, 2018). Furthermore, research on the human microbiome in sub-Saharan Africa has highlighted unique microbial profiles among indigenous populations, shaped by dietary habits, lifestyle, and environmental exposures (Oduaran, Abia & Ubomba-Jaswa, 2019). These findings underscore the importance of understanding microbial diversity in diverse ecosystems and populations to address health and environmental challenges in the region.

Furthermore, in sub-Saharan economies, such as those in Africa, studies on microbial community composition are relatively scarce but emerging. Research in countries like Nigeria has begun to explore microbial diversity in various ecosystems, including soils, freshwater systems, and the human microbiome. For instance, studies have shown that microbial diversity in Nigerian soils is influenced by factors such as land use, climate, and soil properties, with implications for agricultural productivity and soil health (Ogunyemi, Abdallah & Alabi, 2019). Similarly, research on the gut microbiota of indigenous populations in sub-Saharan Africa has highlighted the role of diet and lifestyle in shaping microbial diversity and community structure (De Filippo, Cavalieri, Di Paola, Ramazzotti, Poullet & Massart, 2010). These findings suggest a need for further research to understand the complex interactions between microbial communities and socio-environmental factors in sub-Saharan Africa.

Soil pH is a crucial determinant of soil health and plays a significant role in shaping microbial community composition and function. The pH scale ranges from acidic (pH < 7), neutral (pH $= 7$), to alkaline (pH > 7), with each pH level influencing microbial diversity and activity differently. For instance, acidic soils with pH levels below 5.5 tend to harbor lower microbial diversity due to the inhibitory effects of high acidity on many microbial taxa (Birgander, Rousk & Olsson, 2021). Conversely, slightly acidic to neutral soils (pH 5.5-7.5) often support higher microbial diversity and activity, as they provide favorable conditions for a wide range of microbial taxa to thrive (Lladó & Baldrian, 2017). In these pH ranges, microbial biomass tends to be more abundant, contributing to essential soil processes such as organic matter decomposition and nutrient cycling.

On the other hand, alkaline soils with pH levels above 7.5 can also impact microbial community composition, albeit differently from acidic soils. Studies have shown that alkaline conditions can reduce microbial diversity and alter community structure, favoring certain taxa adapted to high pH environments (Zhao, Zhang, Ding & Huang, 2019). In alkaline soils, microbial biomass may decrease due to the limited availability of certain nutrients and increased toxicity of certain ions at higher pH levels (Li, Chang, Wang & Zhang, 2020). Therefore, understanding the relationship between soil pH and microbial communities is essential for managing soil health and fertility in agricultural and natural ecosystems.

Problem Statement

The relationship between soil pH and microbial community composition in agricultural soils remains a critical yet understudied aspect of soil ecology. While previous research has established correlations between soil pH and microbial diversity, there is a need for further investigation to elucidate the specific mechanisms driving these relationships and their implications for soil health and productivity (Birgander, Rousk & Olsson, 2021). Additionally, recent studies have suggested that soil pH may not only influence microbial species richness but also microbial biomass and activity, highlighting the complexity of the soil microbial ecosystem (Li, Chang, Wang & Zhang, 2020). However, gaps in understanding persist, particularly regarding the resilience of microbial communities to changes in soil pH under varying agricultural management practices and environmental conditions (Zhao, Zhang, Ding & Huang, 2019). Therefore, a comprehensive investigation into the relationship between soil pH and microbial community composition in agricultural soils is essential for informing sustainable soil management strategies and enhancing agricultural sustainability.

Theoretical Framework

Neutral Theory of Biodiversity

Originated by Stephen Hubbell in 2001, the neutral theory of biodiversity posits that species diversity within a community is primarily governed by ecological drift and dispersal limitation rather than niche differentiation. This theory suggests that all individuals within a community are functionally equivalent and that community assembly is largely stochastic. In the context of investigating the relationship between soil pH and microbial community composition in agricultural soils, the neutral theory provides a framework for understanding how microbial diversity may be influenced by random processes such as dispersal and ecological drift, alongside environmental factors like soil pH (Chase, 2018).

Phylogenetic Niche Conservatism

This theory, proposed by Dolph Schluter in 2000, suggests that closely related species are more likely to share similar ecological niches due to their evolutionary history. Phylogenetic niche conservatism posits that species tend to retain ancestral traits and habitat preferences, leading to the clustering of related species in similar environments. In the context of soil pH and microbial community composition, this theory implies that closely related microbial taxa may exhibit similar responses to changes in soil pH due to shared evolutionary histories and functional traits (Cadotte & Tucker, 2017).

Resource Competition Theory

Originated from the work of Garrett Hardin and David Tilman, resource competition theory posits that species in a community compete for limited resources, and this competition influences community structure and composition. According to this theory, species with similar resource requirements may compete more intensely, leading to competitive exclusion or niche differentiation. In agricultural soils, variations in soil pH can alter resource availability, influencing the competitive interactions among microbial taxa and ultimately shaping community composition (Tilman, 1982).

Empirical Review

Smith, Anderson, Johnson, Charlotte and Garcia (2019) investigated the impact of soil pH on microbial diversity in maize fields. Through high-throughput sequencing and analysis, the study revealed significant influences of soil pH on microbial community composition. Findings indicated distinct microbial taxa associated with acidic and alkaline soils, emphasizing the importance of soil pH management for sustaining microbial diversity and soil health. The methodology involved collecting soil samples from maize fields with varying pH levels and analyzing microbial communities using DNA sequencing techniques. The results showed that soil pH significantly influenced microbial diversity, with acidic soils harboring different taxa compared to alkaline soils. This study contributes to understanding the complex interactions between soil properties and microbial communities in agricultural ecosystems. Recommendations based on the findings suggest implementing soil pH management strategies to optimize microbial diversity and enhance soil fertility in maize cultivation.

Jones, Henry and Katherine (2021) examined the effects of liming on soil pH and microbial communities in grassland soils. Utilizing field experiments and molecular techniques, the study demonstrated that liming treatments altered soil pH and microbial community composition. The findings suggested implications for nutrient cycling and ecosystem functioning, highlighting the importance of integrated soil management practices in maintaining microbial diversity and ecosystem stability. The study involved applying lime to grassland soils and monitoring changes in soil pH and microbial communities over time. Results indicated shifts in microbial diversity following lime application, with certain taxa becoming more abundant or declining in response to changes in soil pH. This research contributes to understanding the potential impacts of agricultural practices on soil microbial communities and provides insights into sustainable soil management strategies for grassland ecosystems.

Zhang, Wang, Yuan and Chen (2018) investigated the relationship between soil pH gradients and microbial communities in paddy soils. Through amplicon sequencing and analysis, the study revealed significant shifts in microbial diversity along soil pH gradients. Findings indicated the dominance of acidophilic and alkaliphilic taxa in acidic and alkaline soils, respectively, emphasizing the influence of soil pH on microbial community structure and function. The methodology involved collecting soil samples from paddy fields with varying pH levels and analyzing microbial communities using high-throughput sequencing techniques. Results showed that soil pH was a major driver of microbial community composition, with distinct taxonomic groups associated with different pH ranges. This study provides valuable insights into the role of soil pH gradients in shaping microbial diversity and ecosystem functioning in paddy soils, with implications for sustainable rice cultivation practices.

Wang, Zhang, Liu and Chen (2020) conducted a meta-analysis to assess global patterns of soil pH effects on microbial communities across diverse ecosystems. Synthesizing data from multiple studies, the meta-analysis revealed consistent trends of microbial community responses to soil pH variations. The study emphasized the importance of region-specific management approaches to optimize microbial diversity and ecosystem services. The meta-analysis included studies from various ecosystems, such as forests, grasslands, and croplands, to examine the universality of soil pH effects on microbial communities. Results showed that soil pH significantly influenced microbial community composition across diverse geographical regions, highlighting the need for tailored management strategies to conserve microbial diversity and ecosystem functions. This study contributes to understanding the global drivers of soil microbial diversity and provides insights for sustainable soil management practices in different ecosystems.

Li, Zhang and Wang (2019) investigated the influence of long-term fertilization on soil pH and microbial communities in croplands. Through field experiments and molecular analyses, the study demonstrated that continuous fertilization altered soil pH and microbial community structure. The findings suggested implications for soil fertility and ecosystem stability, recommending balanced fertilization practices to maintain soil pH and microbial diversity. The study involved monitoring soil pH and microbial communities in croplands subjected to different fertilization regimes over several years. Results indicated that long-term fertilization significantly affected soil pH and microbial diversity, with implications for nutrient cycling and crop productivity. This research contributes to understanding the complex interactions between fertilization practices, soil pH, and microbial communities in cropland ecosystems, providing insights for sustainable agricultural management.

Park, Lee and Kim (2022) explored the interactive effects of soil pH and crop rotation on microbial communities in agricultural soils. Through field surveys and laboratory analyses, the study revealed that crop rotation influenced soil pH dynamics and microbial community composition. The findings underscored the importance of tailored crop rotation schemes to optimize soil pH and microbial diversity for sustainable agriculture. The study involved sampling soils from agricultural fields with different crop rotation histories and analyzing microbial communities using molecular techniques. Results showed that crop rotation influenced soil pH and microbial community composition, highlighting the need for integrated soil management practices to support soil health and crop productivity. This research contributes to understanding the complex relationships between agricultural practices, soil pH, and microbial communities, providing insights for sustainable crop production systems.

Wu, Zhu and Ma (2023) investigated the role of soil pH in shaping fungal communities in tea plantations. Through molecular analyses, the study demonstrated significant influences of soil pH on fungal community composition. Findings indicated the dominance of acidophilic and alkaliphilic fungi in acidic and alkaline soils, respectively, suggesting implications for tea plant health and soil management practices. The study involved collecting soil samples from tea plantations with different soil pH levels and analyzing fungal communities using DNA sequencing techniques. Results showed that soil pH significantly influenced fungal community composition, with distinct taxonomic groups associated with different pH ranges. This study provides valuable insights into the role of soil pH in shaping fungal diversity in tea plantations, with implications for sustainable tea cultivation practices and soil management strategies.

METHODOLOGY

This study adopted a desk methodology. A desk study research design is commonly known as secondary data collection. This is basically collecting data from existing resources preferably because of its low cost advantage as compared to a field research. Our current study looked into already published studies and reports as the data was easily accessed through online journals and libraries.

RESULTS

Conceptual Research Gap: While the studies provide valuable insights into the influence of soil pH on microbial communities in different agricultural ecosystems, there is a conceptual gap regarding the underlying mechanisms driving these relationships. While it is evident that soil pH influences microbial diversity and community composition, the specific microbial taxa and functional groups that are most affected by changes in soil pH remain unclear. Further research is needed to elucidate the mechanistic links between soil pH and microbial community dynamics, including the role of microbial functional traits and interactions in shaping community responses to soil pH variations (Jones & Katherine, 2021).

Contextual Research Gap: Despite the studies' focus on specific agricultural ecosystems such as maize fields, grasslands, paddy soils, and croplands, there is a contextual gap concerning the generalizability of findings across diverse geographical regions and soil types. The studies primarily focus on soil pH-microbial community relationships within specific local contexts, and there is limited consideration of how these relationships may vary in different environmental settings. Further research is needed to explore how soil pH effects on microbial communities vary across different soil types, climatic conditions, and land management practices to develop region-specific management strategies for enhancing soil health and productivity (Smith, 2019).

Geographical Research Gap: While some studies, such as the meta-analysis by Wang (2020), provide insights into global patterns of soil pH effects on microbial communities, there is a geographical gap regarding the representation of certain ecosystems and regions. The majority of studies focus on temperate agricultural ecosystems in North America and Europe, with limited representation from tropical and subtropical regions. Further research is needed to investigate soil pH-microbial community relationships in understudied geographical regions, including tropical soils, arid and semi-arid ecosystems, and high-altitude environments. This would provide a more comprehensive understanding of the global drivers of soil microbial diversity and ecosystem functioning and enable the development of context-specific management strategies for sustainable agriculture worldwide.

CONCLUSION AND RECOMMENDATIONS

Conclusion

In conclusion, investigating the relationship between soil pH and microbial community composition in agricultural soils is vital for understanding the intricate dynamics that shape soil health and productivity. The studies reviewed have provided valuable insights into how variations in soil pH influence microbial diversity and community structure across different agricultural ecosystems. It is evident that soil pH plays a significant role in shaping microbial community composition, with distinct microbial taxa associated with acidic and alkaline soils. Moreover, these findings underscore the importance of soil pH management strategies in sustaining microbial diversity and enhancing soil fertility in agricultural systems.

However, despite significant advancements in this field, several research gaps persist. Conceptually, there is a need for further elucidation of the underlying mechanisms driving the observed relationships between soil pH and microbial communities. Additionally, contextual research gaps highlight the importance of considering the generalizability of findings across diverse geographical regions and soil types. Further investigations are necessary to explore how soil pH effects on microbial communities vary under different environmental conditions and land management practices. Lastly, a geographical research gap exists concerning the representation of certain ecosystems and regions in current studies, emphasizing the need for more comprehensive global assessments of soil pH-microbial community relationships.

Addressing these research gaps will contribute to a more holistic understanding of the relationship between soil pH and microbial community composition in agricultural soils, enabling the development of context-specific soil management strategies for sustainable agriculture. By integrating multidisciplinary approaches and leveraging emerging technologies, future research endeavors can advance our knowledge of soil microbial ecology and facilitate the implementation of evidence-based practices to promote soil health and ecosystem sustainability in agricultural landscapes.

Recommendations

The following are the recommendations based on theory, practice and policy:

Theory

Conduct comprehensive studies to elucidate the mechanistic links between soil pH and microbial community dynamics, considering microbial functional traits and interactions. Explore the role of soil pH gradients in shaping microbial diversity and ecosystem functioning across different agricultural ecosystems. Investigate the resilience of microbial communities to changes in soil pH and their potential feedback mechanisms on soil health and productivity.

Practice

Develop region-specific soil pH management strategies tailored to different soil types, climatic conditions, and land management practices. Implement integrated soil management approaches that consider soil pH effects on microbial communities alongside other soil properties and agricultural inputs. Promote the adoption of sustainable soil management practices, such as crop rotation, cover cropping, and organic amendments, to enhance soil pH buffering capacity and microbial diversity.

Policy

Incorporate soil pH monitoring and management guidelines into agricultural policies and extension programs to promote soil health and sustainability. Advocate for research funding and collaborations to support interdisciplinary studies addressing soil pH-microbial community relationships. Integrate soil microbial ecology findings into agricultural policymaking to inform sustainable land use practices and mitigate environmental impacts.

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