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The development of crop data recording system using NFC technology and economic feasibility analysis

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Abstract

This research presents the development and evaluation of a system that integrates Near Field Communication (NFC) tags, a mobile application, and a cloud-based database, enabling real-time crop cultivation traceability through QR codes accessible to vegetable consumers. The system was tested in a hydroponic lettuce farm (10 plots, three planting cycles), where six cultivation activities were recorded and transmitted, with accuracy verified through 300 peer-to-peer transmissions per activity. User satisfaction was evaluated through surveys of 400 farmers and 400 consumers, while an investment analysis was performed on a 6 × 12 m hydroponic greenhouse (four units). The NFC-based system records and transmits data with an average precision of 98.7%. Both farmers and consumers expressed high satisfaction, particularly regarding convenience, durability, and data accuracy. When the selling price of vegetables cultivated with the proposed system was assumed to be 10% higher than that of conventional cultivation, the economic feasibility analysis indicated a payback period (PBP) of 3.84 years, a return on investment (ROI) of 130.09%, a net present value (NPV) of 5,076.07 THB, an internal rate of return (IRR) of 9.46%, and a benefit–cost ratio (BCR) of 1.005. NFC technology, therefore, enhances product credibility and can be regarded as a promising tool for advancing modern agricultural practices.

Keywords: NFC Technology, Economic feasibility, Hydroponic lettuce cultivation

1. Introduction

The collection of agricultural production data is a crucial aspect of precision farming that requires detailed and continuous recording throughout the crop cycle. Such data is essential for optimizing input management and enabling traceability, which has been shown to bolster consumer confidence in the quality and safety of agricultural products [1, 2]. Consequently, accurate and reliable information can enhance the market value of agricultural goods, enabling farmers to benefit from higher prices.

With the growing consumer awareness of food safety and health concerns, there is an increasing demand for transparency regarding agricultural production practices. RFID technology is widely used in agricultural supply chain management and food safety. A cost-effective digital system has even been reported that integrates IoT/RFID-based traceability and a blockchain solution to ensure data integrity, using Hungarian sweet potato production as a model [3]. Nevertheless, in practice, integrating RFID with smartphones is challenging, as it requires additional infrastructure, such as readers at farms and logistics sites. This increases costs and reduces usability, making RFID less practical for small-scale or family farms [4]. Similarly, Quick Response (QR) code technology has become a common tool for providing product information, allowing consumers to access production data directly via smartphones by scanning the code on agricultural products [5, 6]. Although QR codes are widely adopted in smartphone-based applications, traditional data collection processes often lack real-time accuracy, which limits their reliability.

Near Field Communication (NFC) is a technology that enables short-range radio communication, operating at a frequency of 13.56 MHz [7]. NFC chips are small, wireless devices that can transfer data up to a speed of 424 Kbit/sec, without requiring Internet connectivity or a built-in power source [8]. Due to their small size and low cost, NFC chips have gained widespread adoption. Smartphones, in particular, can read and write data to NFC chips. Smartphones connected to the internet can also relay this data to a central database. This simple process makes NFC a practical tool for daily use in various applications, such as payments, retail, transportation [9], and security systems [10]. In agriculture, NFC has been integrated into the Internet of Things (IoT) for farm management systems. Specifically, NFC tags are deployed across farms, working in conjunction with smartphone applications designed for various farm management functions. These applications facilitate efficient data handling within a unified smart farm database [4]. Food safety concerns have emphasized the importance of reliable traceability from farm to consumer. NFC technology provides a practical solution by recording data at each stage of the food supply chain and storing it in a cloud database accessible to consumers via smartphones, enhancing both traceability and production efficiency. The approach has been successfully demonstrated in the pork supply chain [11]. In poultry farming, similar systems combining NFC and QR code technologies has been developed, linking chicken information via NFC foot rings to QR-coded eggs. Based on a three-layer IoT architecture, these systems provide consumers with

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detailed breeding information and demonstrate high stability, indicating their potential for practical agricultural traceability [12]. In addition, livestock farming in Nigeria faces challenges from disease outbreaks, which has led to the development of IoT- and NFC-based systems that use sensors and GPS to monitor cattle health and location in real time. These systems are simple, affordable, and effective even on farms with limited network coverage [13].

Despite its growing popularity, the application of NFC for real-time data collection in agricultural fields remains challenging. The limitations involve tracking production processes, input management, and adherence to production standards throughout the crop cycle. Addressing these challenges is vital for ensuring consumer trust in agricultural products in modern farming systems.

This study aimed to develop an NFC-based agricultural data recording system that enables the tracking of key components such as plot location, planting dates, input usage, and cultivation processes. Data was recorded via a mobile application that connects to a centralized database. Throughout the growing season, the collected data was presented to consumers via a QR code on product packaging, allowing traceability of agricultural practices.

An economic feasibility study is crucial for investment as it evaluates the viability of the investment by analyzing anticipated costs and benefits [14]. Additionally, this study assessed the economic feasibility of implementing NFC technology in small-scale hydroponic vegetable farms, particularly considering the high initial investment required for such systems. Previous studies, such as Pason [15], analyzed the financial returns of off-season longan production in Chiang Mai and Lamphun, Thailand, using payback period (PBP), net present value (NPV), internal rate of return (IRR), and benefit cost ratio (BCR). Other studies on cost-benefit analysis in various agricultural ventures also provide a foundation for evaluating investment in NFC systems [16-18]. Namely, Sodawang et al. [16] explored the potential of cultivating melons in closed greenhouses, offering insights into modern horticultural techniques. Similarly, Sumritsakun [17] compared the costs and returns of growing basil under Good Agricultural Practices (GAP) and conventional farming methods. In another study, Anuruksakornkul et al. [18] investigated the investment in oil palm plantations located in highly suitable and less suitable zones in Chonburi Province, shedding light on regional agricultural investments. Chunud et al. [19] examined the costs and benefits of cultivating Cavendish bananas in Phitsanulok Province, while Keeyangrungreong et al. [20] analyzed the economic returns from mulberry cultivation for sericulture. Additionally, Suksard and Yangkirativorn [21] conducted a financial analysis of the returns from establishing Acacia plantations at the Saithong Silvicultural Research Station, Prachuap Khiri Khan, Thailand.

However, to date, no studies clearly demonstrated the financial viability of NFC technology in hydroponic farming. Therefore, this research sought to analyze the potential financial returns of using NFC tags in small-scale hydroponic vegetable farms, providing valuable insights for farmers considering such investments.

2. Materials and methods

2.1 Development of NFC electronic tags, mobile application, and database system

The development of the plant cultivation data recording system utilizing NFC technology consisted of three main components: an NFC tag, a mobile application, and a database system (cloud-based).

An NFC tag — The selected NFC tags operated on a 13.56 MHz frequency, following the ISO/IEC 18000-3 standard. These tags supported data transfer rates ranging from 106 kbit/s to 424 kbit/s and utilize a peer-to-peer mode that enables direct communication between NFC-enabled devices for ad hoc data exchange. The NFC tags, with a diameter of 25 mm, were attached to plastic tags measuring 9.0 cm by 10.0 cm. Each NFC tag underwent a verification process. This process assigned an IP address, name, code, and attributes using the NFC tools application, resulting in 30 verified tags.

A mobile application — The mobile application was developed for the Android operating system with a user interface designed for ease of use and accessibility based on principles of human-computer interaction. The application interface utilized icon-based buttons representing 6 farm activities, including planting, watering, weeding, fertilization, hormone application, and harvesting. In addition, the application incorporated GPS technology to track and verify the NFC tags' locations [22]. The application was developed using the Kotlin programming language that allows for cross-platform functionality, with a focus on Android as the primary target operating system. The application retrieved latitude/longitude coordinates, NFC tag codes, and timestamps from the Android system, transmitting this data to a centralized database.

A database system — A cloud-based database system was designed to systematically store data for each tag and generate a QR code that links to the corresponding tag's data. The backend system was developed using PHP and MySQL. Communication between the mobile application and the database was established via a RESTful API. In handling large volumes of data, the PHP framework was customized to support up to 2,000 connections per second. This setting allowed the system to efficiently process multiple simultaneous NFC tag scans. All three components were interconnected through a 3G or 4G cellular network. Figure 1 is a diagram illustrating the NFC-based plant data recording system.

Figure 1 Workflow of plant cultivation data recording using NFC tags and traceability of agricultural products.

A mobile application was developed to read NFC tags and retrieve latitude/longitude coordinates, farmer identification, and user-recorded text or images. The retrieved data were transmitted to a cloud server, as illustrated in Figure 2. The server employed MySQL for data storage, and communication between the application and server was established via a RESTful API. All requests and responses were transmitted over HTTP, with data formatted in JSON.

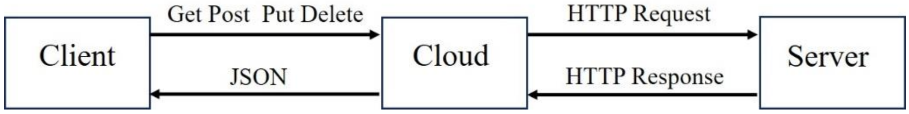


Figure 2 Client–cloud–server architecture for mobile application data communication using RESTful API and JSON.

After completion of the cultivation process (post-harvest), the system generated a QR code linked to the corresponding NFC tag data. The QR code was provided to farmers for attachment to the products, enabling consumers to trace the production process.

2.2 Data recording and transmission accuracy testing with NFC tags

To evaluate the system, NFC tags were installed in 28 hydroponic vegetable plots, each measuring 4 × 12 m, at Thawanya Farm in Lamphun, Thailand. Data recording spanned three planting cycles. Using the mobile application, we documented six farm activities, including planting, watering, weeding, fertilization, hormone application, and harvesting. Data transmission testing involved 300 peer-to-peer (P2P) transmissions for each activity. The precision of data transfer was assessed using the following equation:

$$\%\, precision = \left(\frac{successfully\ transmitted\ data}{total\ transmitted\ data}\right) x\ 100 \quad (1)$$

To log data, users selected the desired farm activity in the mobile application, tapped their smartphone against the NFC tag, and recorded data in two formats – text descriptions and photos of farm activities. After submission, the data was sent to the centralized database. The accuracy of data recording was verified by checking the corresponding tag's information that was made accessible through a QR code unique to each tag. The QR code, attached to the product packaging, allowed consumers to retrieve detailed information about the farming activities, including farmer details, timestamps, location, and photographs of the cultivation processes.

In terms of testing conditions, the average operational distance between the smartphone and the NFC tag was approximately 4–5 cm. The hydroponic greenhouse at the study site was of an open type, without insect nets or protective side walls. Data recording was performed using a Samsung A73 smartphone operating on the Android platform. Farm activities were logged at an average frequency of 3–5 days per week, depending on actual farm operations.

2.3 Satisfaction analysis of NFC electronic tag usage

The satisfaction analysis was conducted with two sample groups. In the first group, five organic or GAP-certified vegetable farmers were selected to evaluate the usability of the cultivation process recording system using targeted questions. The second consisted of vegetable consumers, who assessed satisfaction with the system's display of cultivation data, with emphasis on ease of access and transparency. The sample size for each group was determined using the infinite population formula [23] with a 95% confidence level and a 5% margin of error, resulting in 400 respondents per group. Farmers tested the system during a 60-day hydroponic lettuce cultivation cycle, while consumers evaluated packaged hydroponic lettuce with QR codes attached and distributed at fresh markets in Chiang Mai Province.

Data collection was carried out through structured questionnaires administered via Google Forms. The questionnaire for farmers included (i) demographic information, (ii) satisfaction with usability and system reliability, and (iii) open-ended suggestions for improvement. The questionnaire for consumers consisted of (i) demographic information, (ii) perceptions of hydroponic vegetables, and (iii) satisfaction with the traceability information displayed through QR codes. Responses were measured using a five-point Likert scale, where higher scores indicated greater levels of satisfaction.

2.4 Investment analysis of NFC technology in hydroponic farming

The investment analysis consisted of three main steps. 1) Estimation of net investment – this step involved calculating the initial setup cost and subsequent operational costs for the NFC system in hydroponic farming. 2) Estimation of investment returns – projected financial returns from the implementation of NFC technology were evaluated based on increased efficiency and traceability in the farming process. 3) Investment evaluation – the overall viability of the investment was assessed using financial tools. A purposive sampling method was used to select a hydroponic farm owner for an in-depth interview. The interview was structured into four parts. 1) General information included demographic details such as gender, age, occupation, education level, and household income. 2) Production costs and initial investment collected information on the costs associated with starting and maintaining the hydroponic farm. 3) Returns from hydroponic vegetable farming documented the farm's revenue and sales channels for the produce. 4) Challenges and suggestions addressed problems encountered during the use of NFC technology and other potential improvements.

The cost-benefit analysis compared the initial investment, fixed costs, and variable costs against the projected returns using financial tools. The analysis used both time-insensitive and time-sensitive financial metrics. These metrics included payback period (PBP) – the period required for the investment to recoup its initial cost, return on investment (ROI) – the percentage return generated from the investment, net present value (NPV) – the difference between the present value of cash inflows and outflows, internal rate of return (IRR) – the discount rate that makes the NPV of an investment zero, and benefit-cost ratio (BCR) – the ratio of benefits to costs, indicating the overall profitability of the investment. Table 1 outlines the decision criteria used for evaluating the investment [24].

Table 1 Investment decision criteria using financial tools.

Financial Tool	Criteria	Decision Recommendation
PBP	PBP < 5 years	Suitable for investment
ROI	ROI > 100%	Suitable for investment
NPV	NPV > 0	Suitable for investment
IRR	IRR > interest rate	Suitable for investment
BCR	BCR > 1	Suitable for investment

Information retrieved from Apisitpinyo [24].

3. Results

3.1 NFC tag development, mobile application, and data transmission accuracy

The NFC tags used in this study operate at a frequency of 13.56 MHz, with a diameter of 25 mm, and are affixed to plastic tags measuring 9.0 × 10.0 cm. The tags were covered with water-resistant PVC stickers, making them suitable for outdoor use in vegetable plots. This design allows for durable, long-term application in various weather conditions, particularly in outdoor hydroponic farming systems.

The mobile application, named “MJU Vegetable,” was developed for the Android operating system. The application was designed with two main components – the mobile application and an online web application.

The mobile application (mobile app) was developed with an emphasis on user experience (UX), ensuring ease of use, with an intuitive user interface (UI). The application's home screen features primary buttons that allow users to record six specific farming activities, including planting, watering, weeding, fertilizing, nutrient application, and harvesting. Upon selecting an activity, the application enables real-time recording of NFC tag data, including geographic coordinates (Lat/Long) and timestamps. Additionally, users can take up to three real-time photographs of the activity and input text descriptions before submitting the data to the central database. The design is user-friendly; it reduces complexity, prompting users to record farming data straightforwardly and consistently.

The performance evaluation of the mobile application showed that data exchange between the smartphone and NFC tags occurred rapidly and accurately within a testing 5-cm proximity. The precision of data transmission was calculated using 300 trials per farming activity. The average percentage of precision (% precision) for successful data transmission was 98.7%, indicating high reliability in the communication between the NFC tags and the mobile app. This high accuracy ensures that the data recorded by farmers is consistently transmitted to the cloud database without significant loss or errors.

The second component, the web application (web app), is a front-end system designed for consumers. After scanning a QR code on vegetable packaging, the system directed users to the API endpoint of the corresponding farming data stored in the cloud database. The web app provided a summary of the farming activities, displaying essential details such as farmer information, plot details, tag coordinates, and an ordered timeline of farming activities, including the final harvesting process. The web app successfully presented an easy-to-navigate interface that facilitated traceability, which increased consumer confidence in the product's origin and farming practices. The system, as shown in Figures 3 and 4, highlighted the seamless integration of NFC technology with modern agricultural traceability systems. This high level of data precision and user engagement demonstrated the feasibility and efficiency of integrating NFC technology in agricultural systems, particularly for enhancing traceability and operational recording.

Figure 3 Mobile application interface

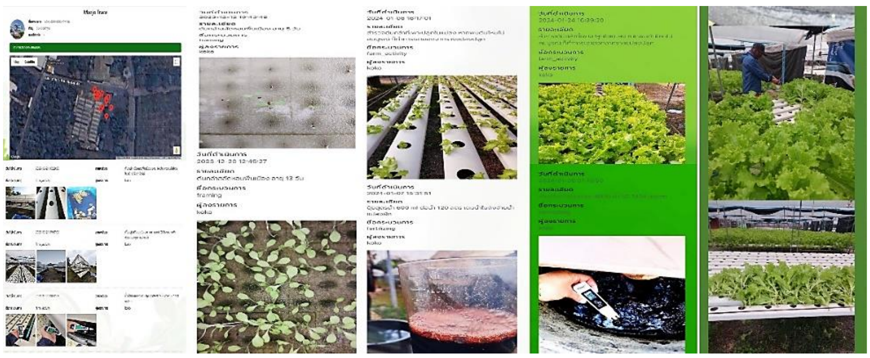


Figure 4 Data display via web application

The database system was designed to sort the NFC tag IP column in ascending order, allowing the recording of various farming activities. The system organized the data records (rows) based on the date and time of the activities, ensuring chronological order. Access to the database was restricted to a single system administrator. In this fashion, farmers using the NFC tags cannot directly access the database. However, the system allowed the creation of a QR code linked to the real-time API address of the data for each tag, facilitating dynamic data sharing with consumers through the web application. This functionality enhanced data security (farmers could not alter submitted data) while providing transparency and traceability to the end-user.

3.2 User satisfaction analysis of NFC electronic tags

A total of 400 users participated in the satisfaction survey regarding the usage of NFC electronic tags and the mobile application for recording farming activities. The analysis revealed three main satisfaction areas related to the NFC tags. First, the average satisfaction index for the size of the tag was 4.4, indicating a high level of user approval regarding the dimensions of the tag. Second, the average satisfaction index for ease of use was 4.2, suggesting that the majority of users found the system user-friendly and straightforward. And third, the average satisfaction index for the durability of the NFC tags was 4.5, indicating strong user satisfaction with the physical robustness of the tags in outdoor farming environments. These results highlighted the effectiveness of the NFC technology in providing a practical, durable, and user-friendly tool for farmers, as shown in Figure 5.

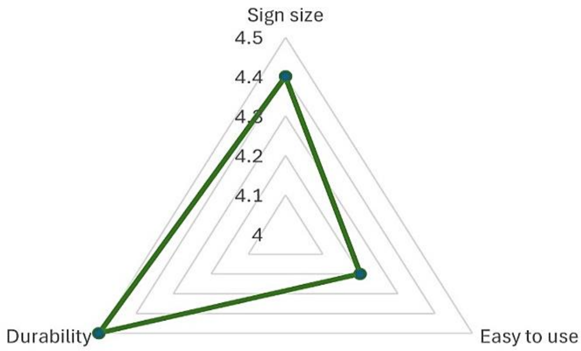
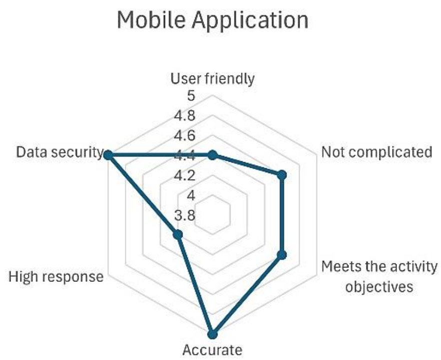


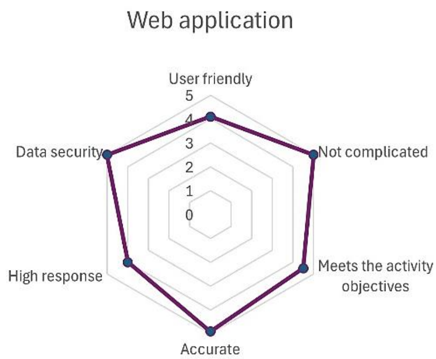
Figure 5 User satisfaction analysis of NFC electronic tags

3.3 User satisfaction analysis of the mobile application for recording farming activities and the web application for agricultural product traceability

In the mobile application part, the average satisfaction index for user-friendliness was 4.4, indicating that users found the mobile app easy to navigate and use. The average satisfaction index for the "not-complicated" aspect was 4.6, showing that users felt the app was straightforward and simple to use. The average satisfaction index "meets the activity objectives" was 4.6, reflecting the users' approval that the app effectively met its intended goals. The mobile application received an average satisfaction index of 5.0 on accuracy, indicating that users were highly satisfied with the accuracy of the recorded data. The average satisfaction index for "high response" was 4.2, suggesting that the app performed well in terms of responsiveness. The mobile app received an average satisfaction index of 5.0 for data security, demonstrating strong user confidence in the security measures implemented. These results are presented in Figure 6(a).



(a)



(b)

Figure 6 User satisfaction analysis of the mobile application for recording farming activities and the web application for agricultural product traceability. (a) mobile application; (b) web application

In the web application part, the average satisfaction index for user-friendliness was 4.1, indicating that the web application was generally user-friendly, though slightly less so compared to the mobile app. The average satisfaction index for the "not complicated" aspect was 5.0. The web application scored an average satisfaction index of 4.5, showing that it effectively supported users in tracking agricultural activities. The average satisfaction index for accuracy was 4.9, reflecting the users' satisfaction with the correctness of the data provided. The average satisfaction index for response time was 4.0, indicating that while the web app performed well, there may be minor improvements needed in terms of responsiveness. Like the mobile app, the web application also scored an average satisfaction index of 5.0 for data security, signaling a high level of trust in the system's security features. These results are presented in Figure 6(b).

3.4 Economic feasibility analysis of investment in vegetable farming using NFC technology

The financial feasibility of investing in vegetable farming using NFC technology in a 6 x 12-meter greenhouse, with four greenhouses per growing cycle on a 1,064 m² area, was analyzed. Table 2 summarized the analysis results. The farming system could complete six growing cycles per year, each lasting 60 days. A discount rate of 7% per annum, which reflects the interest rate on loans from the Bank for Agriculture and Agricultural Cooperatives (BAAC), was applied. Labor costs were calculated based on the minimum wage in Lamphun Province for the year 2024. The selling price of vegetables is influenced by market demand and supply dynamics. In this study, the average selling price was derived from data obtained at Talaad Thai, the central wholesale market for fruits and vegetables in Pathum Thani Province, during the year 2020–2024, with an average of 63.67 baht per kilogram. For greenhouse-grown vegetables with NFC tag application, the price was approximately 10% higher than that of conventional vegetables. This finding is consistent with the results of a consumer market survey conducted in Chiang Mai Province with a sample of 400 respondents.

Initial investment costs, excluding land, were shown in Table 2, with the understanding that depreciation of machinery and equipment was not included in the operational costs for each year. As such, only fixed costs, such as loan interest, were considered ongoing. The operational costs included NFC technology, seedling kits, seeds, fertilizers, herb-based insect repellents, vegetable baskets, labor costs for primary and harvesting labor, and other operational expenses. The project's returns were income generated by vegetable sales.

Table 2 Operational costs per one growing cycle for cultivation using NFC technology on a 1,064 m² area.

Operational cost	Price/unit (THB)	Unit	MTBF (Year)	Total value (THB)
- Fixed cost				
1. Greenhouse	10 ,000	4	5	40,000
2. Plant cultivation equipment system	9,000	4	5	36,000
Total fixed cost				**76,000**
- Variable cost				
1. NFC Tags	210	1	1	210
2. Seed	85	0.33	1	28.05
3. Seedling tray	1,113	4	1	4,452
4. Fertilizer	35	2	1	70
5. Wood Vinegar	20	2	1	40
6. Vegetable basket	210	6	1	1,260
7. Labor	20,580	1	1	20,580
8. Labor for harvesting	343	1	1	343
9. Miscellaneous				1,000
Total variable cost				**27,983.05**
Total cost				**103,983.05**

In the case of the project securing a loan of 200,000 THB with a 7% annual interest rate, where principal and interest are paid equally each period, the following assumptions were made: initial investment in the first year, fixed annual costs, and variable costs for each year. The expected vegetable yield from four greenhouses was approximately 560 kilograms per growing cycle. The average selling price of lettuce over the last five years was 63.67 THB per kilogram. It was expected that using NFC technology would increase the sales price by at least 10% compared to vegetables grown without NFC technology, as supported by the aforementioned survey results.

The project's cash flow for each year was shown in Table 3, and the investment analysis was presented in Table 4. Based on the analysis, cultivating lettuce together with using NFC technology in four greenhouses, with six growing cycles per year, would be economically viable if the selling price of vegetables was at least 10% higher than the standard price of 63.67 THB per kilogram.

Table 3 Initial cost, fixed cost, variable cost, total revenue and net profit from the 5-year project of hydroponic lettuce cultivation using NFC technology in 6 x 12-meter greenhouses, with 4 greenhouses per planting cycle, allows for 6 planting cycles per year, each lasting 60 days.

Year	Initial cost (baht)	Fixed cost (baht/yr)	Variable cost (baht/yr)	Total revenue (baht/yr)	Net profit (baht/yr)	Accom. net profit (baht/yr)
0	76,000			-	(76,000)	(76,000.00)
1		47,640	167,898.30	235,312.00	19,773.70	(56,226.30)
2		47,640	167,898.30	235,312.00	19,773.70	(36,452.60)
3		47,640	167,898.30	235,312.00	19,773.70	(16,678.90)
4		47,640	167,898.30	235,312.00	19,773.70	3,094.80
5		47,640	167,898.30	235,312.00	19,773.70	22,868.50

Table 4 Economic feasibility analysis of hydroponic lettuce cultivation using NFC technology in 6 x 12-meter greenhouses, with 4 greenhouses per planting cycle, allows for 6 planting cycles per year, each lasting 60 days.

Financial indices	Results	The investment decision recommendation
PBP	3.84 years	The investment will be recouped in less than 5 years, making it a suitable investment
ROI	130.09 %	An ROI greater than 100% suggests that the investment is highly profitable.
NPV	5,076.07 baht	An NPV greater than 0 is considered favorable, indicating that the project is financially viable.
IRR	9.46 %	The IRR exceeds the interest rate, the project offers a good return on investment.
BCR	1.005	A B/C ratio greater than 1 indicates that the benefits outweigh the costs, supporting the investment decision.

4. Discussion

Currently, consumer health concerns have led to a growing preference for agricultural products with traceable production processes. Such traceability enhances confidence and transparency in product information, thereby increasing the value of agricultural products while supporting brand management and improving logistics efficiency. This study established a crop cultivation data recording system using NFC technology, a mobile application, and a cloud database that facilitates traceability using QR code.

The application of the NFC technology to agricultural product traceability is a novel concept. The NFC technology for the cultivation process recording system is regarded as highly secure, simple to use directly through mobile applications, convenient, and cost-effective when compared to other wireless data recording technologies. NFC technology has the advantage of being able to identify objects using radio-frequency waves [5]. The system records farm production data, including farmer information, farm location, source, harvest date, and cultivation practices, through NFC tags attached to plots or products, which farmers can update directly via a mobile application. In contrast, RFID-based systems, such as that described by Li et al. [2], require a computer connected to a data writer to record information onto the tag, which makes it impossible to log farming activities or processes at the actual plot in real time. Reading the data also requires a separate RFID reader, as mobile or smart devices cannot directly access the tag information. Divya et al. [25] also reported that using RFID in agriculture requires farmers to have special tools and technical skills to manage and analyze the data. In addition, building the necessary infrastructure, such as communication networks and data storage systems, can be very costly, especially for small-scale farmers. Although RFID has been combined with blockchain in China to improve food supply chain traceability [26], its reliance on specialized equipment still limits its practical use in agriculture.

Besides RFID, data recording has also been implemented using QR codes. Sriyom and Buangam [27] demonstrated that information such as cultivation practices, farmer details, crop growth, harvesting time, and product distribution can be accessed through QR code scanning. QR codes are inexpensive and convenient for mobile use but raise concerns regarding data security. IoT devices combined with blockchain have also been applied in agricultural traceability systems in Thailand. For instance, Surasak et al. [28] employed Raspberry Pi devices to monitor temperature, humidity, and location in refrigerated containers, with real-time tracking via the Google Maps API. However, most IoT applications focus on recording environmental conditions, and their relatively high cost compared with QR codes and RFID limits adoption among small-scale farmers.

NFC tags are battery-free chips [8]. In this study, they were embedded in plastic tags and sealed with waterproof PVC stickers to resist water, moisture, and dirt. Field tests in farmers' vegetable plots confirmed stable performance for more than three years, with communication reliability exceeding 98% under internet-connected conditions. The system demonstrated the advantages of NFC technology, which is simple, low-cost, and directly operable via NFC-enabled smartphones, making it suitable for smallholder farmers. The database can also integrate with blockchain to enhance security and transparency. However, this preliminary study, limited to 10 plots, 30 NFC tags, and three planting cycles, restricts the generalizability and long-term performance assessment. Broader testing with more plots, tags, and extended cycles is required to validate the results.

Future development could integrate NFC with IoT sensors to capture environmental parameters such as temperature, humidity, and nutrient levels. Although the present work focused on reliable consumer information without IoT or AI analysis, combining NFC, IoT, and AI has strong potential to create an intelligent cultivation platform for real-time monitoring, predictive analysis, and improved transparency in agricultural production.

The economic feasibility analysis of this research aligned with the use of financial analysis tools such as IRR and NPV, similar to previous studies [18]. However, this research differed from the other previous studies by integrating technology with smart agriculture, which enhances product quality and competitiveness. The key difference was the inclusion of the production process with marketing strategies, using NFC data as a tool to build consumer trust. This integration helped boost the ROI and reduce investment risks.

A related study by Sodawang et al. [16] analyzed the economic feasibility of melon cultivation in closed greenhouses, focusing on financial tools such as PBP and ROI. While similar in financial evaluation, this research emphasized the added value of NFC technology in traceability. This suggested that NFC has a greater potential in marketing and qualitative value addition compared to traditional methods.

Furthermore, this research builded on the concept of enhancing production efficiency and product quality, as seen in the study by Sumritsakun [17], which compared the costs and returns of basil and mint cultivation under Good Agricultural Practices (GAP) and conventional methods. The findings indicated that while GAP had higher operational costs, it resulted in better returns. This research echoed these findings by demonstrating that the use of NFC technology provided a faster PBP and higher ROI, which better addressed the needs of both farmers and consumers. Thus, vegetable cultivation with the NFC system serves a more effective and profitable investment.

5. Conclusions

The developed NFC usage, consisting of NFC tags with a diameter of 25 mm operating at a frequency of 13.56 MHz, supported the recording of data on up to 30 tags. The database system handled up to 2,000 scans/second via smartphones connected to the cloud. Consumers could access production traceability through QR codes on the products, which enhanced the value of agricultural products by providing traceability and ensuring the quality and safety of the produce. This system met the growing consumer demand for transparency and quality in the modern market. The economic feasibility analysis of hydroponic lettuce cultivation in 6 x 12-meter greenhouses, with four greenhouses per planting cycle, revealed that the NFC technology application could increase the price of lettuce by at least 10% compared to traditionally grown produce. The financial analysis indicated a payback period (PBP) of 3.84 years, a return on investment (ROI) of 130.09%, a net present value (NPV) of 5,076.07 THB, an internal rate of return (IRR) of 9.46%, and a benefit–cost ratio (BCR) of 1.005. These findings demonstrated that NFC technology provides a viable means for modern agriculture. It could contribute not only to improved productivity but also to building consumer trust and ensuring product safety and quality.

6. Acknowledgements

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7. References

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