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Corresponding Author Email
alvenio.mozol@dlsu.edu.ph

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Short Communication

Adapting PLANTdex for Tropical Agriculture: A Local Framework for Sustainable Farming

Alvenio G. Mozol Jr.

De La Salle University, 2401 Taft Avenue, Malate, 699 Manila, Philippines

Abstract

Sustainable agriculture in tropical countries faces pressures from climate change, biodiversity loss, and rising food demands. PLANTdex, a tool developed by Jwaideh and Dalin (2025) that measures the environmental impacts of crops like sugarcane and oil palm, shows that sugarcane has a smaller environmental footprint in high-yield areas. PLANTdex requires adaptation to fit the environmental, social, and policy conditions of tropical nations, creating an opportunity to make it more useful for tropical farming systems where small farms, biodiversity hotspots, and climate risks converge. This study proposes a local adaptation framework for PLANTdex that integrates climate, biodiversity, and social data to make it relevant for sustainable farming decisions in tropical systems. The framework brings together global research, national farming statistics, and illustrative examples from the Philippines and other tropical countries, incorporating: (1) local climate and biodiversity data such as typhoon patterns and native species, (2) social indicators including farmer incomes, land rights, and technology access, (3) waste management innovations and agroecological practices, and (4) alignment with Sustainable Development Goals (SDGs 2, 12, 15). An adapted PLANTdex enables better crop location planning, improved soil and water management, reduced environmental harm, and improved farmer livelihoods. Philippine sugarcane and oil palm serve as illustrative examples demonstrating potential for guiding farm expansion away from biodiversity hotspots, adopting waste-to-energy innovations, and promoting fair land policies. This approach connects global sustainability measures with local realities, helping policymakers, farmers, and educators make better decisions while advancing sustainable agriculture, protecting ecosystems, and supporting interdisciplinary education. The framework addresses data gaps in tropical farming planning and provides a replicable model for other tropical countries facing similar challenges. Empirical validation through pilot implementation and stakeholder engagement remains necessary to confirm the framework's practical utility and cost-effectiveness.

Keywords— Sustainable agriculture, tropical farming systems, environmental impact assessment, PLANTdex adaptation, climate resilience, smallholder farming

1 Introduction

Sustainable farming matters as climate change, biodiversity loss, and rising food needs intensify globally. Sustainable farming refers to agricultural systems that maintain equilibrium between what is applied to and what is removed from the land, avoiding irreversible ecosystem burden [1]. Two approaches support this equilibrium: integrated management produces the same yields with fewer external inputs, while organic management substitutes external inputs with farm-bound natural resources such as biological nitrogen fixation, biological pest control, and maintenance of soil fertility [1].

The agriculture sector must feed a growing population while reducing environmental damage. This challenge is difficult in tropical regions where farm expansion threatens ecosystems, with staple crop yields projected to decline by 10-20% by 2050 under current climate trends [2, 3]. The cro**P** environmenta**L** sust**A**i**N**abili**T**y in**dex** (PLANTdex) was created by Jwaideh and Dalin [4] to measure the environmental effects of crops like sugarcane and oil palm. It shows that sugarcane has a smaller environmental footprint in productive regions compared to oil palm. This matters for tropical countries where these crops drive economies but harm ecosystems.

PLANTdex relies on baseline data from 2000, which may not capture current climate patterns, recent land use changes, or updated biodiversity assessments in rapidly evolving tropical agricultural systems [4]. This paper discusses how to adapt PLANTdex to meet tropical nations' needs, offering a model for sustainable agriculture globally.

2 Methodology

This study develops a conceptual adaptation framework for PLANTdex by synthesizing global research on sustainable tropical agriculture, national statistics from the Philippines, and illustrative examples of sugarcane and oil palm production. The methodology integrates: (1) review of literature on climate-resilient farming and smallholder support systems from Nepal, Indonesia, Malaysia, and Sub-Saharan Africa [5, 6, 7, 8, 9, 10, 11, 12], (2) analysis of Philippine agricultural data and policy documents [13, 14, 15], and (3) examination of PLANTdex's original framework [4]. Four adaptation strategies were developed by identifying gaps between PLANTdex's 2000-era baseline and current tropical conditions: local climate and biodiversity data integration, context-specific benchmarks, socioeconomic indicators, and waste-to-resource innovations. The framework aligns with SDGs 2, 12, and 15 [16], and identifies implementation pathways for policymakers, farmers, cooperatives, and educational institutions in tropical systems.

As a conceptual framework, this study identifies and proposes adaptation strategies that require empirical validation rather than testing them directly. The methodology synthesizes existing research to develop a theoretically grounded framework, recognizing that practical implementation depends on data availability, stakeholder engagement, and pilot testing in real-world settings.

Agriculture uses 70 percent of global freshwater, contributes 30 percent of greenhouse gas emissions, and affects biodiversity [16]. Agriculture drives 80% of deforestation globally and causes biodiversity loss [17]. PLANTdex monitors water use, land damage, and habitat loss, allowing comparisons across regions. It highlights sugarcane's efficiency, which supports strategies like crop diversification to reduce environmental harm. With food demand expected to rise 50 percent by 2050, PLANTdex aligns with global goals for responsible consumption and production (SDG 12) and ecosystem protection (SDG 15) [16].

Current farming research remains divided across fields, which limits solutions. Developing scalable, context-specific sustainability assessments is a challenge in agroecosystem management [18]. Agroecology promotes crop diversity and natural processes. Sustainable intensification focuses on increasing crop yields with minimal environmental cost. These fields rarely work together, which slows progress [2]. Addressing this fragmentation requires interdisciplinary frameworks that integrate multiple perspectives. This study adopts an integral ecology approach, which recognizes how environmental and human problems are connected [1, 19]. This integration, combining sustainability science, agricultural innovation, social equity, and ecological principles, is essential for developing solutions that address both environmental sustainability and human welfare. This perspective informs the adaptation framework proposed here, which brings together climate data, biodiversity metrics, social indicators, and agroecological practices.

3 Tropical Agricultural Context: The Philippine Case

In tropical countries like the Philippines, sugarcane covers 388,000 hectares and produces 1.85 million tons yearly [13]. Oil palm, grown in Mindanao, expanded by 47 percent from 2010 to 2020, reaching 63,000 hectares by 2023 [14]. This expansion shows economic opportunity and environmental risk, as farming moves into areas rich in biodiversity. These crops support livelihoods but create risks in typhoon-prone areas with unique species. Sugarcane farming in the Visayas and oil palm in Mindanao cause soil erosion, water pollution, and coastal damage [20].

Smallholder farmers operate 70 percent of sugarcane farms and 60 percent of oil palm farms. They lack resources and focus on short-term gains over long-term sustainability [14]. Nearly 60 percent of smallholder farmers in tropical regions lack access to climate adaptation technologies, and limited financial resources, knowledge, and institutional support remain barriers to adopting sustainable practices [3, 11]. This creates a cycle where farmers cannot invest in sustainable practices, even when they understand environmental problems. National policies, such as the 2006 Biofuels Act and the 2019 Oil Palm Roadmap encourage industry growth but conflict with environmental goals. Recent programs, such as the 2023 Sustainable Corn and Oil Palm Program, show steps forward by balancing production with conservation [15].

4 Global Insights for Local Solutions

Research from other tropical regions identifies challenges and solutions for PLANTdex adaptation. Successful adaptation requires three dimensions: institutional support, socioeconomic empowerment, and technical innovation [1, 5, 6, 7, 8, 9, 11, 12].

Institutional support drives adoption. In Nepal, farmers adopt climate-resilient practices when they have farm resources, confidence, training, and financial support [5]. Technology alone fails without farmer empowerment through knowledge sharing and financial resources. Education level, credit access, and farmer organization participation support climate change adaptation [11, 12]. In Sub-Saharan Africa, farmers with regular extension services are 2.8 times more likely to adopt climate-smart agriculture practices, demonstrating how knowledge transfer enables adoption [12].

Land security enables sustainable practices. In Sumatra, land ownership disputes in oil palm areas restrict smallholder independence, creating conflicts that harm sustainability and social cohesion [6]. Sustainable palm oil frameworks use agroecological methods and landscape planning to increase biodiversity and empower farmers, yet smallholders still lack adequate market access and skills [7]. Environmental sustainability requires economic viability and land security for smallholder farmers [1, 6, 7].

Technical innovations create multiple benefits. Indonesian research shows potassium fertilization and understory planting improve soil health and yields [8]. In Malaysia, oil palm waste converts to green hydrogen, reducing emissions while adding economic value [9]. These innovations enable circular economy approaches where waste streams become resources. Institutional support, land security, and technical solutions provide precedents for adapting PLANTdex to tropical contexts.

5 Adaptation Framework for Tropical PLANTdex

To make PLANTdex effective for tropical contexts, it must incorporate current local realities that reflect conditions beyond the 2000-era baseline. Consistent, reliable metrics for evaluating sustainable agriculture's impact on biodiversity are critical, as challenges remain, including data gaps among methodologies and the need for tools to assess sustainable agriculture approaches [17, 18]. The following adaptation strategies transform PLANTdex from a global comparison tool into a decision-support system for local use, aligned with global Sustainable Development Goals.

First, adding local climate and biodiversity data, such as typhoon patterns, seasonal rainfall changes, and native species locations, improves its relevance and accuracy. Climate data from the Philippine weather agency (PAGASA) could improve PLANTdex's accuracy by accounting for typhoon impacts. Regions hit by three or more typhoons yearly would receive adjusted scores because these storms damage water infrastructure and cause soil erosion, making water problems worse. Similarly, updating biodiversity data with current information from the IUCN Red List (the global database of threatened species) would provide a more accurate picture of environmental impacts. This would replace PLANTdex's original 2000 data with recent assessments showing where Philippine native species live today and how their habitats have changed over the past two decades. The IUCN (International Union for Conservation of Nature) reports emphasize the role of standardized metrics in measuring biodiversity on farms, with 12 key assessment tools identified through stakeholder consultation, including the Agrobiodiversity Index and the IUCN STAR metric [17]. Mapping oil palm farms in high-production regions like Region XII and Caraga, which account for 33 percent and 27 percent of output, respectively, against biodiversity hotspots protects vulnerable ecosystems while maintaining productivity [14]. Global studies show fewer than 50 percent of oil palm farms are in the best locations, demonstrating the need for location-specific data in PLANTdex [10]. This spatial planning prevents future deforestation while directing farm expansion toward degraded lands that can be improved through productive use.

Second, setting local standards for soil quality, water use, and ecosystem health increases accuracy and usefulness. Work on the Agroecosystem Sustainability Index (ASI) demonstrates that integrating environmental, economic, and social indicators through statistical methods and dimensionality reduction produces robust, adaptable assessment tools applicable across diverse agricultural landscapes [18]. Sugarcane in the Visayas requires more water and fertilizer than in other regions, requiring specific benchmarks that reflect local conditions. These local standards would work alongside global PLANTdex scores, allowing both international comparisons and practical local guidance. For example, water use thresholds could be adjusted for the Philippines' monsoon seasons: irrigation during the rainy season (June-November) would be considered more sustainable since water is plentiful, while the same amount during the dry season (December-May) would raise concerns as water becomes scarce. Similarly, fertilizer guidelines could reflect tropical conditions, since warmer, humid climates break down organic matter faster, Philippine soils need different fertilizer management than cooler regions to maintain soil health while minimizing water pollution. Generic global standards may wrongly classify sustainable practices in water-rich tropical environments or fail to identify problems in water-stressed areas. Regional adjustment ensures that PLANTdex recommendations match local resource availability and environmental conditions.

Third, including social and economic factors, such as farmer incomes, technology access, land ownership security, and market connections, is essential for supporting smallholders who constitute most tropical farmers. Heavy pesticide use in oil palm farming comes from limited resources and knowledge rather than ignoring environmental problems [20]. Economic constraints force farmers into unsustainable practices when sustainable alternatives require upfront investment. Access to credit, government funding, and participation in agricultural groups are associated with climate change adaptation, with adaptation linked to reduced food insecurity among smallholder farmers [11]. Combining socioeconomic information with PLANTdex scores would help identify where improvements are most feasible. For example, areas with high environmental impacts (PLANTdex scores above 0.6) where farmers have secure land ownership and belong to cooperatives would be good candidates for training programs and technical support. In contrast, areas with similar environmental problems but unclear land ownership would need policy changes first before farm-level improvements can succeed. This approach would use existing government data from agencies like the Philippine Statistics Authority and Department of Agrarian Reform, creating a practical guide that shows not only where environmental problems are worst, but also where solutions are most likely to work [21, 22]. PLANTdex can recommend targeted solutions like input subsidies, secure land policies, or training programs that address these causes [6, 7].

Fourth, adding waste-to-resource innovations and agroecological practices expands what PLANTdex does beyond reducing harm to creating value. Currently, PLANTdex measures environmental impacts only during crop production (greenhouse gas emissions, water use, land use, and fertilizer application). However, what happens to crop waste after harvest also matters for sustainability. For example, sugar mills that convert bagasse (sugarcane waste) into electricity can offset their emissions by replacing fossil fuels with renewable energy. A mill generating 50 MW from bagasse would get credit for this environmental benefit in its PLANTdex score. Similarly, composting oil palm waste and returning it to fields as natural fertilizer reduces the need for chemical phosphorus fertilizers, which improves water quality and protects aquatic life. These waste-to-resource practices turn disposal problems into environmental solutions. By including measures for waste repurposing (such as biomass energy from crop residues), agroforestry benefits, and ecosystem services, the adapted tool encourages practices that create multiple benefits. This changes the view from seeing environmental protection as a cost to recognizing it as an investment with economic returns.

Table 1. Key Differences Between Original and Adapted PLANTdex

Aspect	Original PLANTdex (2000)	Adapted PLANTdex (Proposed)
Temporal baseline	Year 2000 data	Current/updated data (2020+)
Primary function	Global comparative benchmarking	Local decision-support system
Spatial application	National to sub-national analysis	Municipal to farm-level guidance
Indicator scope	5 environmental pathways	5 environmental + socioeconomic layer
Data sources	Standardized global datasets	Global baseline + local enhancements
Climate factors	Historical averages	Extreme weather vulnerability (typhoons, droughts)
Biodiversity data	2000-era species distributions	Current IUCN assessments + endemic species
System boundary	Farm gate (production only)	Extended lifecycle (production + waste management)
Target users	Researchers, policymakers, investors	+ Farmers, cooperatives, extension workers, municipal planners
Sustainability approach	Environmental impact only	Integrated environmental-social assessment

Note: These adaptations maintain the core TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) methodology while extending data inputs and decision applications for tropical agricultural systems.

Fifth, aligning the adapted PLANTdex with Sustainable Development Goals (SDGs) ensures that the framework addresses global sustainability priorities while remaining locally relevant. The adaptation strategies support SDG 2 (Zero Hunger) by improving crop productivity through site-specific practices and farmer empowerment, SDG 12 (Responsible Consumption and Production) through waste-to-resource innovations and circular economy approaches, and SDG 15 (Life on Land) by protecting biodiversity hotspots and promoting agroecological practices that enhance ecosystem services [1, 16]. This alignment with SDGs creates practical benefits for policymakers. For example, tracking nitrogen fertilizer use (already part of PLANTdex) directly supports SDG 12.4, which focuses on responsible chemical management. Similarly, monitoring agricultural land use in areas rich in wildlife (also part of PLANTdex) supports SDG 15.5, which aims to protect natural habitats. This means countries can use one tool, adapted PLANTdex, to track progress on multiple global sustainability goals at once, saving time and resources while ensuring consistency across environmental reports. This SDG alignment provides a framework for monitoring progress, facilitating international cooperation, and ensuring that local adaptations contribute to global sustainability commitments. By connecting PLANTdex metrics to SDG indicators, policymakers can track multiple dimensions of sustainability, from food security and resource efficiency to biodiversity conservation, within a unified assessment system. Table 1 highlights key functional differences between original and adapted PLANTdex. This adaptation framework is illustrated in Figure 1.

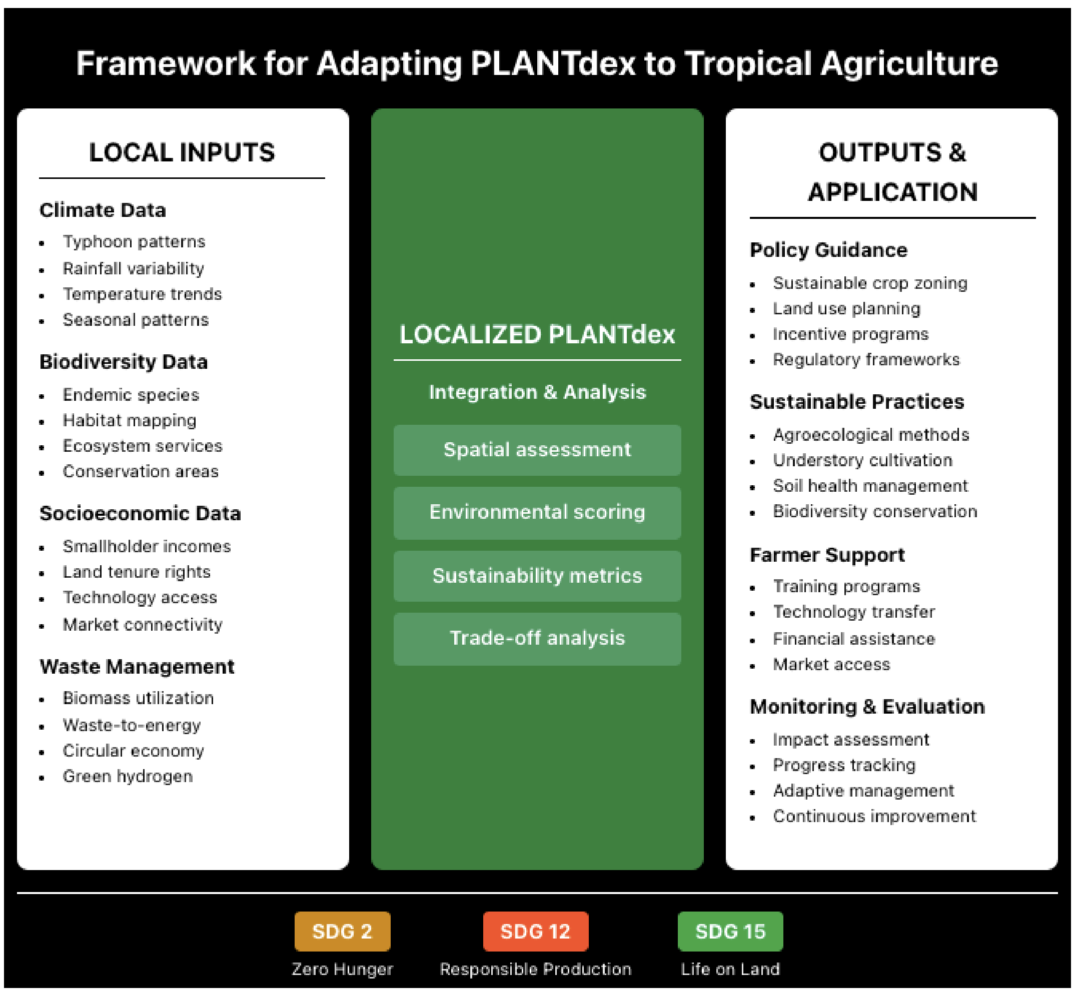

Figure 1.
Framework for adapting PLANTdex to balance productivity and sustainability in tropical agriculture, integrating local climate, biodiversity, socioeconomic factors, and waste management to guide policies and practices

6 Implementation Pathways and Applications

A customized PLANTdex guides decisions at different levels and among various groups. The following implementation pathways are organized by key stakeholder groups and their specific applications:

Policy and Land-Use Planning

Policymakers use spatial PLANTdex data to inform land-use planning, directing new farm development toward areas with lower environmental sensitivity while protecting biodiversity hotspots [10]. More than 45% of the global opportunity to reduce species extinction risk depends on how agriculture is implemented, making spatial planning tools critical for biodiversity conservation [17]. Zoning rules informed by localized PLANTdex prevent conversion of high-value forests while identifying damaged lands suitable for farm improvement. These policy applications support SDG 15 (Life on Land) by prioritizing ecosystem protection in spatial planning decisions [16].

Farm-Level Practice Adoption

Farmers adopt site-specific practices recommended by PLANTdex, such as:

(a) Understory vegetation management for improved soil health [8];
(b) Waste repurposing systems that convert crop residues into biomass energy [9]; and
(c) Soil conservation techniques proven effective in similar local conditions [8].

Extension services use PLANTdex assessments to provide customized advice rather than general recommendations, which improves adoption rates. Secure land rights and agroecological methods support long-term sustainability [6, 7]. These farm-level actions support SDG 2 (Zero Hunger) by enhancing productivity while maintaining environmental integrity [1, 16].

Supply Chain and Market Integration

Agricultural cooperatives and private sector actors use PLANTdex data to improve supply chain sustainability, identify risks, and demonstrate compliance with international sustainability standards. This application supports SDG 12 (Responsible Consumption and Production) by:

(a) Promoting resource efficiency throughout the supply chain;
(b) Reducing food waste through better planning and coordination;
(c) Enabling transparent reporting of environmental impacts [16];
(d) Transforming agricultural by-products from disposal problems into economic opportunities through circular economy approaches [1, 9].

This creates market-based incentives for sustainable practices by linking environmental performance to market access and premium pricing.

Education and Research Applications

Research institutions and universities use the adapted framework as an educational tool. It supports learning that connects environmental science, farm economics, social equity, and policy. Students examining real-world PLANTdex applications develop systems-thinking skills essential for addressing sustainability challenges. This educational aspect aligns with our perspective as humanities educators committed to integral ecology [19]. Educational applications include:

(a) Case study analysis of PLANTdex implementation in diverse tropical contexts;
(b) Interdisciplinary curriculum development integrating sustainability metrics;
(c) Student participation in data collection and validation processes.

Regional and International Adaptation

This framework inspires adaptation in countries like Indonesia, Malaysia, and other tropical countries with similar farming systems and environmental pressures. The model's flexibility allows adjustment to different crops, climate zones, and social contexts while keeping core sustainability principles. Challenges such as data gaps, limited funding, and institutional capacity remain, but partnerships with organizations like the Philippine Coconut Authority and international research networks address them under enhanced institutional cooperation [15]. Future versions should include dynamic data reflecting recent trends, like the 47 percent oil palm growth from 2010 to 2020, and directly involve smallholders in data collection and validation [14]. Citizen science approaches improve data quality while building farmer ownership of sustainability programs. Collaboration aligns PLANTdex with global standards and local needs, addressing barriers related to adoption, site selection, policy reforms, and comprehensive strategies [2, 5, 6, 7, 10].

7 Conclusion

An adapted PLANTdex offers potential as a tool for sustainable tropical agriculture by integrating climate data, biodiversity assessments, socioeconomic factors, and waste management innovations to guide both policymakers and farmers. In the Philippines, where sugarcane and oil palm are economically vital yet environmentally challenging, this framework could direct crop expansion away from biodiversity hotspots while promoting practices such as improved soil management, waste-to-energy systems, and secure land tenure policies. These approaches align with global sustainability goals: SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), and SDG 15 (Life on Land).

This framework's viability depends on three validation steps: (1) confirming data availability at sufficient detail, recognizing that initial implementation may require starting with less precise data for some indicators; (2) pilot testing in 2-3 Philippine provinces with different farming systems (sugarcane in Negros Occidental, oil palm in Agusan del Sur, mixed cropping in Laguna) to ensure practical, locally relevant guidance; and (3) gathering feedback from farmers, cooperative leaders, extension workers, and municipal officers to ensure usability. Only through this validation can we determine whether these adaptations meaningfully improve PLANTdex's utility for tropical agriculture.

While this short communication presents a conceptual framework, several pathways exist for expanding this work. Priority directions include: empirical validation through pilot implementation in selected Philippine regions; comparative analysis across tropical countries (Indonesia, Malaysia, Thailand, Brazil) to assess transferability; development of user-friendly digital interfaces for diverse stakeholders; and participatory action research involving smallholder farmers in co-designing adaptations to ensure the framework addresses real needs while building local ownership. These research directions would transform this conceptual framework into a tested, scalable tool for sustainable tropical agriculture.

As educators, we see this adaptation as an opportunity to build interdisciplinary awareness in students, connecting sustainability science, agricultural innovation, social equity, and integral ecology. This approach prepares future leaders to develop solutions that honor both environmental limits and human dignity, demonstrating that environmental sustainability and economic development can support rather than oppose each other. The framework's flexibility makes it adaptable for other tropical regions facing similar challenges, providing a replicable model where farm development and conservation goals work together.

Statements and Declarations

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Competing Interest

The author declared no conflict of interest.

Ethical Considerations

Not applicable.

Data Availability

Not applicable.

Disclosure of the Use of Artificial Intelligence

Claude 4.5 Sonnet was used in checking for grammatical accuracy, linguistic clarity, more concise presentation of data, and in generating Figure 1. After using this tool, the author reviewed and edited the content as needed and took full responsibility for the content of the manuscript.

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