International Journal of Plant & Soil Science

Volume 37, Issue 9, Page 531-538, 2025; Article no.IJPSS.143291
ISSN: 2320-7035

Smart Nutrient Management for Pest and Disease Control in Tropical Fruit Crops: A Literature Review for Practitioners

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

Article Information

DOI: https://doi.org/10.9734/ijpss/2025/v37i95731

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://pr.sdiarticle5.com/review-history/143291

Minireview Article

Received: 02/07/2025
Published: 11/09/2025

ABSTRACT

Smart nutrient management is emerging as a cornerstone of integrated pest and disease control in tropical fruit crops such as papaya and banana. This review aims to explore how nutrient imbalances, particularly excessive nitrogen, influence pest outbreaks and plant resilience. Drawing on Mulder's chart (Martín-Cardoso & San Segundo, 2025) of nutrient interactions, we examine the antagonistic effects of surplus nitrates on potassium uptake. The paper synthesizes data from recent studies and field-based insights, highlighting smart pest control strategies including real-time nutrient diagnostics and intelligent monitoring systems. These approaches offer practical tools for growers in northern Australia and support sustainable farming practices. The role of AI technologies in shaping future pest management is also discussed.

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Cite as: *Vinesh Prasad. 2025. "Smart Nutrient Management for Pest and Disease Control in Tropical Fruit Crops: A Literature Review for Practitioners". International Journal of Plant & Soil Science 37 (9):531–538. https://doi.org/10.9734/ijpss/2025/v37i95731.*

Keywords: Smart nutrient management; Integrated Pest Management (IPM); nutrient-pest interactions; environmental sustainability; pest resistance; smart pest control; deep learning.

1. INTRODUCTION

In Australia's tropical north, fruit crops such as papaya and banana are not only vital to regional economies but also central to the livelihoods of many farming communities. However, these crops face mounting challenges from pests and diseases, driven by monoculture practices, over-reliance on chemicals, and climate variability. Traditional pest control methods while effective in the short term pose long-term risks including resistance, environmental harm, and reduced biodiversity (Biratu, 2022; Kriticos & Paini, 2014; Live to Plant, 2025).

To address these issues, smart pest control is emerging as a forward-thinking approach that integrates technology with ecological principles. Tools like deep learning, AI-driven diagnostics, and sensor-based monitoring systems are enabling more targeted and sustainable interventions. These innovations are particularly relevant in Queensland's tropical systems, where pest pressures are dynamic and influenced by both environmental and management factors. Climate-smart pest management (CSPM) frameworks are also gaining relevance, promoting adaptive strategies that align with Australia's sustainability goals. At the same time, nutrient management is being reevaluated, with evidence showing that imbalances especially high levels of nitrogen can increase pest susceptibility. This review aims to synthesise current knowledge and provide practical insights for Australian growers and agronomists.

In response to these challenges, the concept of smart pest control has emerged as a transformative approach that integrates advanced technologies with sustainable agricultural practices. Smart pest control leverages tools such as deep learning, large language models, and intelligent pest monitoring systems to enable precise, data-driven interventions that reduce chemical inputs and enhance ecological resilience (Xie & Sun, 2025). These innovations are particularly relevant in tropical systems where pest dynamics are complex and influenced by both biotic and abiotic factors.

Climate change further complicates pest management by altering pest population dynamics, expanding the range of invasive species, and increasing the unpredictability of disease outbreaks. The Climate-Smart Pest Management (CSPM) framework addresses these issues by promoting adaptive strategies that align with sustainable development goals and environmental stewardship (Bouri et al., 2023). CSPM emphasizes early diagnosis, risk assessment, and the integration of ecological principles to mitigate the impact of climate variability on crop health.

Sustainable pest management also involves rethinking nutrient management practices. Emerging evidence suggests that nutrient imbalances particularly elevated nitrogen levels can increase susceptibility to pests such as mites in crops like papaya and banana. This phenomenon is explained through nutrient antagonism, as illustrated by Mulder's chart (Martín-Cardoso & San Segundo, 2025), where excess nitrogen can suppress potassium uptake, thereby weakening plant defences and reducing resilience (Francis, 2023).

This paper aims to provide a comprehensive literature review on the intersection of nutrient management and smart pest control in tropical fruit crops. By synthesizing current research and practical insights, it seeks to equip practitioners with actionable knowledge to enhance pest resistance, promote environmental sustainability, and support resilient farming systems.

2. BACKGROUND

Modern tropical fruit production systems, particularly for crops like papaya and banana, are increasingly shaped by monocropping practices. While these systems offer eco-nomic efficiency, they also contribute to reduced genetic diversity and increased vulnerability to pests and diseases. Monocropping simplifies agroecosystems, limiting natural pest resistance and resilience, and often necessitates heavy chemical inputs to maintain productivity (Jacques & Jacques, 2012; Weih et al., 2022; Raju et al., 2024). The widespread use of chemical pesticides in banana and papaya cultivation has led to significant environmental and health concerns. In regions such as Oaxaca, Mexico, pa-paya producers frequently apply mixtures of insecticides and fungicides, often with limited knowledge of safe handling practices. This has resulted in acute poisoning symptoms among farmworkers, including skin irritation, respiratory issues, and neurological effects (Bernardino-Hernández et al., 2024). Additionally, pesticide residues in bananas have raised consumer concerns due to their potential link to chronic diseases (Méndez et al., 2023).

Climate change further exacerbates pest and disease pressures in tropical fruit crops. Rising temperatures, irregular rainfall, and increased humidity create favourable conditions for pest proliferation and disease outbreaks. These abiotic stressors disrupt crop phenology, reduce fruit quality, and increase the need for chemical interventions (Raju et al., 2024; Bacelar et al., 2024). Current industry practices in pest management for banana and papaya often rely on chemical control, which is increasingly proving ineffective due to the development of pest resistance. For example, Fusarium wilt in bananas, caused by Fusarium oxysporum f. sp. cubense, has spread globally and remains difficult to manage with fungicides alone. Biological control using microbial agents such as Trichoderma and Pseudomonas spp. has shown promise but requires further research and field validation (Pretty & Bharucha, 2015; Bernardino-Hernández et al., 2024).

The limitations of conventional pest control—chemical dependency, resistance development, and ecological harm highlight the urgent need for sustainable alternatives. Integrated pest management (IPM), biological control, and smart nutrient management are increasingly recognized as viable strategies to reduce pesticide use and enhance crop resilience (Sullivan et al., 2025; Bacelar et al., 2024).

3. LITERATURE REVIEW

3.1 Nutrient-Pest Interactions in Tropical Fruit Crops

Nutrient management is a foundational aspect of plant health and productivity, but its influence extends beyond growth to include susceptibility or resistance to pests and diseases. In tropical fruit crops such as papaya and banana, nutrient imbalances—particularly involving nitrogen and potassium—have been shown to significantly affect pest dynamics and disease severity. Nitrogen (N) is a critical macronutrient involved in numerous physiological processes, including amino acid synthesis, photosynthesis, and hormone regulation. However, its role in plant-pathogen interactions is complex. Excessive nitrogen fertilization has been linked to increased susceptibility to biotrophic pathogens and pests, including mites and fungal diseases, due to weakened physical barriers and altered metabolic pathways (Sun et al., 2020). In papaya, elevated nitrate levels have been associated with higher mite infestations, potentially due to increased leaf succulence and reduced potassium uptake, which compromises cell wall integrity and defense enzyme activity.

Potassium (K), on the other hand, plays a vital role in enhancing plant resistance by strengthening cell walls, regulating osmotic balance, and activating defense-related enzymes. According to Mulder's chart (Martín-Cardoso & San Segundo, 2025) of nutrient interactions, excessive nitrogen can antagonize potassium uptake, thereby reducing the plant's ability to mount effective defense responses (Martín-Cardoso & San Segundo, 2025). This antagonism is particularly relevant in banana cultivation, where potassium deficiency has been linked to increased vulnerability to Fusarium wilt and other soil-borne pathogens (Zakaria, 2023).

The relationship between nutrient status and pest susceptibility is further complicated by environmental factors such as soil type, irrigation practices, and climate conditions. For example, nutrient stress, whether due to deficiency or excess, can disrupt hormonal signaling pathways and reduce the synthesis of phytoalexins, antimicrobial proteins, and other defense compounds (Martín-Cardoso & San Segundo, 2025). These disruptions can create favorable conditions for pest colonization and disease progression. Understanding these nutrient-pest interactions is essential for developing smart pest control strategies. By optimizing nutrient inputs and balancing NPK ratios, growers can enhance plant resilience and reduce reliance on chemical pesticides. This approach aligns with the principles of sustainable agriculture and integrated pest management (IPM), offering a pathway toward more ecologically sound and economically viable production systems.

3.2 Smart Nutrient Management and Pest Control

Smart nutrient management is increasingly recognized as a key strategy for enhancing crop resilience and reducing pest pressure in tropical fruit systems. In crops like papaya and banana, nutrient imbalances—especially excessive nitrogen—can exacerbate pest infestations, while balanced nutrient delivery can strengthen plant defenses (Sun et al., 2020). In papaya, integrating organic and inorganic nutrient sources with biocontrol agents has shown promising results. Chinnasamy et al. (2025) demonstrated that a combined nutrient formulation significantly improved plant vigor and reduced the incidence of Papaya Ring Spot Virus (PRSV) by activating defense enzymes such as peroxidase and polyphenol oxidase. This approach aligns with sustainable pest control by reducing reliance on chemical pesticides.

Banana cultivation has benefited from precision fertigation systems that deliver nutrients based on crop stage and environmental conditions. Chen et al. (2025) developed a dynamic monitoring system using UAV remote sensing and GIS technologies, which reduced fertilizer inputs by up to 27% while increasing yields. These systems use machine learning algorithms to analyze soil nutrient status and generate adaptive fertilization recommendations, contributing to both productivity and pest resistance.

Real-time nutrient diagnostics are also transforming field-level decision-making. Singh et al. (2023) introduced a portable colorimetric sensor capable of detecting nitrogen and phosphorus levels in soil with high accuracy. This tool enables farmers to make immediate, data-driven adjustments to nutrient applications, minimizing the risk of over-fertilization and its associated pest-promoting effects. By maintaining optimal nutrient balance—particularly avoiding excess nitrogen that can suppress potassium uptake and weaken plant defenses—smart nutrient management supports integrated pest management (IPM) and contributes to environmental sustainability (Martín-Cardoso & San Segundo, 2025).

3.3 Intelligent Pest Monitoring Systems

Intelligent pest monitoring systems are revolutionizing pest management in tropical agriculture by enabling early detection, accurate classification, and real-time response. These systems utilize deep learning, edge computing, and sensor technologies to monitor pest populations and environmental conditions simultaneously (Ferreira Lima et al., 2020). Automated sensor-based traps are among the most widely adopted technologies. These systems use infrared, audio, and image-based sensors to detect pest activity. Ferreira Lima et al. (2020) reviewed various sensor platforms and found that image-based classification systems are particularly effective in identifying pests across multiple insect orders, supporting timely interventions and reducing pesticide use.

Advanced deep learning models have further improved detection accuracy. Yuan et al. (2025) developed a pest monitoring system using EfficientNetv2-S and Adaptive Feature Pyramid Networks (AFPN), achieving a detection accuracy of 95.72% and real-time monitoring at 127 FPS. This system integrates mechanical separation devices and is suitable for deployment in complex field environments. To address computational limitations in remote areas, Xiao et al. (2023) proposed a lightweight pest detection algorithm, GCSS-YOLOv5s, which incorporates GhostNet and CARAFE modules. This model achieved a mean average precision of 90.5% while reducing computational load by 44%, making it ideal for edge devices in low-infrastructure settings. These intelligent systems support data-driven pest control by integrating pest population data with environmental variables such as temperature, humidity, and crop phenology. This integration enables predictive modeling and adaptive management, aligning with smart pest control principles and enhancing resilience in the face of climate variability (Bouri et al., 2023).

3.4 Sustainable Farming and Resilience: IPM, Biological Control, and Agroecological Approaches

Sustainable farming systems aim to balance productivity with ecological integrity, and pest management is central to this balance. In tropical fruit production, where pest pressure is high and chemical dependency is common, transitioning to integrated and ecologically grounded approaches is essential for long-term resilience. Integrated Pest Management (IPM) is a cornerstone of sustainable agriculture. It combines biological, cultural, mechanical, and chemical tools in a coordinated strategy to manage pest populations at economically and ecologically acceptable levels. IPM emphasizes prevention, monitoring, and targeted interventions, reducing the need for broad-spectrum pesticides (Ramasamy, 2024). Its adaptability to local conditions makes it particularly suitable for diverse cropping systems and smallholder contexts, where resource constraints and environmental vulnerabilities are pronounced.

Biological control is a key component of IPM and involves the use of natural enemies—such as parasitoids, predators, and entomopathogenic fungi—to suppress pest populations. Recent studies have demonstrated the effectiveness of biocontrol agents like Metarhizium anisopliae and Beauveria bassiana in managing pests such as fruit flies and whiteflies in tropical systems (Pratissoli, 2025). These agents offer a sustainable alternative to chemical pesticides, with minimal impact on non-target organisms and the environment. Agroecological approaches further enhance resilience by promoting biodiversity, soil health, and ecological interactions. Practices such as intercropping, crop rotation, and the use of botanical extracts contribute to pest suppression while improving overall system stability. For example, Kirui et al. (2023) found that agroecological pest management practices in crucifer and traditional African vegetable systems significantly reduced pest incidence and improved farmer knowledge and adoption of sustainable methods.

These approaches not only reduce chemical inputs but also build resilience against climate-induced pest outbreaks. As climate change alters pest dynamics and increases the frequency of extreme weather events, farming systems that rely on ecological processes rather than external inputs are better equipped to adapt and recover. Sustainable pest management strategies thus contribute to both climate adaptation and food security, especially in vulnerable tropical regions (Ramasamy, 2024; Pratissoli, 2025). However, the widespread adoption of these practices faces challenges, including limited access to biocontrol products, lack of training, and insufficient policy support. Addressing these barriers requires coordinated efforts in research, extension, and policy to scale up sustainable pest management and embed it within broader agricultural development frameworks.

4. DISCUSSION

This review highlights the importance of integrating smart nutrient management and intelligent pest control systems to build more resilient and sustainable tropical fruit pro-duction in Australia. While chemical control remains common, it is increasingly clear that over-reliance on pesticides is unsustainable. Smart pest control offers a viable alternative by combining early detection, data-driven decision-making, and ecological awareness. In Australia's tropical and subtropical regions, where climate variability and biosecurity threats increasingly challenge agricultural productivity, fruit crops such as papaya and banana are central to both regional economies and community livelihoods. These crops face mounting pressures from pests and diseases, exacerbated by monoculture practices, chemical overuse, and shifting climatic conditions (Parliament of Australia, 2025). While traditional pest control methods have offered short-term relief, they often contribute to long-term ecological risks such as resistance development, biodiversity loss, and environmental degradation.

To address these challenges, Australian agriculture is embracing smart technologies that support proactive and sustainable pest and disease management. Tools such as remote sensing, portable nutrient sensors, and AI-based pest identification systems are transforming Integrated Pest Management (IPM) strategies by enabling real-time diagnostics and targeted interventions (Mansoor et al., 2025; Frontiers, 2025). These innovations not only reduce chemical inputs but also help growers comply with environmental regulations and meet market expectations for sustainability. For instance, intelligent nutrient monitoring can prevent nutrient-induced pest susceptibility, while AI-guided surveillance systems allow for timely and precise responses to emerging threats. Together, these approaches form a holistic framework that aligns with Australia's goals for climate resilience and sustainable agriculture (Parliament of Australia, 2025; Mansoor et al., 2025). Smart pest control integrates advanced technologies such as deep learning, large language models, and sensor-based monitoring systems to enable precise and adaptive pest management. These systems reduce pesticide usage, lower operational costs, and improve ecological outcomes by facilitating early detection and targeted interventions (Xie & Sun, 2025). In tropical fruit crops like papaya and banana, where pest dynamics are influenced by nutrient status and climatic variability, such technologies offer a transformative solution for managing complexity.

Climate change further complicates pest and disease management by altering pest population dynamics, expanding the range of invasive species, and increasing the unpredictability of outbreaks. The concept of Climate-Smart Pest

Management (CSPM) addresses these challenges by promoting adaptive strategies that integrate environmental monitoring, risk assessment, and sustainable practices (Bouri et al., 2023). CSPM emphasizes the need for scalable technologies and collaborative research to enhance resilience in agricultural systems, particularly in developing regions where capacity building is essential.

Integrated Pest Management (IPM) remains a foundational strategy in sustainable agriculture. It combines biological, cultural, mechanical, and chemical methods to man-age pests in an ecologically sound manner. Evidence from Asia and Africa shows that IPM can reduce pesticide use by up to 70% while increasing crop yields by over 40%, demonstrating its effectiveness in promoting both productivity and sustainability (Pretty & Bharucha, 2015). However, widespread adoption of IPM is hindered by limited policy support and resistance from the pesticide industry, highlighting the need for institutional reforms and farmer education. The integration of smart technologies into IPM frameworks can enhance their effectiveness and scalability. For example, intelligent pest monitoring systems can provide real-time data to inform IPM decisions, while smart nutrient management can prevent nutrient-induced pest susceptibility. Together, these approaches offer a holistic framework for pest and disease control that is adaptive, efficient, and environmentally responsible. In conclusion, the convergence of smart pest control, climate-smart agriculture, and integrated nutrient management presents a promising pathway for building resilient and sustainable tropical fruit production systems. Future research should focus on refining these technologies, improving accessibility for smallholders, and developing policy frameworks that support their implementation.

5. CONCLUSION

Smart nutrient management and intelligent pest control are no longer aspirational; they are actionable strategies for enhancing tropical horticulture in Australia. Technologies such as precision fertigation, AI-driven pest monitoring, and real-time nutrient diagnostics have shown strong potential to reduce pest pressure and improve crop resilience. When integrated with ecological approaches like IPM and biological control, these innovations support biodiversity, soil health, and climate-smart agriculture. Scaling these solutions will require coordinated efforts in research, training, and policy support. With the right frameworks, Australia's growers can adopt a more sustainable and resilient model for pest and disease management—one that aligns with both environmental goals and market demands.

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The author of this paper is a practicing agronomist based in Far North Queensland, Australia. The views, interpretations, and conclusions presented in this research are entirely his own and do not reflect, in any way, the position, policies, or opinions of the organization with which he is affiliated. All research, analysis, and recommendations have been independently conducted and are intended solely for academic and practical discourse within the field of agronomy.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://pr.sdiarticle5.com/review-history/143291