Coconut Tree Disease and Nutrient Deficiency Identification: A Systematic Review of Current Methods and Emerging Technologies

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ABSTRACT

Coconut farming is a vital livelihood for millions across tropical regions, yet the health of coconut trees is increasingly threatened by nutrient deficiencies and diseases. Traditional methods, including visual inspection and laboratory testing, remain foundational for assessing coconut tree health but face significant drawbacks in scalability, subjectivity, and timeliness. In recent years, there has been rapid technological advancement in early, accurate, and large-scale detection methods. These include image processing, machine learning, remote sensing, and IoT-based systems integrated to a mobile device. However, challenges such as data availability, infrastructure costs, and user adoption continue to hinder widespread implementation. Despite these limitations, the application of emerging technologies remains relevant, as they address the gaps of traditional approaches. As such, this review presents a summary of current and emerging methods for detecting these issues, drawing on studies published between 2020 and 2025. It highlights both the strengths and trade-offs of each method, aiming to inform future research in coconut-producing countries.

Keywords:- Coconut Tree, Disease Detection, Nutrient Deficiency Monitoring, Precision Agriculture, Agricultural Technology, Coconut Farming

I.   INTRODUCTION

Coconut is often called the "tree of life" because every part of it can be used in various ways [1]. Its parts are processed into valuable products such as coconut oil, desiccated coconut, coconut water, and construction materials. These products are widely used in food, health, cosmetics, and building industries.

Globally, the demand for coconut-based products has been rising steadily since 2020. A report by Allied Market Research estimated that the global coconut market was valued at nearly $13 billion in 2019 and is projected to reach $31 billion by 2024 [2,3]. This growth reflects coconut's growing role in health-conscious markets and sustainable product development.

In tropical countries like the Philippines, coconut farming plays a key role in rural economies. It provides food, jobs, and a source of income for around 2.5 million farmers. With 69 out of 82 provinces producing coconut, the industry covers 3.62 million hectares of farmland [4]. The country had over 347 million fruit-bearing trees and produced 14.7 million metric tons (in nut terms) in 2018 [4]. The Philippines remains the second-largest coconut producer in ASEAN, contributing about 40% of the region's total production [5]. Major production regions include CALABARZON, Davao, Northern Mindanao, and Zamboanga Peninsula. In the second quarter of 2023, coconut production reached 3.41 million metric tons, a 1.5% increase from the same period in 2022 [4]. Davao Region led with 13.5% of total production, followed closely by Northern Mindanao and Zamboanga Peninsula [4].

Despite strong demand, the supply of coconuts is often limited by several factors. One major issue is the impact of pests, diseases, and poor soil health, which reduce crop yields and threaten long-term sustainability [5]. Many coconut trees are old and less productive. In addition, natural disasters such as typhoons have repeatedly damaged large areas of coconut farmland. For instance,

Typhoons Pablo (2012) and Yolanda (2013) caused widespread destruction, while Typhoon Haiyan in 2015 alone destroyed or damaged over 33 million coconut trees [6,7]. After such events, recovery is slow and costly, leaving many farmers economically vulnerable. The coconut scale insect (CSI), or cocolisap, is another serious threat [5]. First observed in 2010, it feeds on leaves, fruits, and flowers, often leaving only the trunk. Outbreaks led to significant yield loss and forced farmers to cut down infested trees. Control measures included pesticide application, leaf pruning, use of biocontrol agents, and improved fertilization. These factors: ageing trees, pest infestations, and environmental stress, lead to lower yields and economic losses in the coconut industry.

Detecting diseases or nutrient deficiencies early is critical for maintaining coconut productivity. However, traditional methods mainly rely on visual inspection, which can be inaccurate and labor-intensive. Subtle signs of disease may go unnoticed, and farmers may lack the training or resources to assess tree health properly. Most smallholder farmers still use conventional practices, and many coconut-producing areas have limited access to diagnostic tools, agricultural support, or infrastructure. Without timely intervention, these problems often escalate, resulting in further losses.

To address these challenges, researchers have started using modern technologies to improve early detection of coconut diseases and deficiencies. These include artificial intelligence (AI), the Internet of Things (IoT), and image processing. These tools allow for more accurate, faster, and large-scale assessments of tree health. Precision agriculture, using data and

technology to manage crops, is becoming more common in tree-based farming systems. Although adoption is still limited in some regions, there is growing interest in these innovations due to their potential to support sustainable and efficient farming.

This review summarizes current research on early detection of coconut tree diseases and nutrient deficiencies. It highlights technological developments, their applications, and the challenges of adopting them in real-world settings. The literature reviewed was selected through online databases and published studies from 2020 to 2025. Sources focused on coconut-producing countries with an emphasis on technological approaches to disease and nutrient detection. Studies that did not directly address detection technologies or were not peer-reviewed were excluded from the scope of this review.

II. COCONUT TREE HEALTH: OVERVIEW

A. Common Diseases of Coconut Trees

Although often called the "tree of life," coconut trees are increasingly affected by diseases that weaken them, making them less able to produce fruit as expected. Trees that contract these diseases are not only cut down but also become unsuitable for use as lumber, as their wood is weaker than that of healthy trees.

Many diseases impact coconut trees, but the major ones include fungal infections, bacterial and phytoplasma diseases, the Cadang-cadang viroid, and pest damage [8].

1. Fungal Diseases

a) Bud Rot, mainly cause by Phytophthora palmivora, is the most destructive disease of coconuts [9]. It begins with the spear (unfolding) leaf utrning pale and wilting, resulting to the inner bud tissues rotting and emitting foul odor [10]. Infected palms rapidly lose all young fruits, with the crown collapsing within months [10]. Bud Rot causes significant yield losses annually [10]. To manage this disease, farmers rely on removing and burning affected palms, improving drainag and sanitation, and fungicidal protection to healthy trees [11], [12].

b) Stem Bleeding, also called thatch bleeding is caused by the fungus Thielaviopsis paradoxa [13]. It is characterized by reddish-brown to black ooze running down the trunk from wounds. Affected palms develop soft, rotting tissue around the wound that eventually causes the trunk to collapse [14]. Palms other than coconut may show bleeding but it is most common and damaging in coconut. It is because the fungus degrades wood tissue from the outside and fibers remain as stringy black material while the rest of the tissue decays [14]. To control this, they mainly avoid the trunk wounds, use sanitizing tools, and promptly removing infested palms to reduce the spread [15].

c) Numerous leaf-spot and blight fungi causes nectrotic spots of streaks on fronds. For example, gray leaf spot of coconut was recently attributed to a Pestalotiopsis sp. producing gray or brown patches on leaflets [16, 17]. These leaf diseases are usually of minor importance it becomes severe ones it is under wet conditions as it can quickly defoliate palms [18]. For instance, it caused losses of millions of nuts in China and up to ~20% yield reduction India when epidemics were severe [19, 20]. To manage, it generally invovle cultural sanitation and fungicides to reduce inoculum.

2. Bacterial and Phytoplasma Diseases

a) Lethal yellowing (LY), a diseased caused by phytoplasma is a fast -acting palm declining. Infected trees display premature fruit and flower drop, blackening of inflorescences, yellowing of fronds, and death within months. This diseases has devastated palms in the Caribbean and Africa [21, 22]. Specifically, American palm cixiid (Haplaxius crudus) is a proven vector of LY phytoplasmas where millions of coconut palms have died in affected regions, causing major economic loss [23]. Control focuses on using resistant varieties, destroying symptomatic palms and prevent the spread of vector.

b) Kerala Coconut Root is a chronic phytoplasma-associated syndrome that is found in India [24]. Its earliest symptom is "flaccid" leaflets on the older fronds, starting near the tips and progressing inward [25]. Affected palms often show stunted inflorescences, premature nut shedding, and poor root growth [26]. Eventually, a palm produces very few nuts. This disease is also associated with sap-feeding insects, such as leafhoppers, though not exactly fully confirmed yet. To manage, they maintain the soil fertility, green manures, irrigation and replanting of healthy palms, as treatment is yet to exist [25, 27].

3. Cadang-cadang viroid is a lethal disease endemic to the Philippines where symptoms develop slowly at 8-15 years and progress through defined stages [28]. Early signs include tiny orange or yellow spots on leaflets and slight distortion of young leaves. As it advances, fronds become choloritc and inflorescenes die, so the palm stops fruiting. In late stages, the crown turns bronze and eventually only naked trunk remains. Over 30 million coconut palms have been reportedly killed by cadang-cadang, making it a historically catastrophic loss [29]. There is not cure yeat but controlling it is possible by removing affected palms and breeding for tolerance.

4. Pest Damage

a) The Coconut Rhinoceros Beetle (Orcytes Rhinoceros) lives in the crown, especially the unopened spear leaf and flowers, destroying the growing point . Adult beetle excavate large holes in the crown, feeding on the internal bud tissue causing adjacent leaves to wither and drop, leading to complete loss of fruits on affected fronds [30]. Outbreaks kill seddlings and reduce yield of mature palms. To control this phenomenon includes pheromone trapping, removing decaying palms or logs, and the use of biological agents.

b) *The Red Palm Weevil (Rhynchophorus ferrugineus)* is a stem-borer whose larvae tunnel inside the trunk. Infested palms often showing sawdust-like frass anf fermented sap ozzinv from wounds, then the fronds wilt and die. Severe infestations can kill mature palms. Because of this, it is considered as one of the most serious coconut pests worldwide, causing direct losses through palm death and reduced yield[31,32, 33]. Similar to earlier, control also include pheromone traps, early detection, and insecticidal injections or entomopathogens to kill larvae.

TABLE I. SUMMARY OF KEY SYMPTOMS, IMPACTS AND CONTROL MEASURES OF MAJOR COCONUT DISEASES AND PESTS

Disease/Pest	Cause (Pathogen/Pest)	Key Symptoms	Impact & Control
Bud rot	Phytophthora palmivora (oomycete)	Browning/rotting of spear leaf and inner bud, foul smell	Severe yield loss; palms die. Managed by sanitation (cutting and burning infected palms), improved drainage, fungicide (e.g. metalaxyl, Mancozeb) treatments.
Stem (Trunk) bleeding	Thielaviopsis paradoxa (fungus)	Dark reddish-brown/black ooze on trunk (especially near wounds).	Causes trunk failure and palm death. Control: prevent trunk injuries, sanitize tools, remove infested palms promptly.
Leaf spots/blights	Various fungi (Pestalotiopsis, Botryodiplodia, Cercospora, etc.)	Necrotic spots or streaks on leaflets (e.g. gray or brown spots). Severe outbreaks lead to defoliation.	Generally minor; severe epidemics (in wet, crowded stands) can reduce photosynthesis and yields. Managed by pruning, improving air circulation, and fungicide sprays if needed.
Lethal Yellowing	"Candidatus Phytoplasma palmae" (phytoplasma)	Palmlets droop, flowers/nuts abort, fronds yellow from older to younger. Kills palm in 3–6 months after symptoms.	Major losses in Caribbean and Africa. Spread by planthopper vectors (e.g. Haplaxius crudus). Control: use resistant cultivars, quarantine, destroy symptomatic palms.
Root (Kerala) wilt	Phytoplasma (16SrI Group)	Older fronds show "flaccid" curved leaflets (cup-shaped foliage)	Chronic disease reducing the yield. Suspected spread by leafhoppers (Proutista, Stephanitis). Management: nutritional care (green manures, organic matter), irrigation; cut severely affected palms.
Cadang-cadang	Coconut cadang-cadang viroid (CCCVd)	Slow onset: early tiny yellow/orange spots on leaflets, small, rounded nuts	Catastrophic losses. No cure and control by removing affected parts.
Rhinoceros beetle	Oryctes rhinoceros (insect)	Holes in crown bud and spathes, with brown viscous sap. Bud and young fronds bent or broken; affected nuts abort	Kills seedlings and reduces yield of mature palms. Controls: sanitation, pheromone trapping, biocontrol.
Red palm weevil	Rhynchophorus ferrugineus (insect)	Sawdust-like frass and fermented sap at entry holes; frond curling, wilting, and collapse. "Frizzle top" of crown; internal rot.	Causes palm death and yield loss. Control is through pheromone traps, monitoring, insecticidal/biological treatments in trunk.

B. Nutrient Deficiencies

Aside from diseases, other factors affecting the health of coconut trees include nutrient deficiencies and abiotic stressors.

1. **Macronutrient deficiencies** includes Nitrogen (N), Phosphorus (P), and Potassium (K)[34, 35]. Table II shows a summary of the nutrients' deficiency symptoms, effects, and management.

TABLE II. SUMMARY OF NUTRIENT DEFICIENCY, SYMPTOMS, EFFECTS, AND MANAGEMENT

Nutrient Deficiency	Symptoms	Effects	Management
N	Uniform chlorosis of old fronds (tip-to-base yellowing)	Stunted growth, thin yellow palms. Leads to reduced protein and poor nut set.	Apply N fertilizer (e.g. urea) via foliar spray or soil application (1–2 kg tree^{-1}/yr). Regular N improves leaf development and yield.
P	Stunted palms with darker (sometimes purplish) fronds.	Poor root development; leaf size and number decrease. Yield declines due to fewer nuts.	Soil or foliar P (e.g. 5 kg FYM or rock phosphate per palm, or 2% DAP spray) helps; incorporate organic matter.
K	Chlorotic/orange spotting on old leaflets, progressing to brown necrotic margins.	"Frizzle top" of new leaf. Thin, yellow palm with pencil-top spears. Reduces bunch size.	Regular potash (e.g. KCl or K_2SO_4) is needed. Apply 3–4 kg K_2SO_4 (plus $MgSO_4$) per palm annually, or root-feed 1% KCl solution periodically [36].

2. **Micronutrient deficiencies**. Boron (B) is essential for the development of buds [34, 37]. Early B deficiency makes leaves "hooked" in appearance: pinnae of young leaves fuse or curve into a hook at the tip [34], [37]. Leaves can develop extremely short or absent pinnae, and in advanced cases the spear leaf does not open properly. Small chlorotic spots symmetrically on veins can form on seedlings. Zinc (Zn) deficiency results in stunted, narrow fronds (~50% normal leaf length) with chlorotic leaflets; flowering is slow and shedding of buttons results [34, 36, 37]. Iron (Fe) deficiency (quite prevalent in waterlogged soils) results in interveinal chlorosis on new leaves – young fronds appear yellow between veins, subsequently with necrotic tips [34, 36, 37]. Magnesium (Mg) deficiency appears as wide yellow bands along margins of mature leaves with green centers (opposite of K deficiency); extreme Mg deficiency causes leaflet tip necrosis and bronzing [34, 37]. Manganese (Mn) deficiency is uncommon in acid soils but in alkaline soils makes newest leaves come out chlorotic with necrotic longitudinal streaks; subsequently, leaflets wilt (causing "frizzle top" too) and growth may stop. Micronutrient disorders can be prevented through the maintenance of soil pH and supplementing trace elements if necessary [34, 37]. For instance, foliar borax or soil $ZnSO_4$ will cover up for B or Zn deficiencies, respectively, $MgSO_4$ or $FeSO_4$ drenches will cover up for Mg or Fe deficiencies. Leaf

analysis regularly will catch concealed deficiencies before yield is lost [38].

3. **Environmental stressors**. Coconut palms are moderately salt-tolerant but extended salt stress, such as sea-water intrusion, saline irrigation, damages water uptake and leads to leaf burns and stunted [39]. Likewise, drought and heat stress decrease yield, for instance, recent Indian extreme heatwaves (2024) resulted in extensive coconut wilting and severe production [40]. Drought-stressed palms exhibit leaf yellowing, smaller nut size, and death of young palms [41]. Climate change like increased temperatures and shifting rainfall will likely enhance these stresses and potentially intensify pest/disease prevalence [19, 42]. Mitigation includes irrigation, mulching, and breeding/clonal selection of more tolerant cultivars to maintain production under changing conditions.

III. TRADITIONAL METHODS

Traditional methods for detecting nutrient deficiencies and diseases in coconut farming primarily rely on visual assessment and laboratory testing. These time-tested approaches have been the foundation of crop health monitoring for decades and remain widely used by farmers. The following section describes these conventional techniques, their procedures, and their typical applications.

A. Visual Assessment Methods and Protocols

Farmers traditionally begin by inspecting coconut palms visually, examining the canopy, fronds, stalks, and nuts for signs of stress or disease [43]. Leaf symptoms serve as key indicators of nutrient deficiencies, potassium deficiency causes rust-colored spots and yellowing on older leaflets, while magnesium deficiency leads to pale-yellow interveinal chlorosis on mature fronds [43, 44, 45]. These symptom patterns are widely recognized and documented in agricultural extension guides. For instance, CPCRI guidelines are used in India and Sri Lanka to teach farmers how to identify symptoms through visual charts [46].

Bud rot and wilt diseases can also be detected through leaf symptoms, particularly on the spear leaf. A brown, withered emerging leaf that bends or collapses often indicates a Phytophthora infection. Trunk diseases exhibit different signs, such as sticky brown resin exudates or "bleeding" on the stem [45]. Additionally, insect pests may create boreholes and dust residues on leaves.

In practice, standardized protocols often specify a particular leaf rank (e.g., the eighth frond) for symptom observation [43]. Simple diagnostic charts or photo reference decks may be used to match symptoms. While visual checks are inexpensive and provide immediate results, they rely entirely on the observer's experience and can be subjective.

- Nutrient deficiency cues: Older fronds turn yellow or scorched in specific patterns (e.g. K deficiency: rust spots and yellowing at frond tips; Mg deficiency: pale yellow leaflets with green midrib). New growth is typically green until visible symptoms appear.

- Disease cues: Early bud rot shows yellowing and water-soaked spots on the spear, progressing to browning and collapse of new fronds. Ganoderma stem rot ("stem bleeding") produces reddish-brown exudate on the trunk. Leaf diseases (fungal or insect) cause distinct leaf spots or blotches.

B. Manual Sampling and Lab Testing

Visual diagnosis is complemented by sample collection and laboratory analysis [47]. Soil and leaf tissue samples are routinely collected for testing. For example, several central leaflets, often 20 cm long, are cut from a specified frond, commonly the ninth oldest leaf, to form a composite sample [48]. Soil samples, typically taken from a depth of ~0-20 cm beneath the canopy, are also collected and sent to labs for chemical analysis.

Specifically, soil tests determine pH levels and the availability of essential nutrients such as nitrogen (N), phosphorus (P), and potassium (K). Leaf tissue tests measure nutrient concentrations using spectrometry or digestion methods [49].

Additionally, pathogen assays are performed on suspected tissues. Wet lab methods include culturing fungi or bacteria from diseased tissue, conducting serological tests (ELISA), or using molecular PCR to detect specific pathogens [50]. For nutrient deficiencies, plant analysis reports identify hidden imbalances, often unnoticed until severe symptoms appear, using guidelines such as those from the NMSU Extension [51]. As only lab tissue analysis can confirm whether a crop is adequately nourished, these methods provide quantitative validation for visual observations.

C. Limitations of Conventional Methods

Traditional methods, such as visual assessment, come with several limitations. First, they introduce subjectivity and delays, as visual scouting depends on the observer's skill and often only detects problems after severe symptoms have developed [52]. Early-stage issues may remain hidden and go undetected.

Second, manual sampling and lab testing, while accurate, are costly and time-consuming [53]. Processing samples at a laboratory may take weeks, and extension officers can only evaluate a limited number of farms at a given time, leading to delays in diagnosis and intervention [53].

A recent review highlights these challenges, noting that expert visual inspection is "time-consuming and requires specialized training," while lab diagnostics are "expensive and time-consuming but impractical for large-scale monitoring" [53].

Third, both visual surveys and lab tests do not scale well for large plantations. Covering hundreds of hectares requires significant labor and extensive sampling [54]. In practice, most farms rely on occasional checks or farmers' intuition, but as mentioned earlier, this is not a reliable approach [55].

Table III presents a summary of conventional methods, their purposes, strengths, and limitations.

TABLE III.   SUMMARY OF CONVENTIONAL METHODS, THEIR PURPOSES, STRENGTHS, AND LIMITATIONS

Method/Tool	Purpose	Strengths	Limitations
Visual inspection (field	Survey palms for visible symptoms on	Immediate, no equipment cost, leverages farmer	Subjective and error-prone, only detects

Method/Tool	Purpose	Strengths	Limitations
scouting)	fronds, trunk, nuts.	experience.	mid-to-late symptoms with limited coverage.
Leaf/tissue sampling	Determine internal nutrient levels of plant tissue.	Quantitative data on plant nutrient status and detects hidden deficiencies before/with symptoms.	Requires lab facilities, delays, and cost for analysis.
Soil sampling	Assess soil fertility and pH under palms.	Guides fertilizer planning and identifies soil constraints.	Does not reflect plant uptake, lab cost, and time.
Lab pathogen assays (culture/PCR)	Identify specific disease agents (fungus, virus, etc).	Highly specific and sensitive to known pathogens.	Very costly and technical, slow, and requires specialized skills.

IV. TECHNOLOGICAL APPROACHES

While each technological approach offers distinct advantages, from high-precision image classification to large-scale UAV surveillance and real-time mobile diagnostics, understanding their broader impact requires a structured comparison with traditional methods. The following section summarizes and evaluates these approaches across key criteria to provide a clearer picture of their practical strengths, limitations, and field-readiness in the context of coconut farming.

A. Image Processing and Computer Vision

Modern methods use digital imagery of palms to automate symptom detection. High-resolution photographs of leaves, fronds, or nuts are processed to highlight disease patterns. For example, algorithms can segment a coconut leaf from its background and apply color or texture filters to isolate spots or necrotic areas. These image-processing steps, such as edge detection, color thresholding, and morphological filtering, prepare inputs for classification [56].

Such systems have been applied to coconut disease detection where color-based thresholding has been used to identify Ganoderma stem-bleeding spots, while object-detection models have been employed to locate coconut fruits or symptomatic leaves in images [57]. In general, image-based analysis is appealing because it is non-intrusive and relies on easily captured photos [58]. Once preprocessing extracts regions of interest, features such as histograms, shape descriptors, and color indices are passed to AI classifiers [56]. This pipeline, from raw image to feature extraction, enables objective symptom recognition across large image datasets.

B. Machine Learning and Deep Learning Models

Classifier networks are now widely used to identify coconut diseases and nutrient deficiencies from images, with deep learning and machine learning among the most popular approaches. Convolutional neural networks (CNNs) can learn visual patterns of stress on leaves [59]. For example, Huang et al. (2023) developed an enhanced VGG16 model via transfer learning to classify coconut leaf diseases, achieving approximately 97.7% accuracy on test images .[55] Other studies compare models like GoogleNet, ResNet, or Faster R-CNN, reporting high classification rates (often achieving over 90%) for common diseases, far exceeding traditional scouting reliability [60].

In one nutrient-focused study, a YOLOv9 model was trained on thousands of leaf images and achieved ~80% accuracy, 98.6% precision, and 80.4% recall in identifying specific nutrient deficiencies [61]. Classical machine learning techniques, such as

SVM and KNN, have also been applied using manually extracted features, but deep neural networks (NNs) generally yield superior results.

Despite the high performance of these classifiers, challenges remain. AI models require large, labeled datasets of diseased and healthy palms and can be sensitive to lighting conditions, occlusion, or background variation [62]. They may overfit to data from a single farm or region. Additionally, building and fine-tuning these models demand technical [63] . Nonetheless, many studies confirm that ML/DL tools can reliably classify disease types and estimate severity, reducing the reliance on expert observation.

C. Remote Sensing and UAV Applications

Remote sensing extends monitoring from individual palms to entire plantations. Drone (UAV) surveys equipped with multispectral or thermal cameras can map canopy health and nutrient status over large areas [64]. Researchers compute vegetation indices (NDVI, NDRE, chlorophyll indices) from UAV imagery to estimate palm health. For instance, a multispectral drone was flown over a coconut plot and found strong correlations between image-derived indices and ground truth measurements: NDVI correlated with soil nitrogen ($R^2 \approx 0.57$), while NDRE and chlorophyll indices correlated with leaf chlorophyll (SPAD) values ($R^2 \approx 0.71$–0.73) [65, 66, 67]. This shows drone imaging can non-destructively predict nutrient levels across fields [68].

Similarly, object-based image analysis (OBIA) on UAV data has been used for disease detection [69]. A support-vector-machine was applied on four-band (blue, green, red-edge, NIR) UAV imagery to distinguish trees with Weligama coconut leaf wilt disease (WCLWD) from healthy ones [70]. They achieved ~79% classification accuracy ($\kappa \approx 0.49$), demonstrating feasibility of aerial disease mapping [70]. Satellite imagery can also be used in situations like counting palms or detecting large-scale stress patterns, although resolution limits fine disease diagnosis. In summary, remote sensing, such as drone or satellite, enables frequent, large-scale surveillance. It is highly scalable and can flag problem zones early for targeted field checks.

D. Mobile and IoT-Based Monitoring Systems

Smartphone apps and IoT platforms are emerging as practical tools for field diagnostics. Researchers have developed mobile apps where farmers photograph palm leaves and receive automated analysis. For example, an app "COCODY" (India) uses a CNN backend so that a farmer can snap a diseased leaf and get an on-device diagnosis of pest or disease type [71]. On the sensor side, IoT devices (soil moisture probes, temperature/humidity sensors, etc.) can continuously stream field data to the cloud [72, 73]. Although not yet widespread in coconuts, these systems mirror precision-agriculture trends.

A notable case is India's CPCRI 'e-kalpa' mobile app, a multilingual extension tool for coconut farmers. It includes a knowledge base, input calculators and a

"field issue reporting" feature. Farmers can upload audio, video or image reports of palm problems and get expert feedback in real time [74, 75]. Such apps essentially turn farmers' phones into remote diagnosticians and connect them directly with extension experts. In practice, IoT and mobile solutions for coconut are still evolving and many are in pilot stages or research prototypes. But pilot projects (e.g. IoT-based irrigation controllers or nutrient advisors) indicate how decision-support platforms could provide real-time, location-specific alerts. These technologies promise to augment traditional practices by making monitoring continuous and interactive.

V. COMPARATIVE ANALYSIS OF METHODS

To evaluate the strengths and limitations of different approaches, this section presents a comparative analysis of traditional and technological methods for identifying nutrient deficiencies and diseases in coconut trees. Table IV summarizes key criteria, including accuracy, cost, scalability, required expertise, and field-readiness, based on insights from recent studies and real-world implementations.

TABLE IV.   SUMMARY OF NUTRIENT DEFICIENCY, SYMPTOMS, EFFECTS, AND MANAGEMENT

Criterion	Traditional Methods	Technological Methods
Accuracy	Moderate and variable, often relies on human interpretation of symptoms. Early problems are often missed.	Generally higher. AI models report 80–98% accuracy on image data. Drone indices can predict nutrient status ($R^2 \approx 0.7$).
Cost	Low equipment cost for visual checks, but high labor cost (multiple field visits). Lab tests incur moderate fees per sample.	High up-front cost: sensors, drones, computing infrastructure and software development. However, they save labor by automating analysis.
Scalability	Limited since covering large plantations is labor- and time-intensive. Often only sample plots are inspected.	High because UAV or satellite imaging and cloud-based AI can monitor thousands of palms per flight. Methods can be deployed farm-wide or regionally.
Expertise Required	Mainly agronomic knowledge where extension workers learn visual and lab protocols. No special tech skills needed for field scouting.	Specialized since data scientists and engineers are needed to develop and maintain AI models and IoT systems. Farmers need some training to use apps/sensors.

Criterion	Traditional Methods	Technological Methods
Field-readiness	Mature and proven. Farmers already use scouting and laboratory testing routinely.	Emerging as many tools are in research or pilot phases. A few are available, but most require further validation before widespread adoption.

These methods are being tested globally but have particular relevance in Asia-Pacific, where coconut farming is vital. India (3rd largest producer) and Sri Lanka are actively developing both lab-based and digital tools [76]. For example, Sri Lankan researchers demonstrated UAV-based nutrient mapping and disease detection [64], while Indian institutions introduced the 'e-kalpa' farmer app [74]. The Philippines, another major coconut producer, also relies on visual extension clinics, and local research is gradually integrating AI approaches [77]. As the literature shows, combining traditional knowledge with new tech promises the most effective strategy for coconut health monitoring.

VI. CONCLUSION AND FUTURE DIRECTIONS

Early identification of tree diseases and nutrient deficiencies is essential for improving and protecting the livelihoods of coconut farmers. While traditional methods are still widely used, they often detect problems too late or require expensive laboratory work.

Current technologies, ranging from image analysis and drone surveys to IoT devices and mobile apps, offer faster, more scalable, and often more accurate solutions. However, these technologies come with their own challenges, including technical requirements, limited access in rural areas, data availability, and the need for farmer training and orientation.

Bridging the gap between proven traditional practices and innovative technologies is the key to succeed. With the right investments in research, technological infrastructure, and education, these emerging tools can significantly enhance coconut farming and crop health monitoring.

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