ADB TA-9993 THA: Climate Change Adaptation in Agriculture for Enhanced Recovery and Sustainability of Highlands

Digital Technology-based Farm-To-Fork Traceability Solutions for Organic Agricultural Products in the Highlands

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Foreword

The increasing awareness of climate-smart agriculture and the rising demand for organic and safe products highlight pathways for improving highland farming practices and market responsiveness. Digital tools play a crucial role in streamlining production processes and strengthening traceability, bringing farmers and consumers closer together. However, institutional and infrastructural constraints often prevent highland farmers from fully leveraging the advancements in digital tools.

This knowledge product offers practical insights and strategies for implementing digital traceability systems in highland regions, drawn from hands-on experience and research. The report begins by examining the agricultural landscape in Bua Yai Subdistrict, highlighting the shift towards perennial crops as a viable livelihood alternative. It then underscores the significance of organic certification in market access and maintaining high standards of quality and safety. The benefits of group certifications are explored, illustrating how they not only ensure compliance but also enhance operational efficiency and long-term sustainability.

Subsequent sections explain the role of digital traceability in achieving group certifications, detailing its key components and its importance for food safety. Relevant policies supporting the digitization of farming in Thailand are reviewed, along with current digital traceability tools and success stories from organic herb and vegetable agriculture.

The pilot implementation of digital traceability tools in a highland farmer enterprise is discussed in detail, showcasing approach and benefits. The document concludes with lessons learned and outlines future directions for scaling the initiative to support broader adoption of digital tools.

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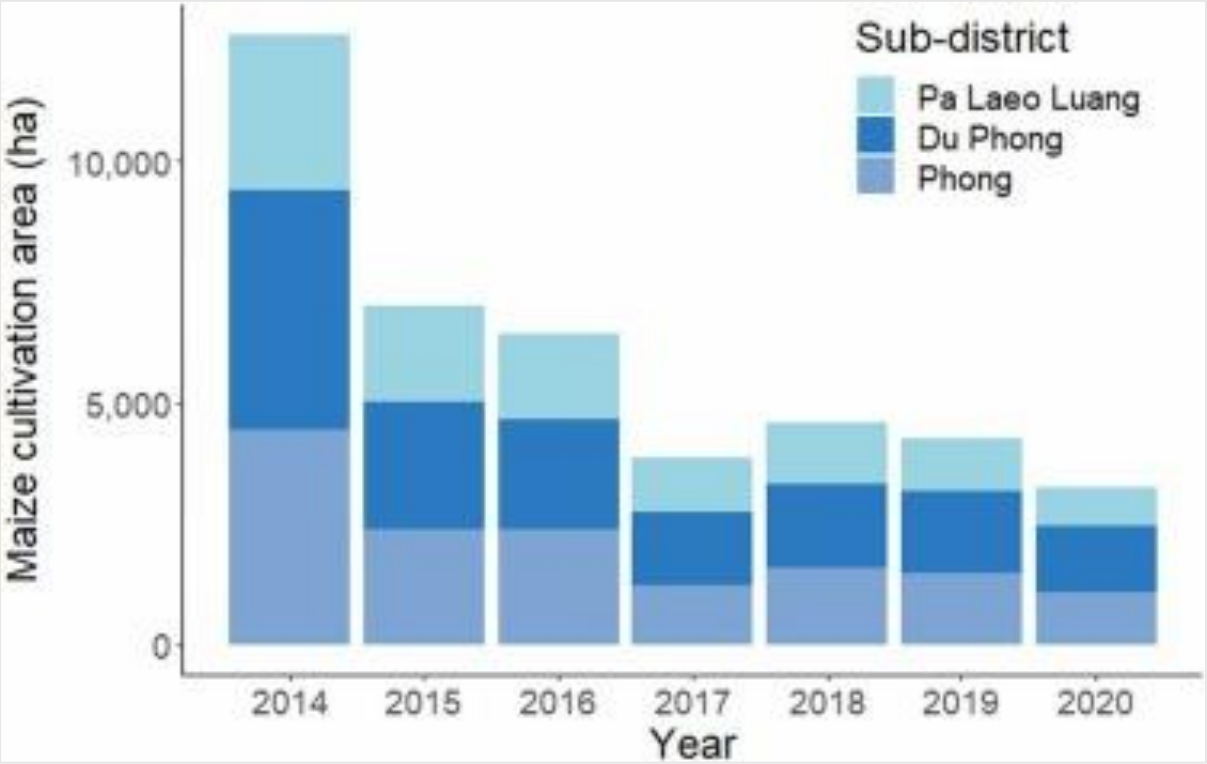
Abbreviations

ADB	Asian Development Bank
AFD	Agence Française de D é veloppement
ANOVA	Analysis of Variance
CDD	Community Development Department
CGIAR	Consultative Group on International Agricultural Research
COVID	Coronavirus Disease
CSA	Climate-Smart Agriculture
DOAE	Department of Agriculture Extension
FAO	Food and Agriculture Organization
GCAN	Gender, Climate, Agriculture, and Nutrition
GHG	Green House Gases
IFAD	International Fund for Agricultural Development
JFPR	Japan Fund for Prosperous and Resilient Asia and the Pacific
MOAC	Ministry of Agriculture and Cooperatives
OAE	Office of Agricultural Economics
PDR	People ’s Democratic Republic
SDG	Sustainable Development Goals
SEP	Sufficiency Economy Philosophy
USD	United States Dollar
WEAI	Women ’s Empowerment in Agriculture Index

1. Perennial Cropping: A Potential Livelihood Alternative

Intensive maize cultivation in Nan has led to degraded soils and reduced yields, further impacted by rising temperatures and extreme weather events [1]. With increasing production costs and climate change risks, farmers are exploring perennial cropping as a supplementary income source. Since 2015, maize cultivation has notably decreased [2].

Figure 1:
Decreasing maize cultivation in Santi Suk district from 2014 to 2020 (Nan Department of Agricultural Extension).



Perennial crops such as Lemongrass are generally more climate resilient and require less tilling and labor, helping maintain or even improve soil health. Despite the high initial investment cost of approximately THB 10,000 per rai, a cost-benefit analysis in Nakhon Nayok showed a profit of THB 3,000 per rai per year, with a return on investment (ROI) of 30% and a benefit to cost ratio (BCR) of 1.30. Moreover, its oil extraction potentially offers a profitable alternative livelihood for farmers. Essential oils in Nan have higher market value compared to raw herbs. Raw lemongrass typically sells for THB 5 to 10 per kilogram, while its essential oil can fetch prices as high as THB 5,000 per kilogram.

Figure 2:
Mr. Thaphumin and the enterprise producing essential oils sourced from smallholder herb farmers.

The growing interest in holistic and natural remedies for relaxation and well-being has increased demand for essential oils extracted from plants and herbs. In 2016, the market was valued at approximately THB 3.92 billion and grew by over 30% in 2017. The market is projected to increase by 10% annually [3].

2. Organic and Safety Certification and Market Access

Issues of health and safety are important to consumers because of the many reported cases of pesticide contamination in Thailand [4]. Organic farming focuses on natural methods and sustainable practices. Organically grown crops are free from synthetic pesticides, herbicides, and genetically modified organisms (GMOs). To ensure quality and safety, organic regulations oversee the entire production process from farm to consumer (FAO, 2001). Third-party certification confirms that both the farm and the product adhere to organic standards. This certification is essential for market access, as it provides authenticity beyond mere compliance claims [5].

Organic farming can offer financial benefits to farmers through reduced input costs and higher selling prices. An assessment conducted in Chiang Mai revealed that farmers growing organic rice, vegetables, fruit, and herbs had greater access to marketing channels and higher prices. Securing multiple certifications gave farmers not only opens various organic values chains but also enhances farmers ' credibility by reassuring consumers of the genuine organic nature of their products.

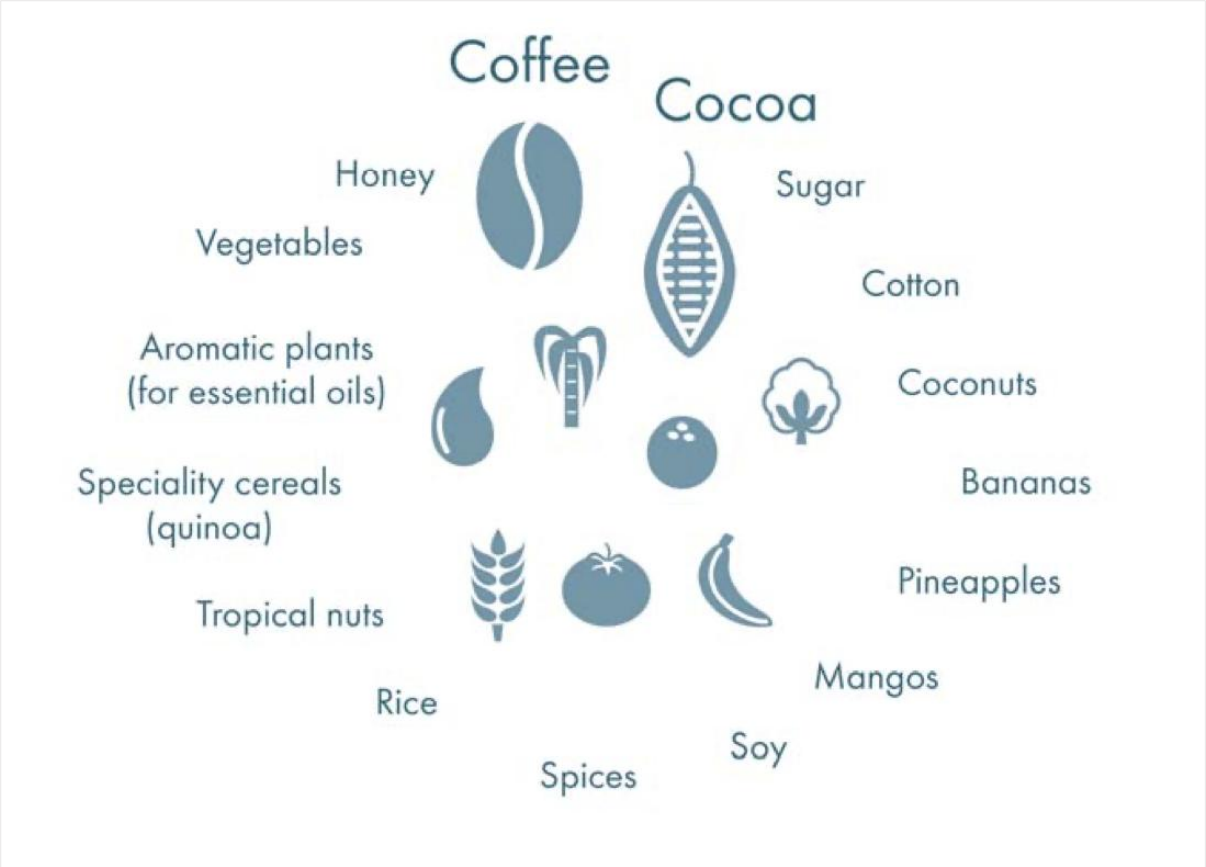
For manufacturers, adherence to Good Manufacturing Practice (GMP) standards is required before receiving safety certification from the Thai Food and Drug Administration (Thai FDA) [6]. GMP mandates manufacturers to maintain traceability of materials and suppliers. Records of manufacturing and distribution must also be kept in a clear and accessible format, ensuring that each batch's history can be fully traced [7].

Additionally, the Cosmetic Act B.E. 2558 (2015) establishes standards for the registration, labeling, manufacturing practices, and safety evaluations of cosmetic products. To comply, manufacturers must submit **comprehensive documentation** including product formulations, ingredient lists, labeling information, and safety data. The Thai FDA reviews these submissions to ensure that all products adhere to established safety and quality standards [8].

3. Group Certifications – Beyond Compliance

While the demand for organically produced food will remain strong for the foreseeable future, organic certification in highlands will require collaborative and sustainable value chains. Relevant stakeholders, including buyers, extension service providers, and certification agencies, must actively engage with farmers to ensure compliance. Since many organic regulations allow group certifications, stakeholders must support the farmer group to establish an internal control system that ensures all individual members comply with the standard. A well-managed group certification extends its benefits beyond mere compliance. It fosters systems thinking among farmers, helping them see the broader perspective of their work. This encourages long-term planning and enhances the efficiency and sustainability of their practices.

Figure 3:
Most important crops certified by group certification (Research Institute of Organic Agriculture, 2019).



Source: https://orgprints.org/id/eprint/35159/7/fibl-2019-ics.pdf

Central to the effective implementation of group certifications is a comprehensive traceability system. Traceability documents the stages and operations involved in the farm, post-harvest processing, packaging, and distribution, for the purpose of certification compliance and optimization of farming operations [9]. Traceability streamlines inspections and makes crucial information, such as farm locations and productivity data, readily available. Without traceability, audits and root cause analysis become challenging and less flexible. The introduction of

traceability systems often requires a shift from paper-based to digital record-keeping, which can be daunting for many smallholders. As such, farmers may perceive traceability as an added burden due to the associated learning curves, time constraints, and costs.

4. Digital Traceability

A digital traceability system plays a crucial role in supporting group certifications by providing a detailed record of a product 's journey from the farm to product distribution. By enabling precise tracking of product origins, production locations, and distribution paths, digital traceability facilitates faster recalls and thorough investigations in case of issues. This system enhances the reliability of product information, boosting consumer confidence. However, it is essential to view digital traceability as a strategic tool for maintaining compliance with safety and quality standards rather than just a technical requirement. Its effective implementation aligns with the broader goals of group certifications, which include improving operational efficiency and ensuring sustainability, while also addressing the practical challenges of transitioning to digital record-keeping.

The use of smartphones, remote-sensing, IoT, cloud computing and other digital tools is a key enabler in solving multiple challenges for different stakeholders in the highlands. For farmers, it can help them record management practices with greater accuracy and efficiency. The transparency ensures optimal growing conditions are met, reducing production costs, improving efficiency and compliance. For extension service providers and research institutes, precise farm-level data supports expanded outreach and deeper engagement with farmers through tailored recommendations and services. For buyers and certification agencies, transparent and verifiable farmer products ensure compliance with quality standards. Governments and other development sector stakeholders can leverage data to develop evidence-based programs and policies, improving public service delivery and fostering equitable and resilient highland agriculture systems.

4.1 Components

4.1.1 Data Capture and Recording Tools

From a farmer 's perspective, frequent data requests can cause fatigue and reduce their willingness to collaborate with other stakeholders. Effective traceability systems significantly reduce response times when there is a request for information during audits and product recalls. Both on-site and off-site data collection methods are essential, including manual data entry, mobile and web-based applications, and remote sensing technologies. Satellite imaging, weather stations and soil moisture sensors offer continuous and precise records of growing conditions. Mobile and web-based applications are useful for documenting management practices and processing methods. Customized software is necessary to collect and organize all relevant data from the farm to the processing facility, as off-the-shelf solutions often do not accommodate the unique and diverse needs of smallholder farming systems and are usually buyer centric. The system should also feature modular and flexible designs to adapt to changing user needs and maintain functionality and efficiency.

4.1.2 Unique Lot Identification

Each lot must be assigned a unique identification number or code, which acts as a digital fingerprint for that lot. The unique identifier should be linked to detailed information about the lot, including its contents, production date, expiration date, batch number, raw material source, and other relevant details. This allows stakeholders to easily search for specific lots in the event of quality issues, recalls, or regulatory inspections.

4.1.3 Labeling

Labeling is essential for conveying key practices and product attributes to the consumer. It provides crucial information about pesticide and chemical-free production, support for biodiversity, fair trade,

social justice, and others. As a direct link between farmers and consumers, labels play a vital role in enhancing consumer confidence and supporting informed purchasing decisions.

4.1.4 Data Exchange

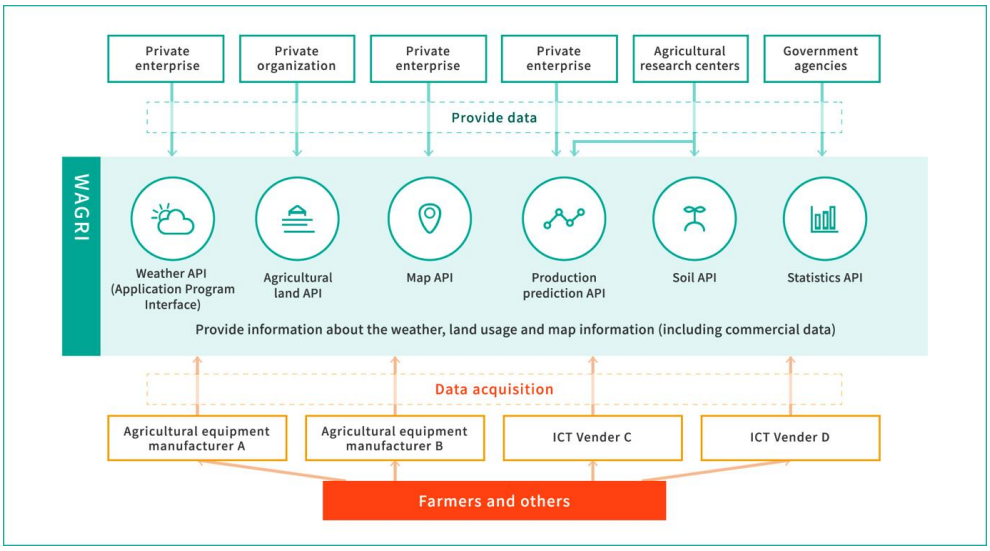
Streamlined data exchange reduces duplication and information asymmetries, which can minimize inefficiencies in resource management. This improvement can benefit smallholders by lowering service delivery costs and enhancing service design. Although data sharing has been transformational in larger, commercial farming systems, its current implementation in highlands is constrained by an underdeveloped ecosystem and limited understanding of its benefits. The diversity in data collection approaches, definitions, and methodologies further affects data quality and increases acquisition costs. To overcome these challenges, the system must ensure Data Consistency and Interoperability.

Data Consistency: It is essential to ensure that data formats align with regulatory standards set by buyers, certification bodies, and other stakeholders. This involves maintaining uniform data structures and formats across the system to guarantee accuracy and completeness.

Data Interoperability: Implementing open APIs is crucial for enabling seamless data exchange between systems. The system should integrate with broader ecosystems, including ERP, SCM, audit applications, consumer platforms, and analytical tools. This allows for the sharing of diverse agricultural data—such as farm operations, weather conditions, soil data, crop status, water usage, and fertilizer applications—across various platforms.

These measures promote coordinated cooperation, optimize production strategies, and enhance transparency throughout the agricultural supply chain. For example, in Japan, a data collaboration platform was developed for private and public agriculture businesses, allowing stakeholders to discover new ways to address local problems more effectively, which eventually benefits the farmers. A similar model could be adopted and expanded in Nan, incorporating Organic and CSA Practice Monitoring and Traceability to improve farmer competitiveness and market access.

Figure 4:
Data collaboration platform developed by Wagri (Japan). Public and private stakeholders engage in data sharing to improve service for farmers and expand their outreach.



Source: https://wagri.net/en-us/aboutwagri

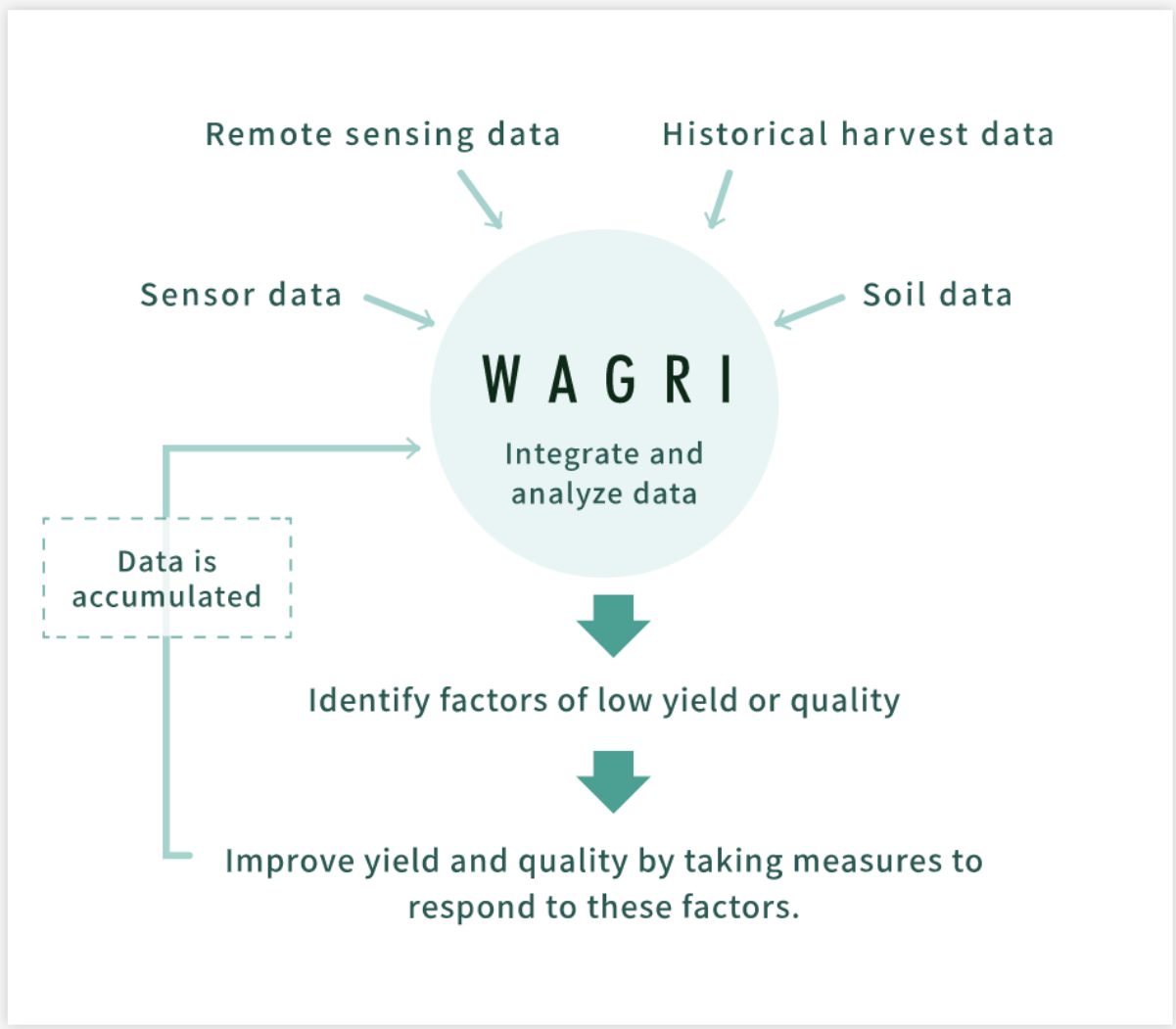
4.1.5 Reporting and Analytics

The traceability system must incorporate robust reporting and analytics capabilities to deliver actionable insights into supply chain operations. Aside from tracking product movement, reports

on yield performance, microclimate trends, manufacturing cycle times enable data-driven decisions. This can help businesses detect areas for improvement, optimize processes, and ultimately reduce input and operational costs for smallholder farmers.

In addition to standard reports, the system should offer support for ad-hoc queries and custom analytics.

Figure 5:
Analyze heterogeneous data and disseminate agricultural insights to relevant stakeholders.



4.1.6 Data Privacy and Security

As the system handles sensitive information from various stakeholders, including farmers, consumers, and manufacturers, protecting this data is paramount.

(1) Implement role-based access control (RBAC) to restrict data access based on user roles. For example, only authorized personnel like farm managers or compliance officers should have the ability to alter critical records, such as input usage or product details. This minimizes the risk of unauthorized data manipulation and ensures that sensitive information remains protected.
(2) Utilize industry-standard encryption protocols to safeguard data. For instance, employ AES-256 (Advanced Encryption Standard with a 256-bit key) for encrypting data at rest and TLS (Transport Layer Security) for encrypting data in transit. These standards provide strong protection against data breaches and unauthorized access.

(3) Maintain immutable audit logs using blockchain technology or similar systems that ensure records cannot be altered once they are created. For example, employing a blockchain ledger for audit trails ensures that every data access and modification is permanently recorded.
(4) Perform regular security audits and vulnerability assessments to identify and address potential weaknesses in the system. Regular penetration testing can also be employed to simulate attacks and uncover security gaps before they are exploited.
(5) Conduct training sessions for all stakeholders on best practices for data security and privacy. For example, implement workshops that cover data protection protocols, phishing awareness, and secure password management. Ensure that all parties understand their responsibilities in safeguarding sensitive information.
(6) Adhere to data protection regulations such as GDPR (General Data Protection Regulation). Develop and document privacy policies that comply with these regulations and implement features like data subject access requests (DSAR) and right to data erasure to meet legal requirements.

4.2 Barriers to Adoption

4.2.1 Institutional

Political and social marginalization is prevalent across Asian highlands. Top-down or centralized agricultural policies often overlook local priorities and traditional knowledge systems, complicating resource management. Farmers also struggle with limited access to formal credit and financial services, hindering investment in modern agricultural technologies.

4.2.2 Lack of digital infrastructure

Around 60% of the population in low- to middle-income countries (LMICs) still do not have internet access. Among those without internet access, people living in rural areas are particularly disadvantaged and less likely to be connected compared to urban areas [10]. In Nan, electricity is also unstable. Poorly developed road infrastructure increases transportation costs and hampers efficient technology support.

4.2.3 Location specificity

Agricultural interventions are highly location-specific and knowledge-intensive. Factors such as microclimate, soil properties, and farming practices vary significantly, making it challenging to implement a one-size-fits-all approach. When interventions are not adapted to unique regional factors, they often lead to inefficiencies and suboptimal outcomes. Therefore, interventions must focus on developing cost-effective methods to address these variations, ensuring that solutions are relevant and practical.

4.2.4 Sustainability

Farmers may find that the benefits and return on investment (ROI) for technology investments take several years to materialize. Additionally, shifts in local or national leadership can result in changes to policies or priorities, affecting the support and promotion of digital farming initiatives. If funding or subsidies are reduced or withdrawn, farmers may struggle to maintain these tools. Given these challenges, farmers and SMEs often need ongoing support to transition to digital technologies.

Table 1:
Key challenges and recommendations to increase the adoption of digital traceability in highlands.

Key Challenges	Recommendations
Institutional: Lack of protective institutions that can secure access to essential services and facilities. Political and social marginalization is also prevalent across Asian highlands, further exacerbating challenges.	• Strengthen local institutions through training and resources to effectively support farmers. • Public-Private Partnerships: Encourage collaborations between government, private sector, and NGOs to create sustainable support systems for highland communities.
Infrastructural: Poor overall development due to isolation	• Broadband Expansion: Promote initiatives to expand high-speed internet access, including satellite internet solutions for remote areas. • Community Hubs: Establish community centers equipped with digital tools and internet access to serve as focal points for education, training, and business activities.
Relevance: Tailoring solutions and content to farm-level decision making	• Launch targeted education and awareness campaigns to demonstrate the tangible benefits of digital tools, such as increased yields, reduced costs, and improved market access. • Localization: Increase the granularity of measured parameters (soil fertility, weather, crop growth) to ensure the provided information to farmers are actionable and based on their specific needs. • Extension Services Support: Strengthen agricultural extension services to provide continuous support and guidance to farmers, helping them integrate digital tools into their farming practices effectively.
Sustainability (Ensuring Long-Term Adoption and Impact): Shifts in local or national leadership can result in changes to policies or priorities, affecting the support and promotion of digital farming initiatives. If funding or subsidies are reduced or withdrawn, farmers may struggle to maintain these tools.	• Community Engagement: Foster strong community networks and peer support groups to encourage knowledge sharing and collective problem-solving among farmers. • Monitoring and Evaluation: Implement robust monitoring and evaluation systems to track the impact of digital tools on farming practices and outcomes. Use this data to refine strategies and demonstrate the long-term benefits to policy makers.

5. Current Policies on Digital Agriculture

This section explores key initiatives under Thailand's national strategic frameworks, specifically focusing on Thailand 4.0 and Community Product Standardization, which collectively aim to support the advancement of the agricultural sector. These policies ensure that local producers can compete on both national and international stages by adhering to standards and leveraging digital tools.

5.1 Thailand 4.0

Thailand 4.0 is an economic model aimed at transitioning Thailand into a value-based and inclusive economy. This framework is underpinned by the 20-Year National Strategy (2017–2036), aiming to achieve security, prosperity, and sustainability through six main strategies. The core of Thailand 4.0 is the application of the Sufficiency Economy Philosophy, fostering development that is economically viable, environmentally sustainable, and socially inclusive.

5.1.1 Economic Reform and Industrial Development

There is a concerted effort towards Industry 4.0 integration, emphasizing the modernization of traditional industries such as Automotive, Agriculture and Biotechnology and the cultivation of new high-tech sectors such as Robotics, Biochemicals and Digital Industry. Initiatives include transitioning the automotive industry to electric vehicles and propel the bio-industry towards producing value-added products such as ethanol and bioplastic. In agriculture, the focus is on promoting modern farming practices and the use of agricultural machinery to increase efficiency and reduce costs. For example, in sugarcane cultivation, the adoption of mechanized farming techniques is expected to improve production effectiveness. Additionally, efforts are being made to enhance water management systems to ensure that sugarcane is cultivated optimally in each locality, considering regional specificities and environmental conditions.

5.1.2 SME Development

Recognizing the crucial role SMEs play in driving economic growth and innovation, various measures have been implemented to support startups, enhance competitiveness, and foster innovation. Initiatives such as the Big Brother program and Creative Innovation Villages are designed to build local economies by leveraging cultural capital and local wisdom.

The Ministry has established a network of 22 Industry Transformation Centers (ITCs) across the country. The main center is in Bangkok, with 11 regional centers at Industry Promotion Centers and the remainder situated within industrial estates. These centers provide essential services such as public access to machinery, expert consultation on product and packaging design, and collaborative market promotion efforts involving government, private sector, and educational institutions.

5.1.3 Environment Sustainability

Measures have been implemented to ensure businesses, factories, and mines strictly comply with environmental regulations. Key policies include the promotion of green mining standards, comprehensive waste management strategies, and the development of Eco Industrial Towns. These initiatives aim to balance industrial growth with environmental stewardship, ensuring that economic progress does not come at the expense of the environment.

For instance, in the mining sector, the adoption of remote sensing technologies enhances the sustainability of inspection and monitoring activities. Satellite remote sensing provides real-time

data, improves inspection and monitoring efficiency and safety by addressing accessibility issues and reduces risks associated with traditional survey methods. Unmanned aerial vehicles (UAVs) further enhance monitoring by providing more precise data.

5.1.4 Regional Development

The Eastern Economic Corridor (EEC) initiative aims to transform Thailand's eastern provinces into a premier center for advanced industries, logistics, and education. The project is designed to enhance Thailand's regional economic standing by fostering growth in high-tech sectors, upgrading infrastructure, and advancing educational opportunities.

Spanning the provinces of Chachoengsao, Chonburi, and Rayong, the EEC project seeks to create a model for capital accumulation, knowledge, and technological innovation, while also focusing on personnel development at all educational levels. Additionally, the initiative includes investment in logistics and transportation infrastructure, enhancing both freight and public transport systems to create a cohesive network. The overarching goal is to position Thailand as a regional hub for trade, investment, and transportation, which will improve connectivity across the country, boost income levels, increase employment, and elevate the overall quality of life.

5.1.5 Human Resource Development

The government invests in developing a skilled workforce capable of driving innovation and adapting to new technologies, ensuring that the industrial sector can thrive in the global market. The Ministry encourages personnel to achieve their highest potential by obtaining an innovative and creative mind along with a desire to learn, and most importantly to have a sense of social responsibility. By organizing training and educational seminars, the personnel would be able to adapt to new situations and improve services and operations effectively.

Key programs include advanced training in digital marketing and effective management of Special Economic Zones (SEZs), aimed at leveraging these zones' unique advantages for economic growth. The Ministry is also preparing civil servants for elevated roles through structured training that covers leadership at various levels, from entry to senior positions. This program ensures that administrators acquire essential skills for implementing ministerial policies and achieving strategic objectives. Additionally, specialized capability development programs are offered, focusing on administrative proficiency and communication skills, with training provided by prestigious institutions.

5.1.6 Integrative linking and development of big databases

The policy emphasizes the use of Big Data and digital technologies to improve industrial efficiency and competitiveness. This involves the creation of specialized Big Data teams, the establishment of robust data collection methods, and the design of advanced data architecture to enable the integration of information across government agencies, effectively creating a digital ecosystem.

For instance, the development of a centralized data platform has been implemented to consolidate information from various government departments, such as economic, environmental, and health data, into a unified system. This integration facilitates real-time analysis and decision-making, enhancing the ability to address complex industrial and economic challenges. Additionally, projects like the Smart City initiative leverage Big Data to optimize urban planning, traffic management, and public services, demonstrating practical applications of data-driven strategies.

5.2 Community Product Standardization

Under the Thailand 4.0 framework, the Thai Industrial Standards Institute launched a community products standard project. This initiative aims to foster product development, enhance consumer confidence, and promote sustainable production. The goal is to increase distribution channels and

support high-quality products made by local producers, ensuring their acceptance in both international and domestic markets.

The project aimed to bridge the gap between local producers and larger markets, acknowledging that many community-based products lacked the necessary quality certifications to compete on a broader scale. Key activities include issuing 5,082 community product standard certificates and inspecting 1,650 products for quality assurance. This extensive certification process was crucial in ensuring that products such as food items, handicrafts, herbal products, textiles, and household goods met international standards, thereby enhancing their marketability and consumer trust.

Additionally, the initiative focused on capacity building among local producers. Efforts to develop community product manufacturers across various provinces were bolstered by organizing seminars that aimed to enhance production capabilities, prepare for international markets, and evaluate standards. With a total of 6,232 participants, these seminars provided essential training and knowledge transfer, empowering local producers to improve their production processes and product quality.

The project also recognized the importance of continuous monitoring and evaluation to maintain high standards and ensure ongoing compliance. Seminars aimed at officials and monitoring and evaluation activities were conducted to improve the performance of community product certification and enhance certificate inspection capabilities, engaging a total of 827 participants. This not only ensured the integrity of the certification process but also fostered a culture of quality and compliance among producers and certifying bodies alike.

5.2.1 Improving Community Producer Certification with QR Codes

The Thai Industrial Standards Institute has introduced QR codes into Community Product Standards (CPS) certificates, allowing consumers to swiftly access certification details and thereby increase confidence in community products. These QR codes, displayed on product labels, are effective from October 1 of the previous year. Additionally, TISI is spearheading efforts to transition towards Community Product Standards 4.0, focusing on technology adoption and innovation to strengthen support for entrepreneurs, enhance standards, and promote domestically and internationally accepted community products [11].

5.3 Herbal City Program (2023-2027)

Herbal City is a development program that spans multiple provinces focused on enhancing herbal development from cultivation to market, aiming to strengthen local communities, create sustainable economic value from herbs, and align with the National Herbal Policy Phase 2 (2566-2570). This initiative includes developing local herbal clusters across various provinces to boost regional income accumulation.

15 Herbal Cities collectively generated income exceeding THB 1.1 billion in 2024 through the sale of herbal products and related services. Nan province is expected to become the 16th Herbal City, focusing on health tourism, beauty, and traditional Thai medicine. The program plans to leverage local crops such as ginger, Chinese chives, and rice to promote health tourism routes centered around herbal cuisine. The long-term vision for Nan Herbal City over the next 3-5 years includes educating local communities on the benefits of herbal products and elevating industrial standards to enhance economic sustainability [12].

5.4 Smart City Promotion

The Smart City Development Promotion initiative aims to transform urban areas into technologically advanced and sustainable cities. In Thailand, the government's focus includes expanding smart city projects to 17 provinces, including Nan. This program is designed to enhance

urban management, improve infrastructure, and integrate advanced technologies to optimize services and reduce resource consumption.

In Nan, this initiative can lead to significant upgrades in digital infrastructure through the implementation of smart grid technologies for efficient energy use, improved waste management systems utilizing IoT sensors, and enhanced traffic management through smart traffic lights and real-time monitoring. Additionally, the project supports local agriculture by integrating smart technologies into farming practices, such as precision irrigation systems and digital platforms for market access. These advancements aim to improve quality of life, boost economic development, and ensure sustainable growth in the region.

6. Success Stories related to organic herb/vegetable products

This section showcases a series of inspiring success stories that highlight the transformative impact of organic farming in diverse contexts. From revitalizing unused land to creating local employment opportunities, these stories highlight the journey of individuals who have embraced organic agriculture as a path to economic prosperity, environmental sustainability, and community development. Through their resilience, innovation, and dedication, these farmers have not only achieved personal success but have also contributed to the broader movement towards sustainable agriculture.

6.1 From Soil to Shelf: A Tale of Two Thai Women and Organic Farming

Over the past eight years, Khun Mantana's family-owned 60 rai of land had been left unused. However, growing concerns about the quality of vegetables available in the market prompted them to act. They decided to utilize their land and start growing vegetables for their own consumption. Witnessing the rising demand for organic produce, they expanded, collaborating with other farmers to meet market needs. Similarly, Khun Supatra, leveraging her expertise, addressed pesticide residues, facilitating Sum Sung District's transition to organic farming. This led to the establishment of the "Sum Sung" brand, known for pesticide-free vegetables. These efforts respond to consumer demands and contribute to community and environmental well-being. With support from ADB, initiatives aim to strengthen organic vegetable value chains, capitalizing on the global market for organic foods [13].

Figure 6:
Khun Mantana, owner of Sum Sung, producing organic vegetable products.

6.2 Promoting Organic Agriculture in Remote Landscapes

Until 2016, Gasa Dzongkhag remained isolated, disconnected by farm roads, leading farmers to rely solely on organic farming practices due to limited access to synthetic chemicals. Recognizing this commitment to organic methods, the former Minister of Agriculture declared Gasa as an organic Dzongkhag in 2004. Aum Dawa Zangmo, a prominent farmer in Khatoed Gewog, exemplifies the success of this approach. Despite facing challenges such as crop failures, she diversified her farming activities to include organic vegetable cultivation, Shitake mushroom farming, poultry, and dairy. By adhering to organic principles, she not only ensures food safety but also generates significant income for her family. Though labor shortages and wildlife damages pose obstacles, her determination and innovative spirit drive her success, making her a respected figure in her community [14].

Figure 7:
Dawa Zangmo 's vegetable farm (left) and shiitake mushroom farm (right).

6.3 From the Big City to Highlands: Thái Bình Woman's Journey into Organic Farming

Bùi Thị Duyên's bold decision to leave her comfortable life in Singapore to the laborious job of setting up an organic farm in the highlands of Thái Bình Province is notable. Duyên was struck by the realization that Vietnam's agricultural products rivaled those of other Southeast Asian countries but lacked visibility in international markets like Singapore. Fueled by this insight, she embarked on her entrepreneurial venture and founded 'Got-a-farm' to supply, process and sell spice plants and medicinal herbs. Facing initial skepticism and daunting challenges, Duyên persisted, drawing upon her innovative spirit and the support of her local community. She transformed neglected grass fields into flourishing herbal gardens, employing organic farming methods and community engagement to achieve success. Through 'Got-a-farm,' Duyên not only created employment opportunities for locals but also emerged as a beacon of inspiration for the burgeoning start-up movement in Thái Bình Province. Her journey exemplifies the transformative power of vision, perseverance, and a deep-rooted connection to one's land [15]. Currently, the farm grows a variety of medicinal herbs and creates products such as peppermint essential oil and aromatic leaf products.

6.4 Cultivating Success: Journey from Struggling Farmer to Organic Entrepreneur

Despite facing skepticism from friends and family for venturing into medicinal farming over conventional farming, as well as financial constraints and climate-related issues, he remained steadfast in his entrepreneurial pursuit. He meticulously studied organic farming, soil and crop requirements, and climate patterns. With enough support from the government, he put into practice organic techniques market-oriented strategies and was able to turn his vision into reality. Today,

Vinayak Herbal boasts a diverse portfolio of over 120 medicinal plant varieties and collaborates with over 50,000 farmers nationwide. With an annual revenue of approximately 140,000 USD, Rakesh's success not only transformed his own life but also serves as an inspiration for aspiring farmers, highlighting the potential of organic agriculture as a lucrative and fulfilling career path [16].

6.5 Empowering communities through organic tea farming

Through a cooperative approach and women empowerment initiatives, KKTE has established a unique ecosystem that integrates tea cultivation with organic farming, cattle rearing, and community development. This holistic model not only ensures environmental protection but also fosters economic and social sustainability, empowering women and enhancing the overall well-being of the community. Moreover, KKTE's premium quality organic tea, marketed under the brand 'Teatulia,' has gained international recognition, further amplifying its impact on both local and global scales. With certifications from USDA, NOP, LACON, B Corporation, and Rainforest Alliance, KKTE's commitment to organic and sustainable practices has not only transformed barren land into thriving tea plantations but has also uplifted local communities through its unique approach [17].

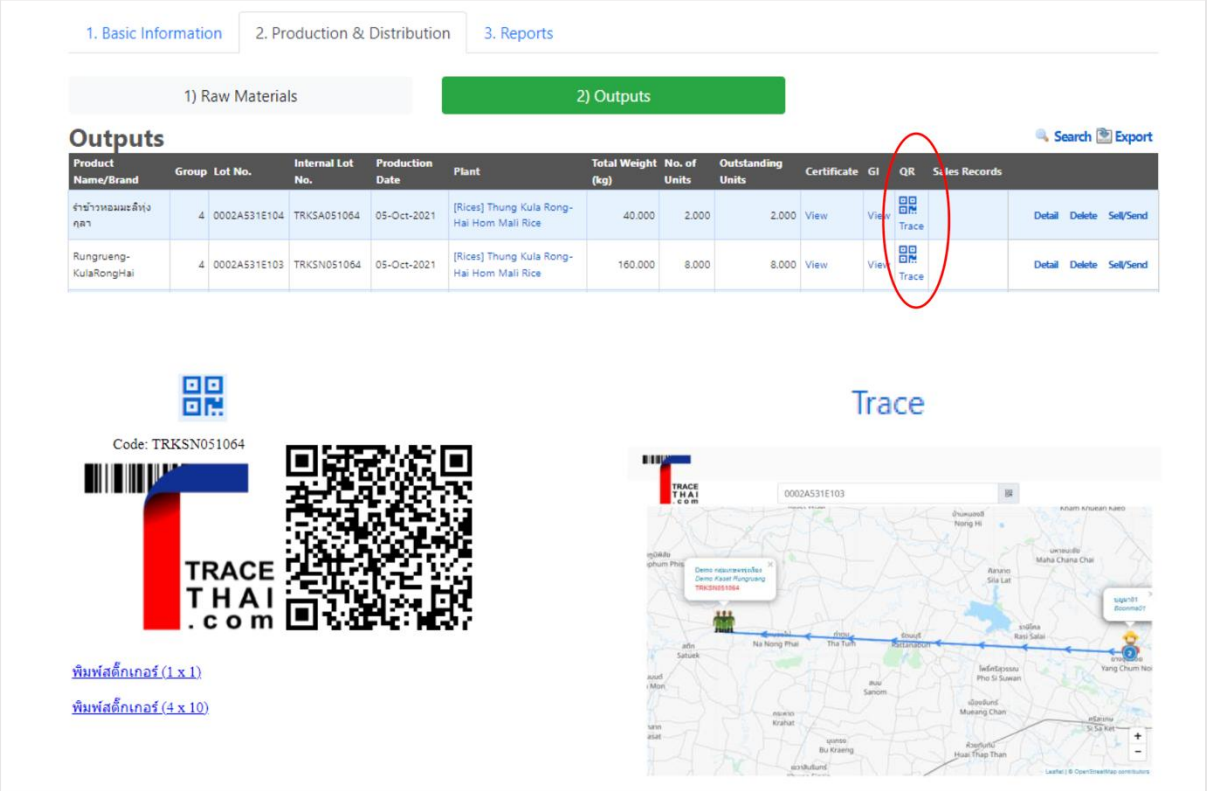
"I realized that the quality of Việt Nam's agricultural products was not inferior to other countries in Southeast Asia, but they have no foothold or have not yet approached the market in Singapore."

7. Digital Traceability Solutions in Thailand

7.1 TraceThai

The Trade Policy and Strategy Office (TPSO) of Thailand's Ministry of Commerce launched the blockchain application TraceThai in 2020 as part of the Thailand 4.0 and 20-year National Strategy frameworks. Developed in partnership with Thammasat University Research and Consultancy Center (TURAC), the system aims to enhance trade in high-value agricultural products by promoting the production of premium items such as organic, safe, processed, and value-added products. This strategy helps Thai agricultural products differentiate themselves and access niche markets amidst a shrinking mass market.

Figure 8:
Product distribution information in TraceThai.



TraceThai records the conversion of raw materials to products, with each user ’s output becoming another ’s input. Key information for traceability, such as farm location, manufacturer details, manufacturing dates, and certificates, is recorded on the blockchain. Internal user account information unrelated to product sales is protected, ensuring trade secrets remain secure. Farmers, community enterprises, entrepreneurs, exporters, and importers independently record relevant data, which is visible to consumers only at a general level, while specific production data remains restricted to relevant parties.

Since its launch, TraceThai has expanded from 17 operators to 61, with the majority in the northeastern region, Thailand's largest rice producing area. The scope of traceability has also widened to include various crops like vegetables, fruits, and Thai GI products. The Ministry of

Agriculture and Cooperatives collaborates with agritech companies and Innovation Centres to integrate databases with the National Farmers' Council, improving services and information access. TURAC's engagement activities, including seminars, workshops, and media outreach, have successfully exceeded participation targets, reflecting growing confidence in the system's ability to manage high-quality organic agricultural products.

7.1.1 Best Practices

Immutable data: Utilizes blockchain for secure, transparent, and tamper-proof production records.

Comprehensive Data Recording: Records key traceability information, including farm location, manufacturer details, manufacturing dates, and certification.

User-Centric Design: Allows independent data entry by stakeholders (farmers, community enterprises, exporters, importers).

Promotes Product Differentiation: Encourages production of high-value, organic, and value-added products to access niche markets. Expanded from organic rice to include vegetables, fruits, and Thai GI products.

Secure Information Access: Protects trade secrets by setting access rights, ensuring sensitive data is restricted to relevant parties.

Government and Private Sector Collaboration: Partners with agritech companies and Innovation Centres to enhance data integration and service access.

7.1.2 Areas for Improvement

Educational Materials: Develop more engaging and practical educational resources, such as video clips and real-world examples.

Product Support: Expand support to include a broader range of products, especially those meeting Good Agricultural Practices (GAP) standards.

Integration with Broader Ecosystems: Improve integration with other organic farming systems and networks to streamline data input and expand the user base.

Verification Procedures: Establish clear procedures for verifying new users' organic certificates and retaining existing users.

Research and Innovation: Promote research and innovation in organic agriculture to increase yield and reduce production costs.

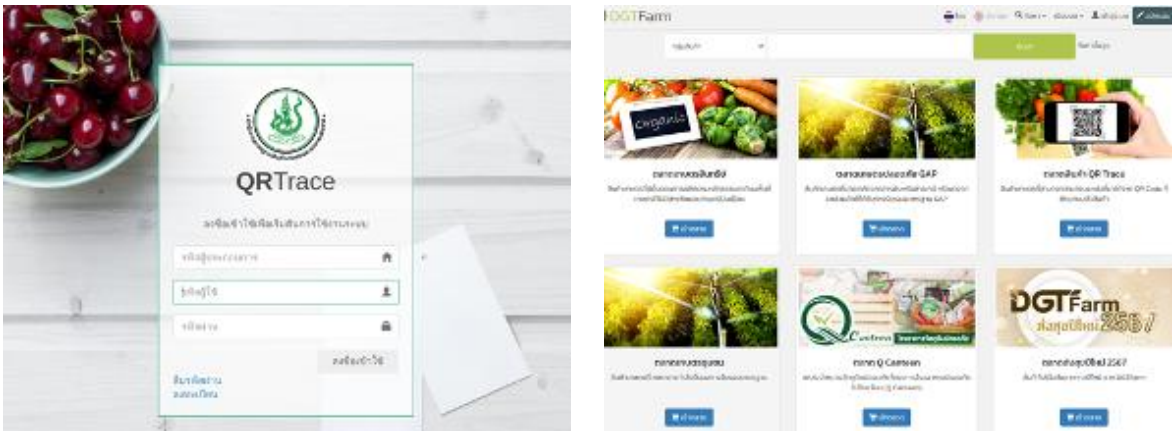
Local Promotion: Enhance efforts to promote domestic organic agriculture at local levels.

7.2 QR Trace

The National Bureau of Agricultural Commodity and Food Standards (ACFS) is committed to establishing, inspecting, certifying, controlling, and promoting agricultural product standards from farm to consumer. Their mission is to elevate the quality and safety of Thai agricultural products to meet international standards and enhance global competitiveness. As part of Thailand's 20-year national strategy, ACFS focuses on building competitiveness through the "3S" model (Safety, Security & Sustainability) under the BCG framework and government policies promoting market leadership, innovation, and income growth.

To achieve these goals, ACFS developed the QR Trace on Cloud system to increase the adoption of safety standards and digital technologies.

Figure 9:
QR Trace application.



The QR Trace on Cloud system requires farmers and producers to register their information, categorized by product type (e.g., fruit and vegetable, rice, egg, livestock, fishery, processed food), and receive an SME code upon approval. Key data, such as farm location, product details, raw material sources, processing steps, and delivery information, are manually inputted into the system. A lot number is generated for each product, and a QR code is produced, which consumers can scan to access detailed product information, including product name, expiration date, certified standards, farmer and manufacturer details, and product features. This system securely records all data on the cloud, linking raw materials to finished products at each step.

Since its launch, the QR Trace on Cloud system has seen significant adoption. From 2017 to Q1 2023, over 2,700 individuals registered across various provinces, with more than 3,800 users signing up for the DGTFarm website. The platform connects producers and entrepreneurs with consumers, creating trade opportunities and ensuring access to high-quality products. Most businesses using the QR Trace system are in the central and northeast regions, primarily comprising individual businesses and community enterprises.

Farmers have reported increased customer interest and steady orders since implementing the QR Trace on Cloud system, as customers can scan QR codes for detailed product information, boosting their confidence. ACFS provides essential support in filling out information and using the system, particularly for those unfamiliar with technology. This support has been invaluable for many farmers, leading to successful sales and increased income.

7.2.1 Best Practices

Categorization by Product Type: Organizes registration and data input by specific product categories (e.g., fruit and vegetable, rice, egg, livestock, fishery, processed food).

Lot Number and QR Code Generation: Assigns unique lot numbers and generates QR codes for each product, enhancing traceability and consumer access to product details.

Cloud-Based Data Storage: Securely records all data on the cloud, ensuring easy access and retrieval of information for stakeholders.

Labeling: Provides detailed product information through QR code scanning, including product name, expiration date, certified standards, and producer details.

Promoting International Trade: Creates trade advantages with key partners like the EU, Japan, and the US, by meeting international standards and ensuring high-quality products.

Promotes a common data infrastructure for agricultural product traceability, benefiting different stakeholders in the supply chain.

(1) Policy makers: Establishing a single, authoritative platform for product traceability (QR Trace) enhances decision making. Because of the standardized reporting of product origins and manufacturing procedures, policymakers can access the same information and develop their own reports. Key decision makers spend less time preparing data and more time analyzing data.
(2) Farmers, buyers, consumers: A one-stop shop for reporting and monitoring product origins and manufacturing processes reduces barriers for adopting traceability. For farmers, it simplifies compliance with various standards. For buyers and consumers, the QR Codes offer easy access to comprehensive product traceability, enhancing their understanding of product origins and building trust in the products and the farmers who produce them.

7.2.2 Areas for Improvement

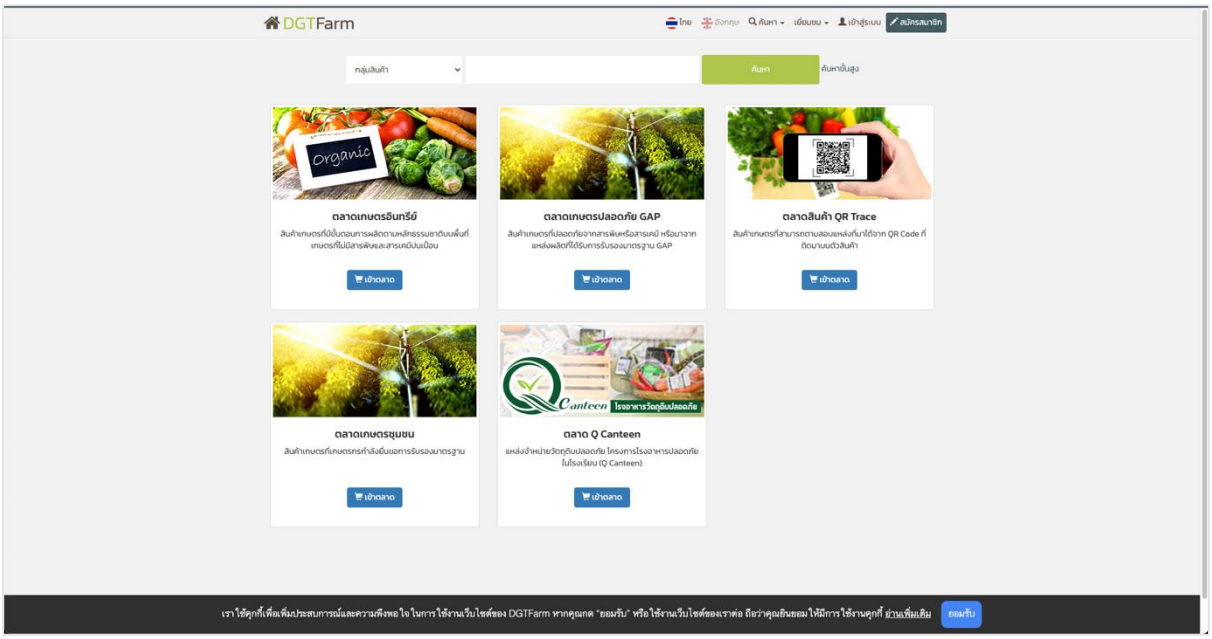
Increase data granularity and automation through API integration: Products in QR Trace currently lack detailed information on crops, soil conditions, microclimate, and cultivation practices, which are important for food safety. While this data can be manually entered, the absence of standardized formats for recording makes it time-consuming and error prone. Integrating with smart farm management systems that specialize in farm-level data management can both increase the level of detail and automate processes. This will enable authorities to track food safety more effectively and manage product recalls or alerts (via ARASFF) with greater efficiency and accuracy.

Figure 10:
Displayed details in the QR Trace application and example of an actual product uploaded in QR Trace. The platform could be enhanced by increasing the level of detail displayed in the Farm section.

7.3 DGT Farm

Also Launched by the National Bureau of Agricultural Commodity and Food Standards (ACFS), DGTFarm.com is an online marketplace designed to support young organic farmers to expand their organic business. This platform features product categories with QR Codes generated from QR Trace (ตลาดสินค้า QR Trace), a traceability standard run by the National Bureau of Agricultural Commodity and Food Standards.

Figure 11:
DGT Farm – An online marketplace for organic products.



The platform categorizes products into three distinct groups:

Organic Produce: Items grown without chemicals or toxins, including vegetables, fruits, rice, and processed foods.

GAP Certified Products: Includes vegetables, fruits, rice, eggs, processed foods, livestock, and fishery products, certified under Good Agricultural Practices.

QR Trace Products: Features products with QR codes for traceability, covering items like rice, eggs, vegetables, fruits, processed foods, and herbal cosmetics.

Currently, DGTFarm.com serves over 1,600 farmers who meet organic and GMP standards, actively participating in the online marketplace. The platform is part of a broader initiative to enhance Thailand's organic sector, aiming to improve farmer incomes and living standards by responding to global trends in health and sustainability.

7.3.1 Best Practices

Marketplace and business matching: Provides a platform for young farmers to market their organic products and connect with buyers.

Organic product categorization: Classifies products into organic, GAP-certified, and QR Trace categories for clear consumer understanding.

Linkage with government-run traceability standards: Farmers can attach QR codes generated from QR Trace when uploading product details online. This streamlines the traceability process

and increases the credibility of a product's traceability claims. Farmers don't need to re-enter information—they simply upload the QR code. For consumers familiar with QR Trace, this provides a consistent, easy way to verify product origins without learning a new system or standard. Overall, recording and monitoring of product traceability is more efficient.

Training and support: Includes training for young farmers and promotes new marketing channels to expand the organic market.

7.3.2 Areas for Improvement

Promoting International Trade: Partners with EU, Japan, and the US, by meeting international organic standards and ensuring high-quality products.

7.4 European Union (EU) as Exemplar of Digital Traceability

The European Union (EU) is known for its strict regulations that mandate comprehensive traceability from farm to fork, ensuring high levels of food safety and consumer confidence. As such, the EU is often regarded as the setter of gold standards for supply chain traceability in food systems. Notably, the EU is at the forefront of enhancing supply chain transparency through digitization.

7.4.1 Digital Product Passport (DPP)

Introduced as part of the European Commission's proposals in March 2022, the DPP is integral to the EU's broader Green Deal, which seeks to make Europe the first climate-neutral continent by 2050 and reduce CO2 emissions by 55% by 2030. The DPP is designed to improve product sustainability by preventing waste, encouraging the reuse of materials, and promoting a circular economy. This passport will provide detailed information about a product's lifecycle, from raw materials to finished goods, enhancing transparency, and allowing stakeholders to make more informed decisions about production, consumption, and recycling. Although currently applicable to industries such as apparel, batteries, and consumer electronics, the DPP will soon expand to other sectors, further solidifying the EU's commitment to sustainable development.

7.4.2 Digital Integration of Agricultural Supply Chains Alliance (DIASCA)

The DIASCA (Digital Standards for Compliance and Accountability) initiative aims to address challenges in traceability and regulatory compliance by developing open standards that enhance interoperability between traceability systems. This initiative is a response to increasing demands from regulations such as the German Supply Chain Due Diligence Act (LkSG), the EU Deforestation Regulation (EUDR), and the Corporate Sustainability Due Diligence Directive (CSDDD), which require companies to prove the origins and sustainability of their agricultural products. DIASCA focuses on creating common, cross-sectoral standards to facilitate efficient data exchange, reduce errors, and support compliance with due diligence requirements. By fostering compatibility between different systems and improving data collection and usability, DIASCA aims to support smallholder organizations, enhance transparency in supply chains, and potentially increase smallholder incomes through better access to digital solutions and market opportunities.

The initiative is also working on a digital public infrastructure (DPI) to meet the EUDR's requirements, such as geolocation of fields, forest monitoring, and comprehensive traceability. This DPI, developed by a consortium including DIASCA/GIZ, Linux Foundation/AgStack, COSA, and CGIAR, will integrate existing digital tools to support smallholders and producer organizations in complying with regulatory standards while promoting sustainable and transparent agricultural practices.

7.4.3 ASEAN Rapid Alert System for Food and Feed (ARASFF)

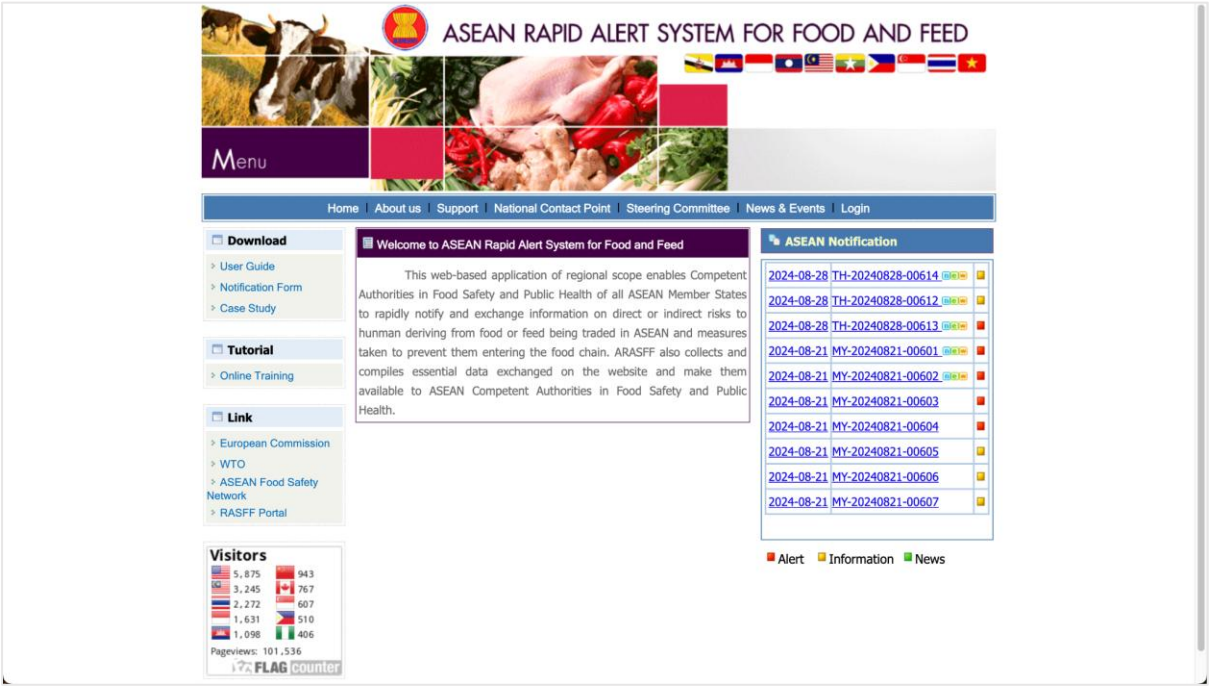
ARASFF (http://www.arasff.net/) is an alert system designed to quickly notify authorities within the ASEAN Member States about at-risk products. Its primary goal is to rapidly disseminate

information about newly identified risks from unsafe products and the measures taken to prevent these items from reaching consumers.

ARASFF began as a bilateral initiative between Thailand and the European Union, launching in December 2006 with joint funding from the European Commission and the Royal Thai Government. Initially involving Thailand, Malaysia, and Vietnam, ARASFF was officially endorsed by ASEAN as the primary tool for exchanging food and feed safety information among member states at the Special SOM-AMAF Meeting in August 2009.

Thailand has ranked 3rd in the number of EU food safety warnings, especially in the herbs and spices category1. With growing demand for herb products, there is a need to strengthen traceability systems and preventive measures from the farm. However, it is essential for competent authorities to first establish and enforce rigorous standards.

Figure 12:
ARASFF Home Page.



The National Bureau of Agricultural Commodity and Food Standards (ACFS) is Thailand 's national competent authority to enforce the Agricultural Standards Act B.E. 2551 (2008), in order to improve food safety and quality to meet the expectations of importers and consumers worldwide. ACFS therefore controls standards for agricultural products and provides accreditation to certification bodies for food products, farming practices and other related activities.

7.4.4 Furthering these Initiatives

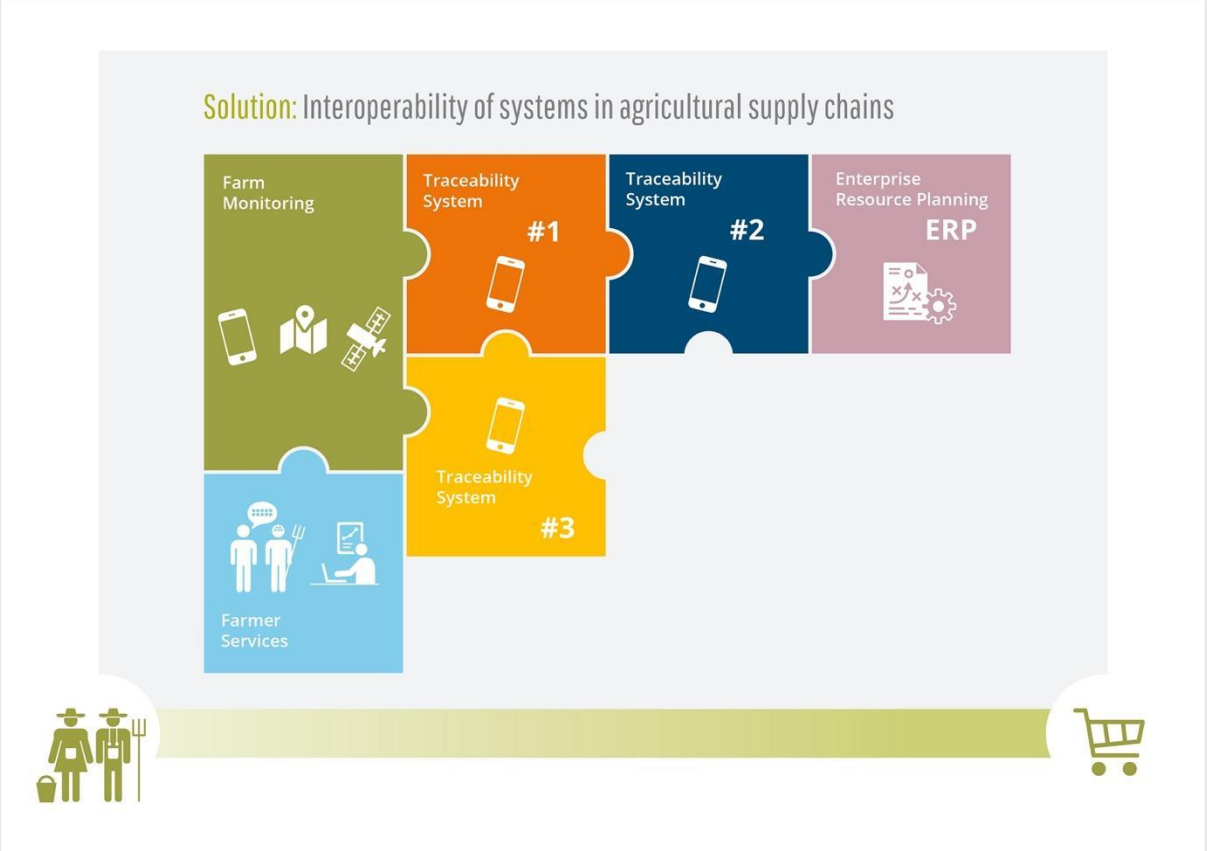
Cost-Effectiveness: Digital traceability solutions, especially for smallholders, can be expensive to implement and maintain. Developing cost-effective technologies and providing financial support or incentives for adoption can help reduce the financial burden on smaller producers and increase overall system efficiency.

Technology Accessibility: Making digital traceability tools more accessible to smallholder farmers and producer organizations is essential. This includes simplifying the technology, providing

[1] https://onlinelibrary.wiley.com/doi/10.1111/jfs.13131

user-friendly interfaces, and ensuring that the necessary infrastructure (e.g., internet connectivity) is available in rural areas.

Figure 13:
DIASCA – Promoting interoperability in agricultural food systems.



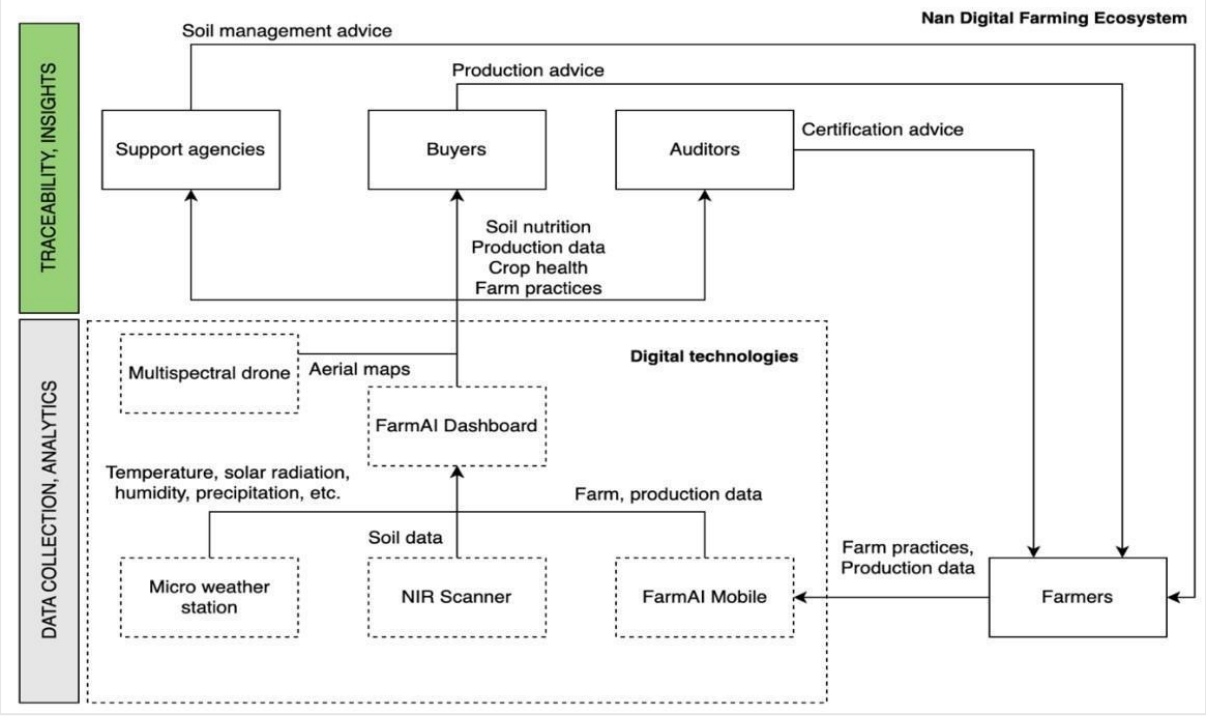
Source: https://www.nachhaltige-agrarlieferketten.org/en/in-practice/diasca-interoperability-between-traceability-solutions

8. Digital Traceability in Nan – Concept

This pilot project represents a frontier initiative aimed at assisting a group of farmers in linking good-quality products from highlands with domestic markets by introducing a suite of digital technologies, comprising:

(1) A mobile phone-based application to record and store farmers' profiles, including details such as name, land conditions, types of crops cultivated, agriculture practices like application of organic manures used, source from where manure is procured, application of organic pesticides, frequency, etc.
(2) A geographic information system to create a digital map of demonstration areas with delineation of farms using global positioning system (GPS) coordinates. In addition, each farm is given a unique ID.
(3) Agriculture drones to monitor crop health by taking aerial images to map crop phenology, identify pests and diseases, and record significant crop production events.
(4) A web application that serves as a comprehensive farming management tool, including crop health monitoring and data integration from soil to harvest for farm analysis. This system is also linked with an external system dedicated to the management of essential oil distillation, demonstrating full production traceability of organic essential oil sourced by smallholders.
(5) A QR code that can be accessed by buyers to view farm and post-harvest information.
(6) Near Infrared Spectroscopy for rapid analysis of soil nutrition of the farmer plots.

Figure 14:
Conceptual framework – creating a digital ecosystem that benefits all stakeholders.



8.1 Farm Group

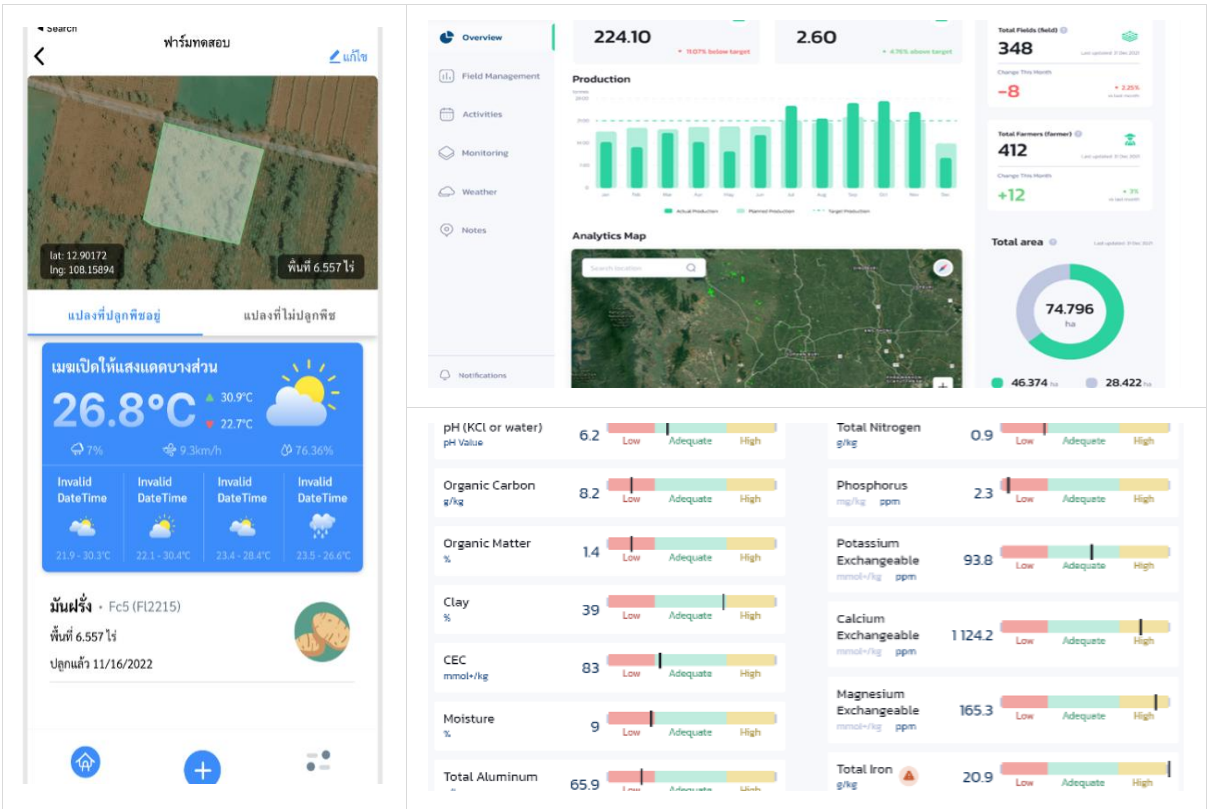
EPS Essen Planters Na Noi is a farmer enterprise adopting organic practices to secure better livelihoods and promote organic farming in the sub district. Comprising 37 farmers, the enterprise grows various herbs to produce essential oils sold to cosmetic and spa-related businesses and directly to consumers through online platforms.

Use of organic and biochar fertilizers: Farmers exclusively use organic and/or biochar fertilizers. Organic fertilizers, derived from natural sources like compost, manure, and plant residues, enrich the soil with essential nutrients, improve soil structure, and enhance its water-holding capacity. Biochar, produced through pyrolysis of organic materials, improves soil aeration, increases microbial activity, and enhances nutrient retention. Biochar also sequesters carbon, making it an excellent complement to organic fertilizers.

Organic certification efforts: All farmers are certified under the Good Agricultural Practices (GAP) standard, with ongoing applications for the Participatory Guarantee System (PGS). The enterprise also plans to seek FDA and Good Manufacturing Practices (GMP) certifications, with facility improvements currently underway.

8.2 Unique Approach

Figure 15:
FarmAI: An easy-to-use FMIS to collect, process, store, and disseminate data.



Data-driven Farm Management Platform: The scarcity of agricultural data in the highlands hinders effective monitoring and analysis of farmer plots, making it challenging to optimize agricultural practices and ensure compliance.

ListenField 's FarmAI Platform was introduced, a data-driven farm management software to make operations from the farm to the factory transparent and traceable, allowing stakeholders to track the final product (essential oil) back to the individual farms and verify microclimate and management practices. Its farmer-facing mobile application is provided for free allowing farmers to digitize their fields and increase their visibility in the supply chain.

At the backend, FarmAI integrates heterogeneous data, including farmer information, remote sensing (high-resolution satellite imagery), microclimate sensors, and soil health measurement instruments. This data is made available in an interactive dashboard, allowing extension services and buyers to support farmers in their organic certification activities and provide them with actionable insights to improve yields and profits sustainably. Simultaneously, the dashboard also provides regional, real-time, and comprehensive information to policymakers and researchers for policy planning, formulation, and research and development. This approach ensures that even in the most remote and challenging environments, farmers can improve their practices through extensive support.

8.3 Methodology

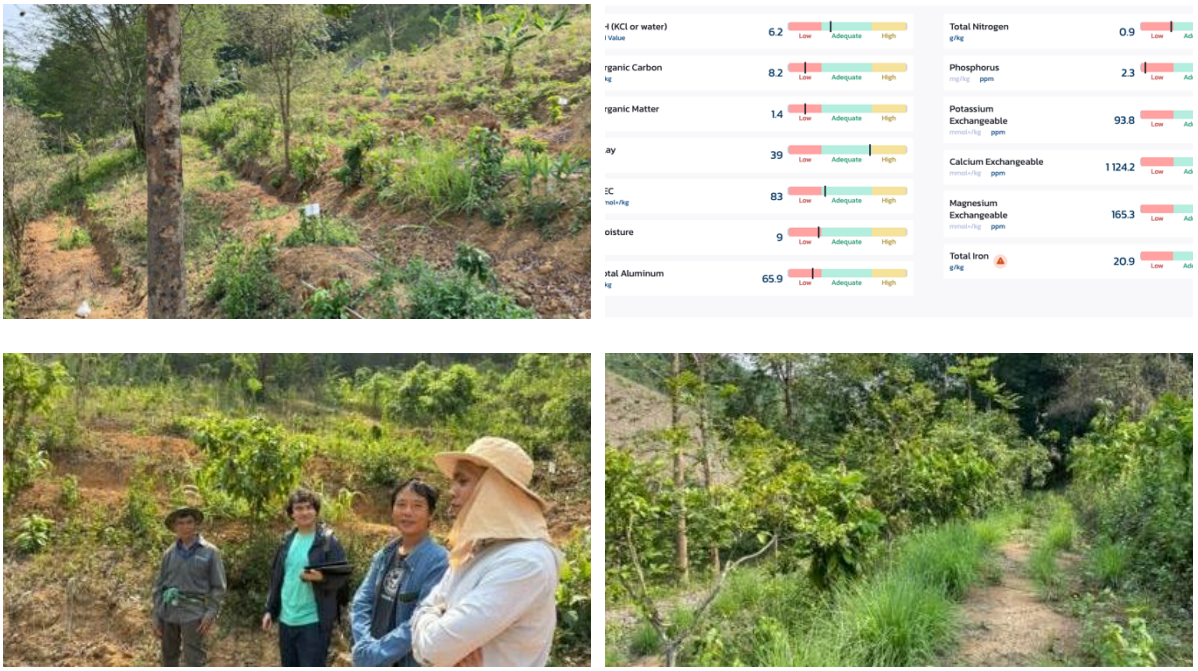
We initiated the monitoring of essential oil production by monitoring relevant information from the farm to the distillation factory.

(1) Digital farmer profiles
(2) Soil nutrition
(3) Plant health
(4) Distillation activities

8.3.1 Digital farmer profiles

Farmer information was collected through direct input from farmers via a mobile application and paper surveys conducted by field staff that were later digitized. This data includes individual farmer details such as field polygons, crop varieties, and planting dates. This information was integrated with the field 's soil nutrition measurements, remote sensing, and other microclimate data through APIs. The result is a comprehensive view of each farmer's plot that displays information on the crop 's current growth stage, soil nutrition, microclimate conditions, and management activities.

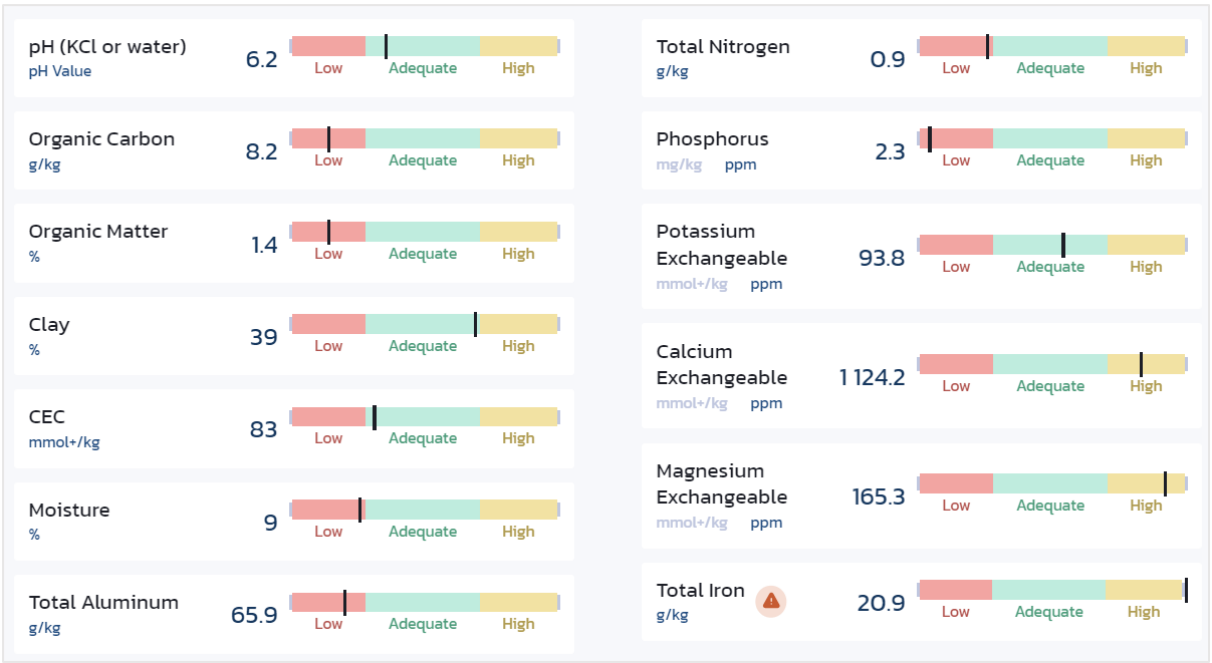
Figure 16:
Farmer profile digitized – plant growth and soil nutrition monitored.



8.3.2 Soil Nutrition

Soil nutrition in selected farmer plots was assessed on-site using handheld Near-Infrared (NIR) scanners, which offer rapid and cost-effective analysis of soil nutrition.

Figure 17:
Soil nutrition of a farmer plot measured and digitized on May 7, 2024.



The unavailability of soil testing equipment or laboratories as well as of trained individuals is the reason why rapid and on the ground soil testing are needed2. Hand-held Near-Infrared (NIR) scanners are designed for simple and on-the spot measurement of soil nutrients, providing data to farmers quicker than other soil testing methods.

Table 2:
Comparison of different soil testing methods applied in the highlands.

	NIR-based soil testing	Soil Testing Kits	Wet Laboratory
Suited for	Quick, on-the-spot, and continuous measurement and monitoring of soil nutrition	Quick measurement of basic soil nutrition parameters	Usually known for its higher accuracy and reliability
Technological maturity	Medium	High	High
Cost	1,000 THB/sample (13 soil properties)	Free (LDD[3]) 5,000 THB (KU[4])	1,000 THB/sample (5 soil properties)
Soil Property Coverage	pH, Organic matter, Total Nitrogen, Available Phosphorus, Exchangeable Potassium, Exchangeable Calcium, Exchangeable Magnesium, Cation Exchange Capacity, Total Aluminum, Total Iron, Clay, Organic Carbon, Moisture, Sand	pH, Nitrogen, Phosphorus, Potassium, and Salinity	pH, Total Nitrogen, Organic Matter, Available Phosphorus, Available Potassium
Scalability	High	High	Low
Procedure difficulty	Easy	Complex	Medium
Time to get results	10 minutes	30 minutes	1-2 months
Limitations	- Less precise	- One test kit can analyze 50 soil samples[5] - Requires separate procedures for measuring different parameters such as pH, Nitrogen, Phosphorus, Potassium, and Salinity - Procedure can be complicated and messy.	- Testing soil frequently or in multiple locations can be costly, time-consuming, and inconvenient - Access to laboratories may be limited in rural areas

[2] https://openknowledge.fao.org/server/api/core/bitstreams/a673cac1-636c-486b-b4c5-a39d522b659f/content
[3] Testing Kit provided by the Land Development Department through the Soil Doctors Program
[4] Testing Kit commercially provided by Kasetsart University
[5] https://globalresearchalliance.org/wp-content/uploads/2023/11/Concept-note_Labs-and-kits_insights-on-soil-analysis_clean.pdf

However, comparative analysis revealed that NIR measurements showed discrepancies when compared to conventional wet laboratory tests. The NIR measurements generally reported lower values for organic matter percentages and exhibited wider variations in available phosphorus and potassium levels compared to the laboratory results from Chiang Mai University (CMU) and Kasetsart University (KU)6. Similarly, the levels of available phosphorus and potassium measured with the NIR scanners displayed a wider range of variation compared to the more consistent results from laboratory tests conducted at CMU and KU.

Although the NIR-based measurements currently do not fully align with conventional methods, the concept of portability and cost-efficiency for data collection offer a promising solution for soil mapping and improving soil health in the highlands. By employing NIR technology, we enhance both spatial and temporal resolution of an area or region at a faster rate, particularly beneficial in areas with limited or no existing agronomic data, such as highland regions. While individual measurements of NIR may be less precise, the overall dataset becomes richer, allowing us to provide more actionable recommendations to highland farmers.

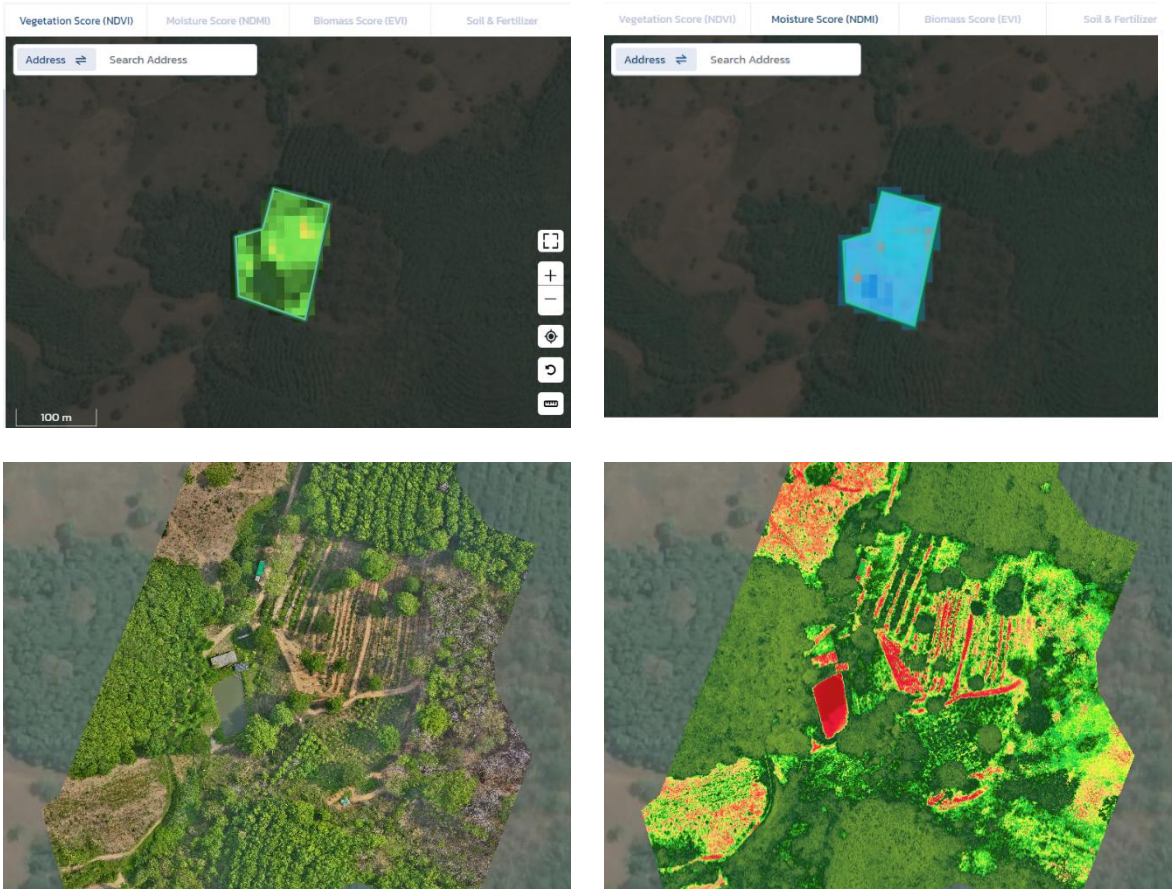
For resilient plants such as Lemongrass, the current level of accuracy of NIR may be sufficient for monitoring. For more sensitive crops, discrepancies in measurements can lead to crop loss. Therefore, further calibration is highly recommended to enhance the accuracy of these devices and fully realize their potential [18][19].

8.3.3 Plant Health

Plant health of farmer plots was measured using high-resolution satellite imagery and multispectral drones, providing information on crop growth and moisture levels using the NDVI and NDMI indices respectively.

[6] The organic matter percentages reported by the NIR scanner ranged from 1.1% to 1.9%

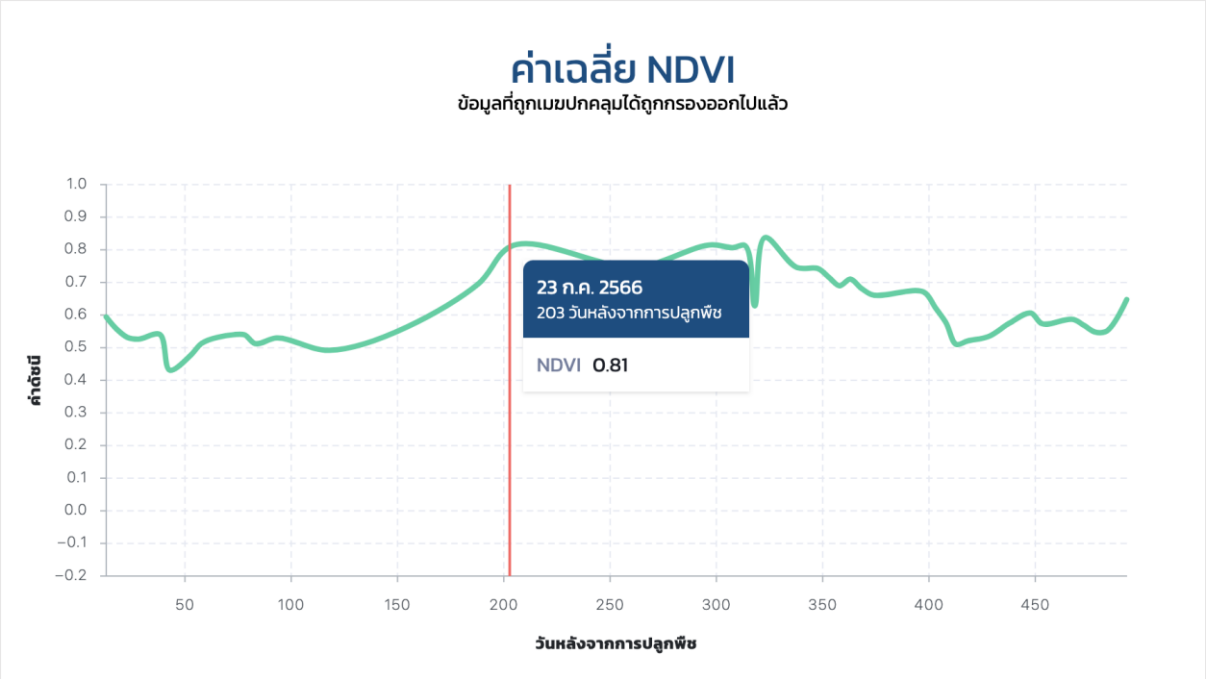
Figure 18:
Farmer plot captured using multispectral drone and satellite to understand plant growth.



Drones, while capable of capturing higher-resolution images than satellites, pose operational challenges in highland areas. Complex terrains with steep slopes and rugged landscapes make navigation difficult. Variable weather conditions, including extreme rainfall, strong winds, and sudden changes in visibility, can disrupt flights and compromise data collection frequency. The steep slopes increase the risk of soil erosion and water runoff and affect sunlight exposure, with steeper slopes potentially casting shadows and altering microclimates within fields [20][21][22].

Satellite images, despite lower spatial resolutions, are a scalable and cost-effective tool suitable for highland agriculture. It has been shown to be cost-effective when considering the cost per unit area compared to drones. Using satellite images also requires less operational effort and investment in equipment, allowing agribusinesses to monitor scattered small plots (generally less than 1 hectare) that would be challenging for drones. It also provides a consistent stream of data that makes it easy to compare and understand long-term changes and trends in crop health and performance. An analysis that covered three (3) decades of satellite data in Udon Thani revealed insights into how agricultural policies affected rice, sugarcane, cassava, and para rubber production. Significant expansions in sugarcane and rice areas from 1989 to 1999 were observed, followed by increases in cassava and para rubber cultivation from 1999 to 2009.

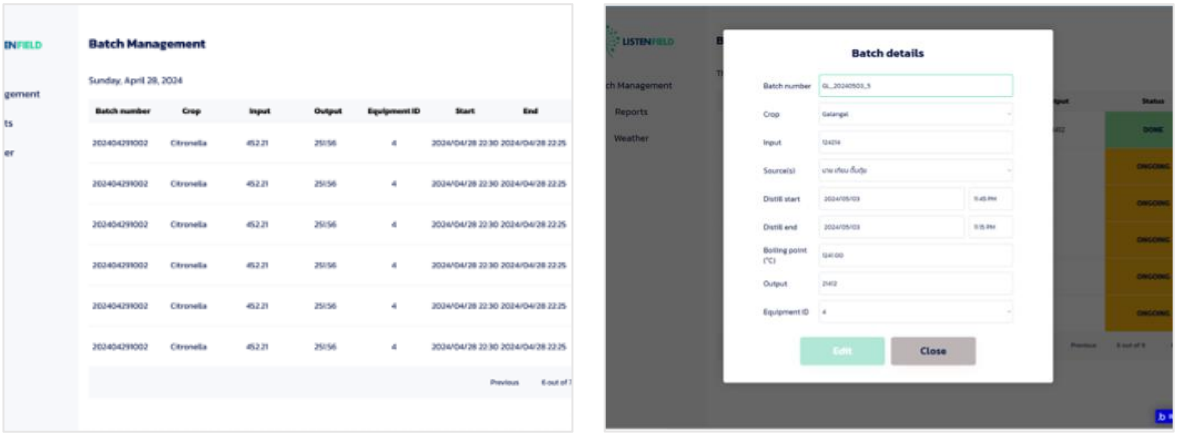
Figure 19:
Growth trend of Citronella plot from January 4, 2024, to June 12, 2024. Chart displays growth phases and stress periods for informed management strategies and optimal yield.

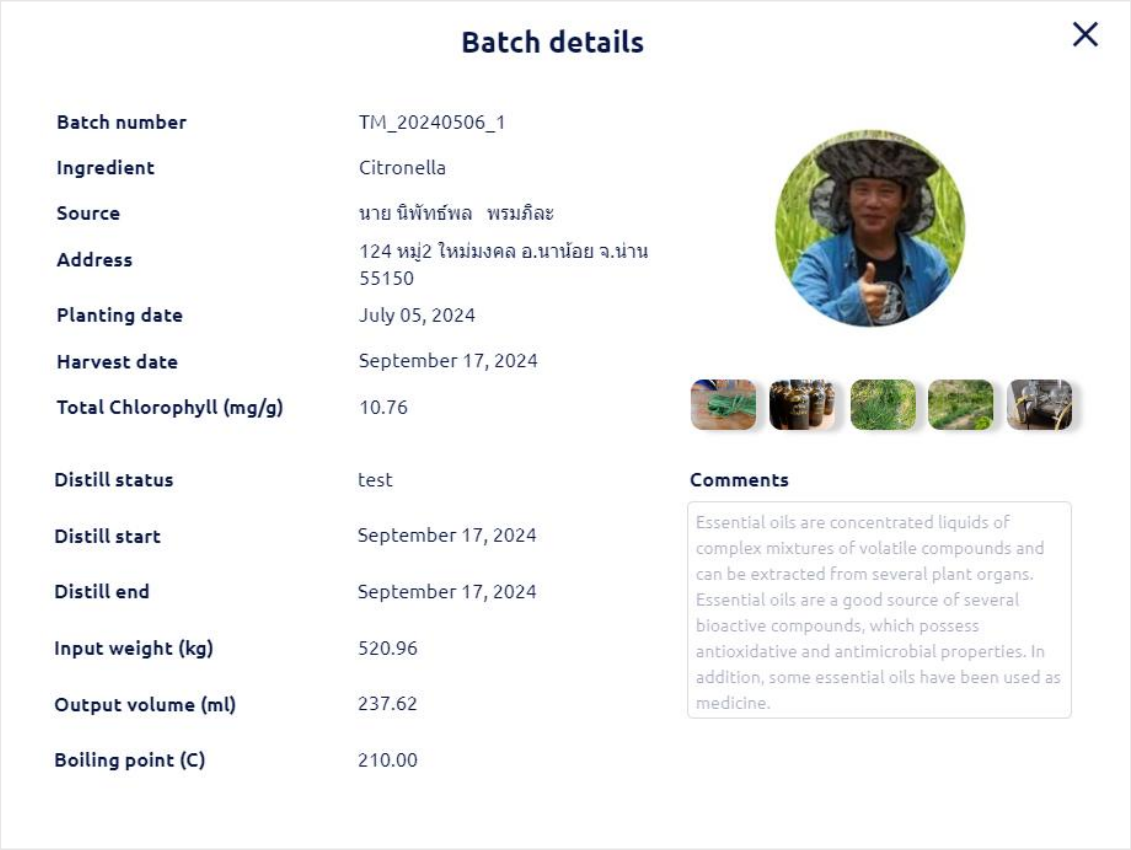


8.3.4 Distillation (Essential Oil Extraction)

In addition to farm-level monitoring, a user-friendly web application for distillers was introduced to help record and track their distillation work easily. Users can input batch information and distillation parameters, including start and end datetime, boiling point, raw product input, output amount, equipment used, and essential oil quality. Unique batch numbers are created.

Figure 20:
Distillation management system allows distillers to input raw material source input and distillation methods.





8.4 Benefits to Stakeholders

The farming community in Nan, as well as extension officers who assist them, benefit from the digital platform in several ways.

8.4.1 Farmers

Data for farm management: The platform delivers key data points, such as real-time data on soil health, weather conditions, and crop performance, enabling farmers to make informed decisions. By using this data, farmers can optimize their practices, improve resource management, and boost productivity.

Premium market access: By participating in the platform, farmers gain access to premium markets that offer better prices for their products, increasing their income potential.

Automatic data linkage: The platform's automatic data linkage feature reduces the time farmers spend on documentation, a task that can be unfamiliar and time-consuming. This allows them to concentrate on farming activities. By automating data processes, the platform helps bridge the digital divide without imposing additional burdens on farmers.

Among these benefits, premium market access is likely to have the most significant impact on farmers' livelihoods by directly increasing their income.

8.4.2 Extension officers

Reduced workload: The platform automates the process of checking data, reducing the need for extension officers to manually review information one by one. For example, having easy access to a farm ’s agronomic data from planting to harvesting eases inspection and enables officers to gain

a deeper understanding of farmer operations. This saves them time and enables them to provide better farmer support and guidance.

Improved data accuracy: Automatic data linkage ensures that the information processed by extension officers is accurate and up-to-date, reducing the risk of errors and inconsistencies that may occur with manual data entry.

8.4.3 Policy makers

From a broader perspective, the diversity and management of smallholder cropping systems are often not accurately reflected in national statistics. Since crop statistics are crucial for planning and policymaking, a data gathering system that accurately depicts on-farm conditions can significantly enhance decision-making of regional and national policy makers. By gaining insights into the relationship between farm-level practices and their outcomes at various scales and timeframes, including cumulative effects, policymakers can create strategies that better support smallholder farming systems. This, in turn, opens opportunities to advance climate-smart agriculture (CSA) in the highlands.

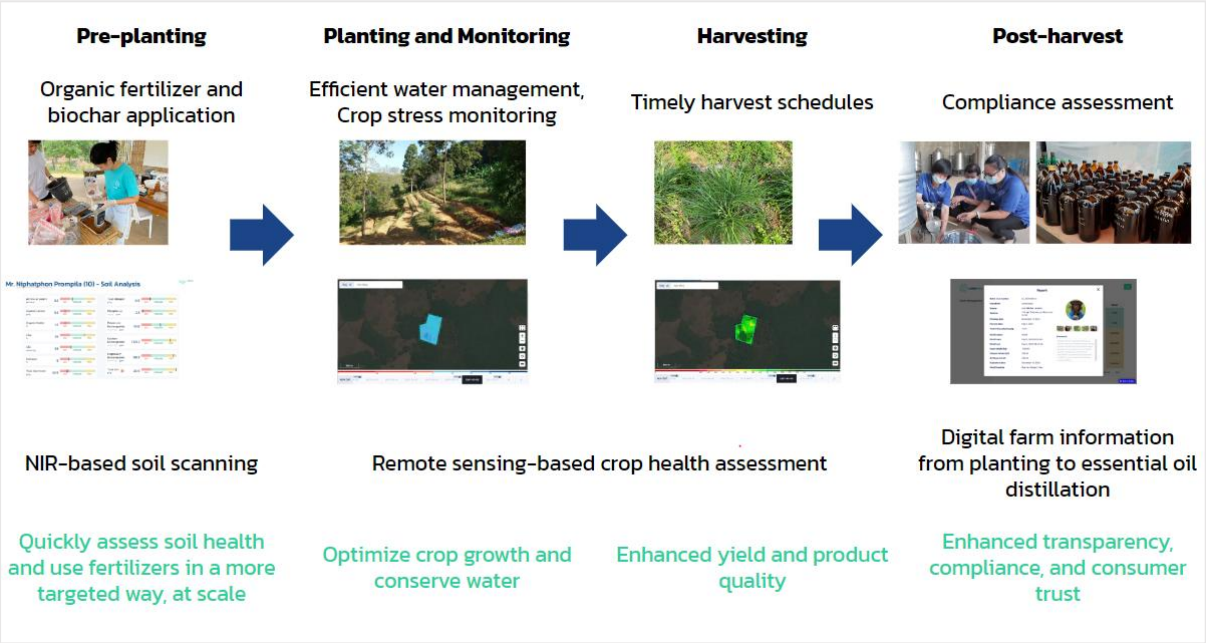
8.4.4 Technology Journey and Value Proposition

In this pilot project, FarmAI was able to demonstrate how it can help intensify the promotion of traceability and CSA practices by providing value in all stages of production, from pre-planting to post-harvesting.

Table 3:
Technology journey and value proposition of FarmAI at every stage of production demonstrated.

Production phase	CSA Practice	Enabler	Value
Pre-planting	Organic fertilizer and biochar application	NIR-based soil scanning	Quickly assess soil health and use fertilizers in a more targeted way, at scale
Planting and Monitoring	Efficient water management, Crop stress monitoring	Remote sensing-based crop health assessment	Optimize crop growth and conserve water
Harvesting	Timely harvesting		Enhanced yield and product quality
Post-harvest	Compliance assessment	Digital farm information from planting to essential oil distillation	Enhanced transparency, compliance, and consumer trust

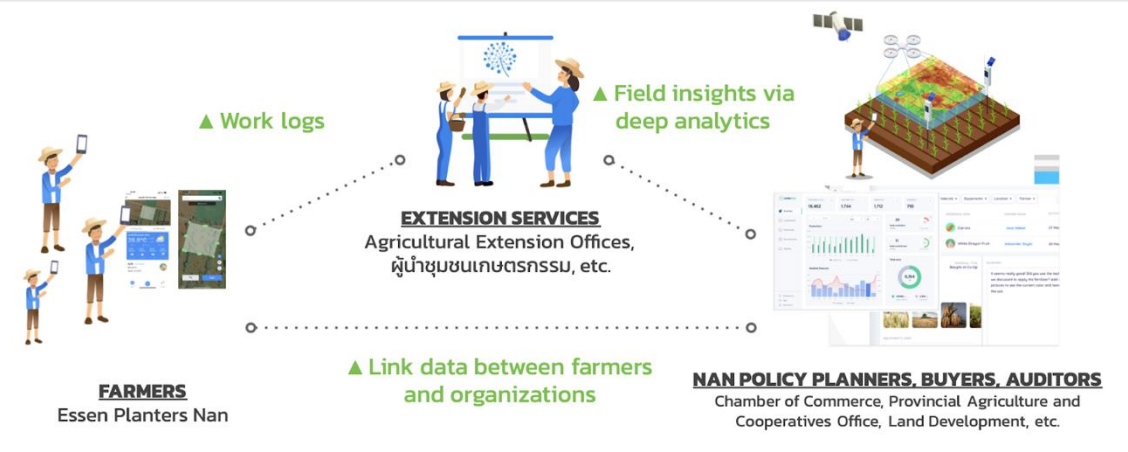
Figure 21:
How FarmAI Platform can intensify CSA practices in the highlands.



9. Way Forward

Achieving organic certifications in the highlands requires dedicated co-working between stakeholders and farmers – enhanced by digital tools for traceability. A substantial number of members of the target farmer enterprise have already registered their data in the digital platform, FarmAI, subject to monitoring for organic and safety certifications in the future.

Figure 22:
Organic certifications require active collaboration between stakeholders.



To ensure the success of this initiative, long-term engagement and an adaptive management approach are essential for effective data collection, adherence to organic practices, continuous improvement, and scaling to other regions. The next steps for this pilot and its potential scaling to other regions is explained below.

9.1 Pilot

Continue farm digitization: Continue the digitization process to gather a full cycle of data, enhancing understanding of farm operations and enabling stakeholders to offer more targeted and relevant advice.

Ongoing education and brand awareness: Continue to offer education and support to farmers to deepen their understanding of digital traceability and certification processes. At the same time, develop and execute strategies to enhance brand awareness and promote the benefits of certified products to consumers. For instance, farmers can increase visibility by joining organic online marketplaces like DGT Farm, which helps in reaching a broader audience and establishing market credibility.

Weather station turnover: Transfer the ownership of the weather station to the community, ensuring local control and sustained use.

Demonstrate effectiveness of digital platforms: Work closely with farmers, agricultural extension services, and buyers over multiple crop cycles to showcase the reliability and benefits of digital platforms for improving traceability and farm productivity.

(1) The District Agricultural Officer has expressed a strong desire for technology providers such as ListenField (LF) to collaborate with the government, specifically the Department of

Agricultural Extension. The government already possesses detailed information on farmers' plots, and they see significant value in the department purchasing the FarmAI dashboard tool. This tool would enable agricultural officers in each province to monitor farmers' plots more effectively. The technology could be made more practical to farmers by providing water management recommendations, drought risk identification, and enhanced plot management with the inclusion of quality recording distillation methods.

(2) Distillation factory users have found the digital platform beneficial in planning the herb harvest and coordinating oil extraction processes. They noted that providing soil preparation recommendations to farmers could significantly enhance the quality of essential oils. Additionally, users suggested the implementation of a reporting feature that summarizes batch production details, including the number of bottles produced and expected demand.

Integrate with QR Trace: FarmAI offers comprehensive data from crop cultivation to final product processing. Its interoperability allows seamless data integration with external systems via API. By integrating FarmAI's detailed information into QR Trace, users can have access to actual information on crops, soil conditions, microclimate, and cultivation practices. Deeper insights can be made into the environmental and social impacts of production, enhancing inspection, quality assurance, and accountability.

Figure 23:
FarmAI can complement QR Trace by providing detailed information on actual farming and processing methods.

Explore blockchain and AI-driven analytics: Explore the potential of blockchain for enhanced traceability and AI-driven predictive analytics for crop management. Blockchain's tamper-proof features ensure data authenticity, enhancing data privacy and consumer confidence. AI-driven predictive analytics can enhance crop management by suggesting optimal planting schedules, irrigation, and harvesting.

9.2 Scale Up

Pilot Evaluation and Results Communication: Analyze data and outcomes from the pilot to identify best practices and areas for improvement in terms of technology and partnership strategies. Organize workshops to share pilot program results and gather feedback from farmers, local authorities, and other stakeholders.

Training and Capacity Building: Develop comprehensive training programs to equip farmers and extension workers with the skills needed to adopt and utilize digital tools effectively. Continuous education will be essential for sustained success.

Partnership Expansion: Collaborate with larger-scale farmers trained for the sustainable production of high-value crops, aiming to improve their traceability, quality, and process efficiency

to meet international standards. Also work more closely with auditors and technology providers to discuss the possibility of creating a standardized certification process (e.g., Thai FDA or GMP) that can be applied to different regions or organizations.

Co-investment Models: Explore co-investments that incentivize climate-smart agriculture practices while supporting farmer livelihoods. This approach not only de-risks investment in digital solutions but also creates opportunities for local entrepreneurs and innovators to contribute to the farming sector in Nan, ultimately driving scalable impact.

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