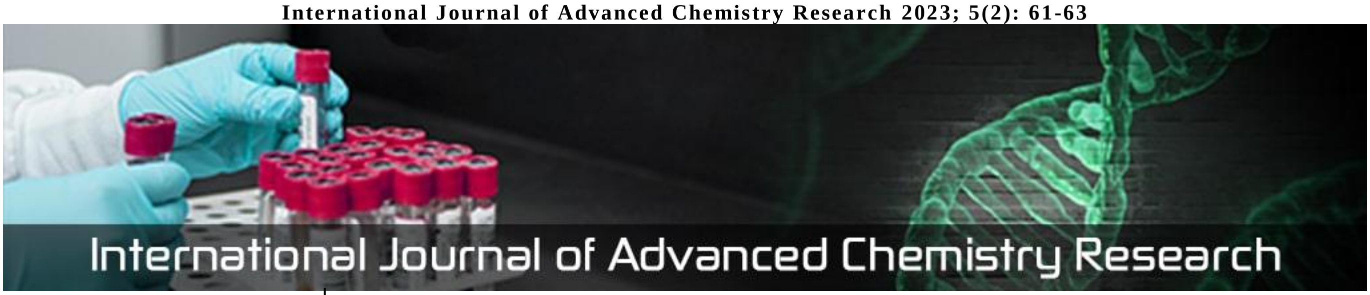

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Fatima Khaled
Department of Soil and Water Sciences, Alexandria University, Alexandria, Egypt

Amina Sayed
Department of Soil and Water Sciences, Alexandria University, Alexandria, Egypt

Corresponding Author:
Fatima Khaled
Department of Soil and Water Sciences, Alexandria University, Alexandria, Egypt

Soil pH and its influence on nutrient availability and plant health

Fatima Khaled and Amina Sayed

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Abstract
Soil pH is a critical parameter that influences nutrient availability and plant health. This review explores the mechanisms by which soil pH affects nutrient solubility and uptake, the optimal pH ranges for various crops, and strategies for managing soil pH to enhance agricultural productivity. Emphasizing the importance of maintaining appropriate soil pH levels, the review synthesizes current research findings and proposes practical solutions for farmers to optimize soil conditions for plant growth.

Keywords: Soil pH, nutrient availability, plant health, soil management, agricultural productivity

Introduction

Soil pH is a critical factor that significantly influences the availability of nutrients to plants and, consequently, their health and productivity. The pH of soil, which measures its acidity or alkalinity on a scale from 0 to 14, directly affects the chemical forms and solubility of various nutrients. Most nutrients are optimally available to plants in a slightly acidic to neutral pH range, typically between 6.0 and 7.0. Deviations from this range can lead to nutrient deficiencies or toxicities, which can adversely impact plant growth and crop yields. The solubility and availability of essential nutrients such as nitrogen (N), phosphorus (P), potassium (K), and various micronutrients are profoundly affected by soil pH. In acidic soils (pH < 5.5), the solubility of toxic elements like aluminium (Al) and manganese (Mn) increases, which can harm plant roots and reduce nutrient uptake. Simultaneously, essential nutrients like phosphorus become less available due to the formation of insoluble compounds. Conversely, in alkaline soils (pH > 7.5), the availability of micronutrients such as iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu) decreases, leading to deficiencies that can manifest as chlorosis and stunted growth. Maintaining an optimal soil pH is crucial for maximizing nutrient availability and ensuring healthy plant growth. Soil pH affects the microbial activity and biological processes that contribute to nutrient cycling in the soil. For instance, beneficial microorganisms involved in nitrogen fixation and organic matter decomposition thrive best within specific pH ranges. Thus, soil pH not only influences the chemical environment of the soil but also its biological health, which in turn affects plant nutrition. Given the importance of soil pH in agricultural productivity, it is essential to understand the factors that influence soil pH and the methods available to manage it effectively. Soil pH can be affected by various factors including parent material, organic matter content, and agricultural practices such as fertilization and irrigation. Changes in soil pH can be managed through amendments such as lime or sulphur to raise or lower pH, respectively, and through the incorporation of organic matter to buffer pH changes. This review aims to provide a comprehensive understanding of the role of soil pH in nutrient availability and plant health. It will explore the mechanisms by which soil pH influences nutrient dynamics, examine the optimal pH ranges for various crops, and discuss strategies for managing soil pH to enhance agricultural productivity. By synthesizing current research findings, this review seeks to highlight the critical importance of maintaining appropriate soil pH levels for sustainable crop production and propose practical solutions for farmers to optimize soil conditions for plant growth. Understanding and effectively managing soil pH is vital for addressing the challenges of modern agriculture, including soil degradation, climate change, and the need for increased food production.

Objective of the paper

The objective of this paper is to explore the influence of soil pH on nutrient availability and plant health, and to propose strategies for managing soil pH to optimize agricultural productivity.

Soil pH influence on nutrient availability

Soil pH affects the chemical forms and solubility of various nutrients, which in turn influences their availability to plants. In acidic soils (pH < 5.5), the solubility of toxic metals such as aluminium (Al) and manganese (Mn) increases, which can be detrimental to plant health. Aluminium toxicity, in particular, can inhibit root growth and function, reducing the plant's ability to absorb water and nutrients. On the other hand, essential nutrients such as phosphorus (P), calcium (Ca), and magnesium (Mg) become less available in highly acidic soils due to precipitation or adsorption onto soil particles. In alkaline soils (pH > 7.5), the availability of micronutrients such as iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu) decreases due to the formation of insoluble hydroxides and carbonates. This can lead to deficiencies in these essential nutrients, manifesting as chlorosis and other deficiency symptoms in plants. Phosphorus availability is also reduced in alkaline conditions as it precipitates as calcium phosphate. The optimal pH range for nutrient availability is typically between 6.0 and 7.0. Within this range, most essential nutrients are in their most soluble forms and can be readily absorbed by plant roots. For instance, nitrogen (N), in the form of nitrate (NO^{3-}), is highly available within this pH range, supporting robust plant growth and development. The influence of soil pH on nutrient availability has direct implications for plant health. Plants growing in soils with suboptimal pH levels often exhibit symptoms of nutrient deficiencies or toxicities, leading to reduced growth and yield. Acidic soils can cause stunted root growth and poor nutrient uptake due to aluminium toxicity and the reduced availability of essential nutrients like phosphorus and calcium. In contrast, alkaline soils can cause deficiencies in micronutrients, leading to symptoms such as interveinal chlorosis (yellowing between the veins of leaves) and reduced photosynthetic efficiency. Research by Marschner (2012) [1] highlighted that maintaining soil pH within the optimal range can significantly enhance nutrient uptake and plant health. For example, studies have shown that liming acidic soils to raise the pH can reduce aluminium toxicity and increase the availability of calcium and magnesium, thereby improving root growth and nutrient absorption.

Strategies for managing Soil pH

Managing soil pH is crucial for optimizing nutrient availability and promoting plant health. Various strategies can be employed to adjust soil pH, depending on whether the soil is too acidic or too alkaline. The application of lime (Calcium carbonate) is a common practice to raise the pH of acidic soils. Lime neutralizes soil acidity by reacting with hydrogen ions to form water and carbon dioxide. This process not only increases soil pH but also supplies calcium and magnesium, essential nutrients for plant growth. The effectiveness of liming depends on factors such as lime quality, soil type, and the initial soil pH. Research by Fageria and Baligar (2008) [2] indicates that regular liming can maintain soil pH within the optimal range, thereby enhancing nutrient availability and crop yields. For soils that are too alkaline, acidifying amendments such as sulphur, ammonium sulphate, or organic matter can be used to lower the pH. Sulphur, when oxidized by soil bacteria, forms sulfuric acid, which neutralizes alkalinity. Ammonium-based fertilizers also acidify the soil as ammonium is converted to nitrate by soil microorganisms, releasing hydrogen ions in the process. Adding organic matter, such as compost or manure, can improve soil structure and increase microbial activity, which can help to gradually lower soil pH. Regular soil testing is essential for monitoring soil pH and making informed decisions about pH management. Soil tests provide valuable information about the current pH levels and nutrient status of the soil, allowing farmers to apply the appropriate amendments in the correct amounts. Monitoring soil pH over time helps to track changes and adjust management practices accordingly to maintain optimal conditions for crop growth. Certain crops can tolerate a wider range of soil pH levels than others. Crop rotation and selection can be used as a strategy to manage soil pH and nutrient availability. For example, legumes such as clover and alfalfa can improve soil structure and increase organic matter content, which can help buffer soil pH. Additionally, rotating acid-tolerant crops with those that prefer neutral pH can help maintain soil health and productivity.

Conclusion

Soil pH plays a fundamental role in determining nutrient availability and plant health, making it a crucial factor in agricultural productivity and sustainability. This review has highlighted the mechanisms by which soil pH influences nutrient solubility and uptake, affecting the overall growth and development of plants. It is clear that maintaining an optimal soil pH range is essential for maximizing nutrient availability and ensuring healthy plant growth. The optimal pH range for most crops lies between 6.0 and 7.0, where essential nutrients are most readily available, and toxic elements are minimized. The impact of soil pH on nutrient availability underscores the importance of regular soil testing and monitoring. By understanding the current pH levels and nutrient status of their soils, farmers can make informed decisions about the necessary amendments and management practices to optimize soil conditions. Liming acidic soils and acidifying alkaline soils are effective strategies to adjust pH levels and enhance nutrient availability. Additionally, the incorporation of organic matter can help buffer pH changes and improve soil structure, further promoting nutrient uptake and plant health. The influence of soil pH extends beyond chemical properties to include biological health. Soil microorganisms, which play a vital role in nutrient cycling and organic matter decomposition, thrive within specific pH ranges. Therefore, managing soil pH not only affects nutrient availability but also supports a healthy soil ecosystem, contributing to sustainable agricultural practices. As climate change and soil degradation continue to pose challenges to global agriculture, the effective management of soil pH will be increasingly important. Ensuring that soils remain within optimal pH ranges can mitigate the effects of adverse weather conditions, improve water use efficiency, and enhance crop resilience. The integration of traditional soil management techniques with modern technological advancements, such as precision agriculture tools, offers promising approaches to maintaining and improving soil pH levels. In conclusion, soil pH is a critical determinant of nutrient availability and plant health. By maintaining appropriate soil pH levels through targeted amendments and management practices, farmers can optimize nutrient uptake, improve crop yields, and support sustainable agricultural systems. Continued research and innovation in soil pH management will be essential for addressing the evolving challenges of modern agriculture and ensuring food security for future generation.

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