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Original Article

Biochemical Approaches to Understanding Soil pH Dynamics and Its Influence on Plant Growth

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Abstract

Soil health in nurseries is an essential factor governing seedling establishment and growth, and soil pH plays a crucial role in the availability of nutrients and mineral absorption. Soil pH is needed at optimal levels to help support plant health by having a direct influence on nutrient acquisition, microbial abundance, and soil condition. Alternatively, unbalanced pH soil content, especially at higher levels, will be to blame for poorer nutrient acquisition, decreased microbial population, and degraded soil structure which eventually impacts plant growth adversely.Soil fertility can also be measured by standard methods like the Walkley-Black method for organic matter estimation and the Olsen method for phosphorus determination. Organic matter improves soil structure, water holding capacity, and microbial activity, and phosphorus aids in the induction of photosynthesis and energy transport in plants.All this research in this case focuses particularly on specifically the effect of soil pH on nursery soil health, especially with regard to the growth characteristics and biochemical fingerprints of Trigonella foenum-graecum (fenugreek/methi) and Raphanus sativus (radish). By examining differential soil samples, the study seeks to create meaningful correlations between indicators of plant health and pH levels of the soil. The outcomes of the study are meant to enhance sustainable horticultural practices, enhance plant yield, and generally enhance soil health. This study is useful in offering information on how to maximize conditions of nursery soil for productive and sustainable horticulture.

Keywords: Soil pH Dynamics, Phosphorus estimation, organic matter, growth parameters, Radish, Methi, Nitrogen, phosphorus, Soil fertility, chemical properties.

Introduction

Soil, the terrestrial ecosystem ground matrix, is crucial to maintaining plant and microbial life. As an organic matter, mineral, gas, liquid, and organism system, soil functions as a plant growth medium, water storage and filter, atmospheric regulator, and habitat for organisms. Soil forms continuously by physical, chemical, and biological activities and is thus a key element of terrestrial ecosystems. Soil quality, in the sense of physical, chemical, and biological properties, exerts the leading influence over agricultural productivity, ecosystem stability, and environmental sustainability of all factors controlling soil quality, Soil pH is a crucial parameter. It regulates the nutrient supply, microbial growth, and chemical speciation of the important elements, and thus determines the biological dynamics of the soil matrix. Soil pH is a scale of soil alkalinity or acidity and different species of plants have various optimal values. Severe acidity or alkalinity can lead to a lack of nutrients, limited microbial processes, and an unfavorable soil structure, eventually impacting plant growth and ecosystem processes.

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Techniques like the Walkley-Black method for organic carbon and Olsen method for phosphorus analysis provide valuable means of assessing soil fertility. Organic matter is accountable for structural stability, water storage, and nutrient supply while phosphorus is accountable for basic processes such as energy transfer and photosynthesis. Environmental factors like intensity of light, temperature, and status of water interact with soil pH to regulate nutrient cycling, microbial processes, and growth dynamics of plants. Light intensity and quality, particularly, have been reported to influence soil biochemistry, including organic matter, enzyme activity, and microbial biomass. Different wavelengths of light can influence photochemical reactions, microbial processes, and nutrient availability, and stimulate plant growth indirectly. For example, increased light intensity enhances organic matter decomposition while some wavelengths like blue and red light enhance microbial growth and photosynthesis, respectively. The present study addresses the effect of soil pH on plant growth and soil health by employing Trigonella foenum-graecum (methi) and Raphanus sativus (radish) as model crops. The research, based on the comparison of soil samples of varying geospatial locations and land use classes aims to realize the relationship of soil pH, biochemical parameters, and plant growth. The results attempt to offer useful recommendations towards enhancing soil health, maximizing crop health, and ensuring sustainable land use management. Through the integration of understanding the dynamics of soil pH, the research aims to make contributions towards robust agricultural systems that can handle existing environmental issues.

Materials and methods

Riverside soil samples (sandy loam) were preconditioned to 5.5, 7.0, and 8.0 pH using sulfuric acid and farm lime, and radish (Raphanus sativus) and methi (Trigonella foenum-graecum) were cultivated under greenhouse conditions with daily observations of growth characteristics over a period of two weeks.

Determination of phosphorus in soil Olsen P method

The Olsen P method, which was developed in 1954, is routinely used to analyze plant-available phosphorus (P) in soils, particularly in calcareous soils, with a 0.5M sodium bicarbonate ($NaHCO_3$) solution at a pH of 8.5. The method works by inhibiting sorption sites on aluminum and iron oxides, hence extracting phosphorus for analysis. The procedure consists of adding 1 g of soil to a 50 mL flask, adding 20 mL of $NaHCO_3$ solution, shaking at 24–27°C for 30 min, filtering the solution, and measuring the P content by colorimetry or by ICP spectroscopy. Olsen P concentrations of Riverside soils in our study were 20.0 mg P/kg for acidic soil, 12.2 mg P/kg for basic soil, and 9.4 mg P/kg for neutral soil. When analyzed at 530 nm, the respective values were 27.6 mg P/kg for acidic soil, 21.4 mg P/kg for basic soil, and 10.4 mg P/kg for neutral soil.

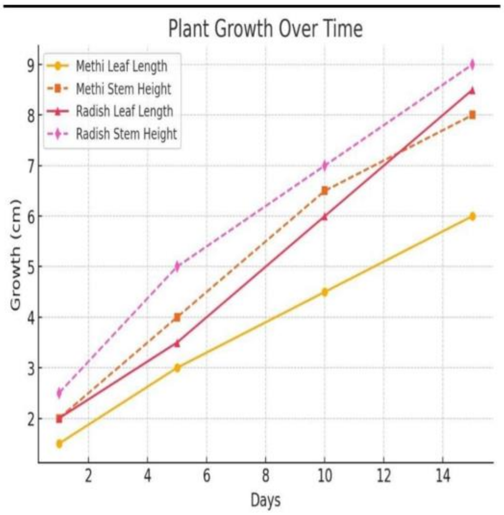
Determination of Organic Carbon in Soil: Walkley-Black Method Walkley-Black procedure is a popular procedure for estimating soil organic carbon (SOC) by oxidizing organic matter with potassium dichromate ($K_2Cr_2O_7$) in sulphuric acids followed by Titration with ferrous ammonium sulfate (FAS). The procedure assumes that the organic matter contains 58% carbon. The procedure involves weighing 0.5 g of soil in a 250 ml flask, adding 10 mlof 1N $K_2Cr_2O_7$ and 20 ml of H_2SO_4, cooling for 30 minutes, and then the addition of 200 ml of distilled water, 10 ml of orthophosphoric acid, and 1 ml of diphenylamine indicator. Titration with 0.5N FAS is done until a dark green color and the readings are recorded. In this study, Riverside soils contained 0.36% organic carbon (organic matter = 0.620%) in acidic soil, 0.21% (organic matter = 0.362%) in basic soil, and 0.0936% (organic matter = 0.161%) in neutral soil.

Plant Growth Response to Soil pH

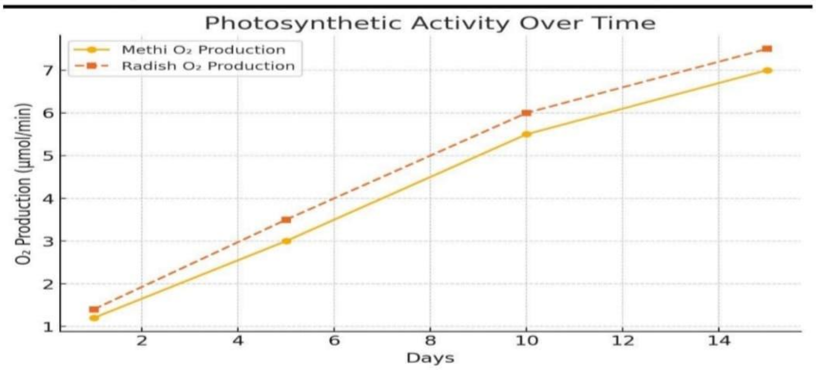
The Riverside soil samples included a broad pH range, from acidic (4.5–5.0) to highly alkaline (9.0–9.5), and were variable in texture and organic matter content. Plant growth varied significantly at various pH levels during the 15-day experiment. On Day 1, seedlings were all similar with no visible differences in growth. By Day 5, differences in growth had already been observed, where plants that grew in neutral soil (pH 6.5–7.0) were faster growing than in acidic or alkaline soils. By Day 15, the most growth and green, healthy leaves were from plants in neutral soil, while acidic soil produced little or dwarfed growth, and alkaline soil produced average growth with yellow leaves.

These findings underscore the significance of maintaining neutral soil pH to ensure the health of plants.

Day	Methi (leaf length)	Methi (Stem height)	Radish (leaf length)	Radish (stem height)
1	1.5	2.0	2.0	2.5
5	3.0	4.0	3.5	5.0
10	4.5	6.5	6.0	7.0
15	6.0	8.0	8.5	9.0

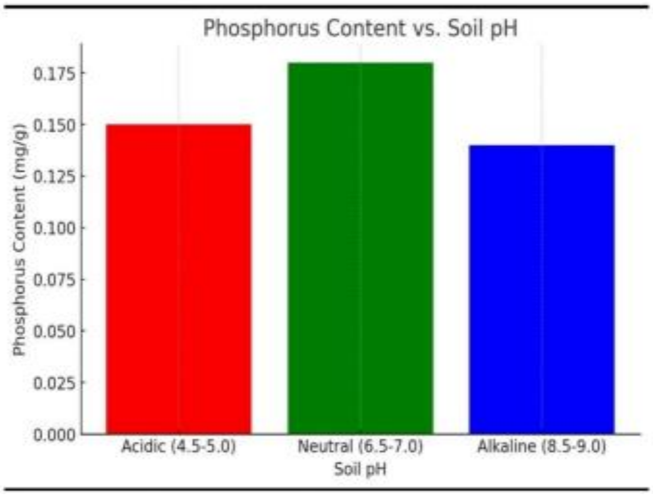


Photosynthetic activity and leaf health were optimal in neutral soil, while acidic and alkaline soils caused reduced efficiency and discoloration.



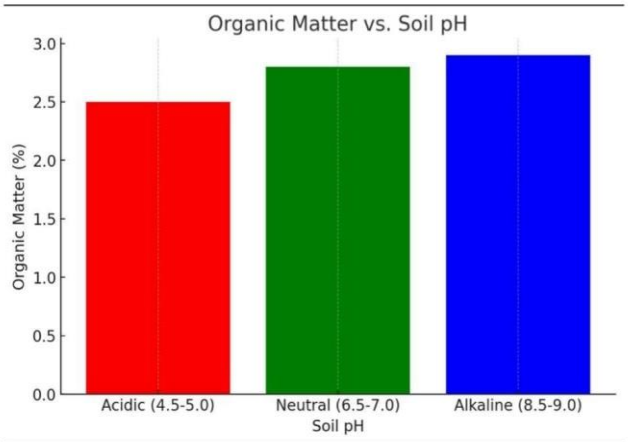
Soil Biochemical Analysis

Phosphorus



Phosphorus Content vs. Soil pH – A bar graph illustrating that phosphorus availability was highest in neutral soil and lower in acidic and alkaline soils.

Organic matter



Organic Matter vs. Soil pH – A bar graph showing organic matter content variation across different soil pH levels.

Conclusion

The present study evaluated the impact of soil pH on plant growth and soil fertility, focusing on the growth response of Trigonella foenum-graecum (methi) and Raphanus sativus (radish) in riverbank soil under varying levels of pH for 15 days. The findings confirmed that soil pH significantly impacts plant health, nutrient status, and microbial activity. Neutral pH (6.5–7.5) provided the optimal condition for plant growth, while the extreme and lowest pH values, either acidic (≤5.5) or alkaline (≥8.0), adversely affected the growth of the plants. Acidic soil restricted essential nutrients like phosphorus and nitrogen, where plant growth was unsuccessful or impaired, and alkaline soil caused impaired growth due to micronutrient deficiencies. Comparative analysis revealed that riverside soil (sandy loam) has low buffering capacity susceptibility to nutrient deficiencies under extreme pH conditions. This emphasizes the importance of organic matter in stabilizing soil pH, improving nutrient retention, and increasing microbial activity. Effective soil management practices are required for sustainable agriculture. Recommendations are to use lime and organic amendments to acidic soils, sulfur-based treatments to alkaline soils, increase organic matter by composting and manuring, and frequent observation of soil pH in order to apply interventions in time. These methods provide effective ways of maintaini ng soil health and increasing crop productivity.

Discussion

Influence of Soil pH on Plant Growth – the present study showed a remarkable association between soil pH and plant growth, especially in the case of Trigonella foenum-graecum (methi) and Raphanus sativus (radish). Plants raised under neutral to slightly alkaline soils (pH 6.5-7.5) showed maximum growth rate, healthiest morphology,and active physiological processes. These results are consistent with previous studies, which emphasize that crops grow well in neutral pH because of the bioavailability of nutrients like phosphorus, nitrogen, and potassium (Jones, 2010). On the other hand, acidic soils (pH ≤ 5.5) limited plant growth, possibly because of phosphorus fixation with aluminum and iron, and suppressed nitrification processes, which decreased nitrogen availability (Olsen et al., 1954; Fixen & Grove, 1990). Alkaline soils (pH ≥ 8.0) moderately limited plant growth, possibly as a result of the lower solubility of micronutrients such as iron and phosphorus, which appeared as chlorosis and reduced growth (Carter et al.,1997). Such findings highlight the significance of optimal pH for effective nutrient uptake and productivity in plants. Riverside soil showed low buffering capacity, with no growth in acidic conditions (pH 5.5), optimum growth in neutral conditions (pH 7.5), and moderate reduction in growth in alkaline conditions (pH 8.0). The low organic matter status of sandy loam rendered it vulnerable to pH variations and nutrient leaching, particularly in acidic conditions (Jarecki & Lal, 2003).

The results underscore the vital importance of organic amendments in enhancing soil structure, nutrient status, and buffering, particularly for sandy soils. Microbial Activity Role in Soil pH Regulation-Microbial activity is crucial for nutrient cycling, decomposition of organic matter, and soil structure maintenance. The microbial activity was indirectly measured in this study by assessing plant growth responses at different pH levels. The findings validated that the highest microbial diversity and activity occur under neutral pH conditions (6.5–7.5), which promote nutrient cyclingand plant growth. In acidic soils (pH ≤ 5.5), populations of microbes associated with nitrification and the decomposition of organic matter were most probably inhibited, leading to nutritional deficiencies. In the same vein, alkaline soils (pH ≥ 8.0) could have suffered from lower microbial efficiency brought about by deficient micronutrients, including iron, zinc, and phosphorus. These findings agree with research suggesting that soil microbial biomass is highest in neutral conditions, where microbial processes contribute importantly to soil fertility (Emery et al., 2019). Implications for Sustainable Agriculture and Soil Management. This research highlights the significance of soil pH management in sustainable agriculture. For acid soils (pH < 5.5), the addition of lime and organic manure like compost or manure neutralizes acidity, increases soil structure, and promotes nutrient availability.

For alkaline soils (pH > 8.0), sulfur-amended inputs and organic matter additions can decrease pH and increase nutrient retention. Organic matter addition, as in nursery soil, improves nutrient availability and maintains a stable soil pH and therefore, it is a key tactic in sustainable farming methods. In addition, the research highlights the significance of taking into account the type of soil in farm planning, as sandy soil such as riverbank soil need regular supplementing with nutrients because of their high leaching rate, while loamy soils are more nutritious and stable. Physiological Effects of pH on Photosynthetic Activity-Photosynthetic activity as measured by oxygen evolution, was most prominent in those plants that had been cultivated in neutral soils, which offer best conditions for the functioning of enzymes during the process of photosynthesis. Reduced photosynthetic activity was also noted in alkaline and acidic soils, most probably caused by the detrimental effect of extreme pH on enzyme systems essential for photosynthesis and nutrient uptake.

These results further confirm the hypothesis that neutral soil pH is critical to optimizing plant physiological processes and crop yields. This paper highlights the significance of soil pH in regulating plant growth, soil fertility, and microbial processes, offering valuable information for enhancing agricultural sustainability by optimizing soil management practices.

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Conflicts of interest
The authors declare that there are no conflicts of interest regarding the publication of this paper

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