IJCRT.ORG ISSN : 2320-2882
INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

Design And Fabrication Of A Paper-Based Microfluidic Device To Test Phosphorus In Soil

[1]Samprita Khune, [2]Neha Lomate, [3]Dipti Patil
[1]Student, [2]Student, [3]Student
[1]Mechanical Engineering,
[1]SVERI'S College of Engineering, Pandharpur, Solapur, Maharashtra, India

Abstract: Sustainable agriculture and soil health management are increasingly critical due to rising food demands and environmental challenges. Traditional soil testing methods often involve expensive laboratory equipment, skilled personnel, and long processing times, making them inaccessible for frequent on-site monitoring by rural farmers. To address these limitations, this study presents the design and fabrication of a paper-based microfluidic device (µPAD) for the rapid, low-cost detection of phosphorus in soil. The device utilizes capillary action to transport soil extracts through hydrophobic wax-printed channels to a reaction zone. Detection is based on the molybdenum blue colourimetric reaction, where orthophosphate ions react with reagents to form a blue complex, the intensity of which is proportional to the phosphorus concentration. Results are quantified via a smartphone application, providing an accessible readout for immediate field decision-making. This portable platform demonstrates significant advantages in time efficiency and affordability compared to conventional methods, supporting sustainable resource management in precision agriculture.

Keywords – Phosphorus detection, Microfluid, Capillary action, soil Testing

I. Introduction

In the modern world, sustainable agriculture and soil health management have become increasingly critical. With the increasing demand for food production and challenges of environmental degradation, traditional soil testing methods, such as laboratory-based chemical analysis, have proven to be limited in their accessibility and practicality. They often require costly equipment, skilled personnel, and significant processing time, making them unsuitable for frequent on-site monitoring by farmers. Soil fertility plays a crucial role in determining agricultural productivity, and the presence of essential nutrients, such as nitrogen, phosphorus, and potassium, is vital for plant growth. Among these, phosphorus (P) is one of the most important macronutrients responsible for root development, energy transfer, and overall plant health. However, excessive or deficient phosphorus levels in the soil can significantly affect crop yield and environmental sustainability.

The traditional method used for element detection requires a long duration; therefore, it is a time-consuming process. Traditional element method for phosphorus detection, such as spectrophotometry or chemical titration, although accurate, requires sophisticated instruments, skilled personnel, and laboratory facilities. These limitations render them unsuitable for field testing, particularly in rural or resource-limited settings.

Paper-based microfluidic devices (µPADs) have emerged as alternatives to overcome these challenges. These devices utilize patterned paper channels to control the flow of liquid samples using capillary action. This project aimed to design and fabricate a paper-based microfluidic device for the rapid detection of phosphorus in soil. The device employs colourimetric detection, where the colour intensity corresponds to the concentration of phosphorus in the soil extract. The concentration of the result, which is BLUE, tells the amount of phosphorus present in the soil for further processing.

II. Problem Statement

Traditional phosphorus testing methods are costly, time-consuming, and require laboratory equipment. There is a need for a low-cost, portable, and rapid detection system that can help farmers easily analyze soil phosphorus levels. This project aims to develop a paper-based colourimetric and smartphone-assisted system for simple and accurate phosphorus detection.

III. Solution

The Paper-Based Microfluidic Device for Phosphorus Detection in Soil successfully demonstrates the potential of integrating simple, low-cost materials with chemical sensing techniques to provide rapid and accurate soil nutrient analysis. The device, fabricated using sodium bicarbonate and microfluidic paper channels, enables farmers and agricultural users to determine the phosphorus content in soil simply by applying a small soil extract sample and observing the resulting colour change. The use of colourimetric detection allows for visual interpretation as well as quantitative estimation of phosphorus levels when paired with a colour sensor or smartphone-based image analysis. This approach provides an affordable, portable, and easy-to-use solution for real-time soil nutrient monitoring, reducing dependence on expensive laboratory tests. This project enhances traditional soil testing methods by providing rapid, on-site, and user-friendly phosphorus detection, empowering farmers to make informed decisions regarding fertilizer use and crop health management.

IV. Objective

- To design and develop a low-cost paper-based microfluidic device capable of detecting and quantifying available phosphorus in soil samples using colourimetric analysis.

- To develop a simple soil extraction protocol suitable for field applications.

- The performance of the paper-based device in terms of sensitivity, specificity, accuracy, and detection limit was evaluated by comparing its results with standard laboratory tests such as the Olsen or Bray method.

- The device was fabricated using an eco-friendly and easily reproducible method.

- To develop a cost-effective testing kit.

V. Methodology

This project enhances traditional soil testing methods by providing rapid, on-site, and user-friendly phosphorus detection, empowering farmers to make informed decisions regarding fertilizer use and crop health management.

1. Soil Sample Collection Module:
In this module, the soil samples are collected from different locations. The samples are dried, ground, and filtered to remove stones or debris. A chemical extracting solution (such as ammonium molybdate reagent) is added to extract the phosphorus ions into liquid form. This prepared liquid sample is used for further testing.

2. Paper-Based Microfluidic Device Module:
This is the core part of the system where detection occurs. The paper-based microfluidic analytical device (µPAD) is designed with hydrophobic channels using wax printing or photolithography. When the extracted soil solution is dropped on the strip, a colour reaction occurs due to a chemical reagent on the paper surface. The colour intensity varies according to the phosphorus concentration.

3. Image Capturing Module:

After the colour reaction, a mobile application is used to capture the image of the paper strip. The app ensures proper lighting and focuses on obtaining accurate colour data. This image acts as the input for the next stage (image processing).

4. Image Processing and Analysis Module:

In this module, the captured image is analyzed using colour recognition algorithms. The system compares the colour shade (RGB or HSV values) with pre-calibrated reference data. Based on this comparison, it calculates the phosphorus concentration in the soil sample. The algorithm provides accurate readings by compensating for lighting variations.

5. Result Display and Database Module:

The analyzed phosphorus value is displayed on the mobile app screen as quantitative data (mg/kg) or qualitative level (Low, Medium, High). The result can also be stored in a local or online database for future reference or agricultural record management. This helps farmers or researchers monitor soil fertility over time.

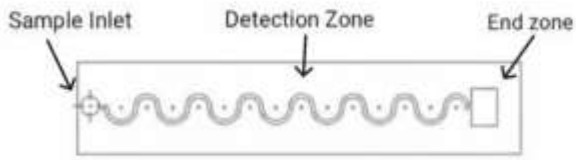

Fig 1: Sample Strip

- Sample Inlet Zone –

A small drop of soil extract is applied onto the inlet pad.

- Capillary Flow –

The liquid travels through patterned hydrophilic channels on a paper substrate bounded by hydrophobic barriers.

- Detection Zone –

The extract reaches the region pre-loaded with reagents (e.g., ammonium molybdate and ascorbic acid).

- chemicals used

1. Ammonium molybdate (for phosphate detection).
2. Sulfuric acid (acidic medium).
3. Ascorbic acid (reducing agent for blue colour).
4. Distilled water (for dilution).
5. Phosphate standard solution (for calibration)

VI. Future Scope

- Multiparameter Soil Testing:

The present design can be expanded to detect other essential nutrients, such as nitrogen, potassium, and pH, on the same microfluidic platform, allowing comprehensive soil fertility assessment for farmers.

- Integration with Smartphones and AI:

The smartphone-based colour analysis can be enhanced using AI algorithms to automatically interpret results, correct for lighting variations, and generate nutrient maps for site-specific fertilizer management.

- Improved Sensitivity and Specificity:

Future versions can incorporate nanoparticle-based reagents or enzyme-assisted amplifications to improve the sensitivity of phosphorus detection, especially in soils with very low phosphorus content.

- Automation and Internet of Things (IoT):

The device can be coupled with IoT systems for real-time data transfer to cloud databases or agricultural dashboards for large-scale soil monitoring across different locations.

- Eco-Friendly and Durable Materials:

Future fabrication can explore biodegradable coatings or laminated hydrophobic barriers to improve device durability under humid field conditions while maintaining sustainability.

- Commercialisation and Field Deployment:

With optimization, the technology can be scaled into an affordable field test kit for agricultural extension workers, promoting widespread adoption among small and medium-scale farmers.

VII. Conclusion

The designed paper-based microfluidic device successfully demonstrates a low-cost, portable, and rapid method for detecting phosphorus in soil using a colourimetric molybdenum blue reaction. The device effectively replaces laborious laboratory methods by utilizing capillary-driven fluid flow for autonomous operation and smartphone-assisted colour quantification for accurate, field-level assessment. The results validate that this system can provide reliable phosphorus concentration estimates suitable for immediate field decision-making in fertilizer management. Compared to conventional spectrophotometric analysis, the proposed device offers significant advantages in time efficiency, affordability, and ease of use. With further improvements in sensitivity, multiplexing, and digital data processing, this microfluidic platform holds strong potential to become a key tool in precision agriculture—empowering farmers with accessible soil health diagnostics and supporting sustainable resource management for future food security. These sections will conclude your report with scientific strength, clear future potential, and alignment with modern research trends in portable soil testing and microfluidic technology.