



## Literature review: Early detection kits for deficiencies in micronutrients and macronutrients in soil

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### Abstract

Soil nutrient deficiencies, particularly in macronutrients (nitrogen, phosphorus, potassium) and micronutrients (iron, zinc, copper), pose significant threats to agricultural productivity and food security. Early detection kits offer a rapid, cost-effective means to identify these imbalances, enabling timely interventions. This review synthesizes recent literature on commercial test kits, biosensor technologies, and IoT-integrated systems for soil nutrient analysis. Drawing from 15 key studies, we highlight advancements, accuracy challenges, and future direction's for sustainable soil management. Emphasis is placed on portable, field-deployable solutions that bridge laboratory precision with on-site usability.

**Keywords:** Soil nutrient deficiencies, macronutrients, micronutrients, early detection kits, soil testing, biosensors

### Introduction

Soil health is foundational to global agriculture, yet nutrient deficiencies affect over 50% of arable lands worldwide, leading to yield losses of up to 40% [2]. Macronutrients like nitrogen (N), phosphorus (P), and potassium (K) are essential for plant growth, while micronutrients such as iron (Fe), zinc (Zn), and copper (Cu) play critical roles in enzymatic processes [8]. Early detection of deficiencies prevents crop failure and optimizes fertilizer use, reducing environmental impacts like eutrophication [12]. Traditional lab-based analyses are accurate but slow and expensive, prompting the development of portable detection kits. This review examines literature from 2016 to 2025 on these kits, focusing on their mechanisms, efficacy, and limitations.

Importance of Early Detection in Soil Nutrient Management  
Nutrient imbalances in soil directly correlate with reduced crop yields and increased susceptibility to pests and diseases [2]. For instance, zinc deficiency, prevalent in alkaline soils, impairs root development and chlorophyll synthesis, while iron shortages cause chlorosis in high-pH environments [9]. Early intervention through detection kits can mitigate these issues, promoting sustainable farming practices. Studies underscore the economic benefits: precise nutrient mapping can enhance yields by 20-30% while cutting fertilizer costs by 15% [2]. Spatial diagnostics reveal yield-limiting factors, identifying micronutrient hotspots that macronutrient applications alone cannot address [2]. Furthermore, neglected micronutrients influence soil microbial communities, amplifying deficiency effects on plant health [9].

### Traditional and Commercial Soil Test Kits

Commercial kits dominate early detection due to their affordability and ease of use [3]. These colorimetric or chemical-based tools typically assess NPK and pH, with some extending to micronutrients [3]. The Rapitest Soil Test

Kit, for example, provides quick results for deficiencies, recommending amendments like nitrate of soda for low nitrogen [5]. However, accuracy varies; evaluations of kits like Luster Leaf and Transchem show discrepancies with lab standards, particularly for phosphorus in low-fertility soils [3, 7]. In classroom settings, such kits facilitate hands-on learning of soil quality, though they often overestimate organic matter [5]. Portable macronutrient kits from LaMotte include sampling tools for NPK, aiding smallholder farmers in resource-limited areas [3]. Despite limitations in micronutrient coverage, these kits enable rapid field triage, with error rates below 20% for major elements when calibrated properly [3].

### Advanced Technologies: Biosensors, IoT, and Machine Learning Integration

Recent innovations shift toward biosensors and digital platforms for real-time, multi-nutrient detection [6]. Electrochemical biosensors excel in portability, detecting NPK via ion-selective electrodes with limits of detection as low as 0.1 mg/L [13]. Nano-biosensors, transitioning from lab to field, offer specificity for micronutrients like Fe and Zn through biorecognition elements [10]. Bioelectrochemical systems leverage microbial activity to monitor fertility, providing insights into dynamic soil processes [11]. IoT-enabled analyzers integrate sensors for pH, moisture, and minerals, coupled with machine learning for crop recommendations [4]. For nitrogen-focused detection, optical and electrochemical methods achieve sub-hour turnaround, surpassing traditional kits [14]. Whole-cell biosensors, encapsulated for soil deployment, detect deficiencies without preprocessing, ideal for remote monitoring [6]. Field-effect transistor (FET)-based devices further enhance sensitivity for environmental analytes, including soil ions [15].

Technology	Key Nutrients Detected	Advantages	Limitations	Example Reference
Colorimetric Kits	N, P, K, pH	Low cost, user-friendly	Low accuracy for micronutrients	[3]
Electrochemical Biosensors	NPK, Fe, Zn	High sensitivity, portable	Requires calibration	[13]
IoT-Integrated Sensors	All major + moisture	Real-time data, predictive analytics	Connectivity issues in remote areas	[4]
Nano-Biosensors	Micronutrients (Cu, Mn)	Field-deployable, specific	Emerging, high initial cost	[10]
Bioelectrochemical	Microbial-linked fertility	Holistic soil health insights	Complex setup	[11]

### Challenges and Future Directions

**Despite progress, challenges persist:** commercial kits often underperform for micronutrients, with false positives in organic-rich soils [3, 7]. Biosensors face matrix interferences from soil heterogeneity, necessitating robust encapsulation [10, 11]. Standardization across kits remains elusive, hindering global adoption [8]. Future research should prioritize hybrid systems combining AI with low-cost sensors for comprehensive profiling [1, 12]. Long-lived spore-based biosensors could enable continuous monitoring, while policy integration could subsidize kits for small farms [6]. Addressing these gaps will foster precision agriculture, minimizing nutrient runoff and enhancing resilience to climate variability [12].

### Conclusion

Early detection kits have revolutionized soil nutrient management, evolving from basic colorimetric tools to sophisticated biosensors and IoT platforms [6, 15]. Literature affirms their role in curbing deficiencies, though accuracy and accessibility must improve [3]. By leveraging 15 pivotal studies, this review advocates for interdisciplinary advancements to support sustainable yields. Future kits promise integrated, AI-driven solutions, ensuring fertile soils for generations [1].

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