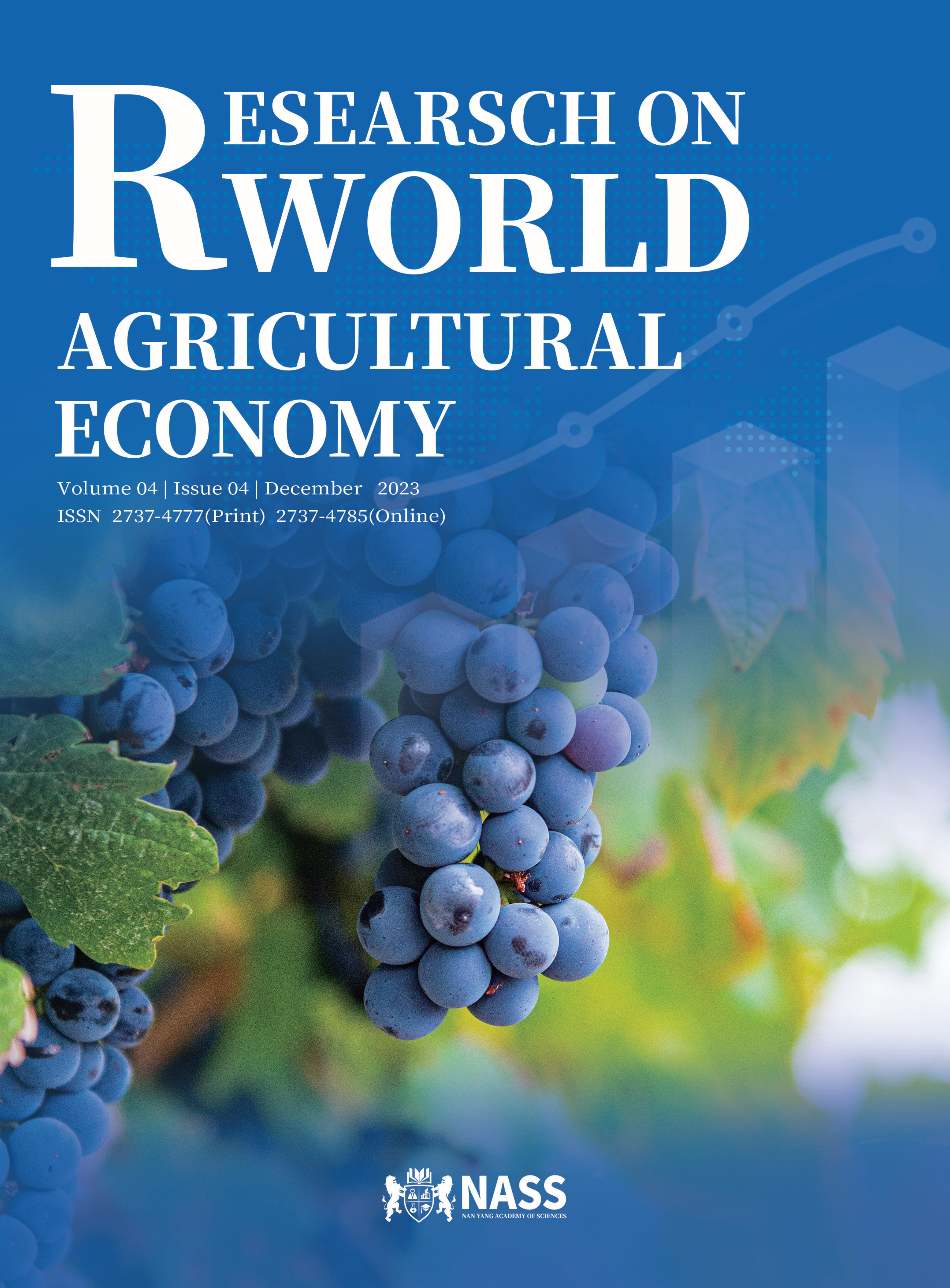

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RESEARCH ARTICLE

Mapping the Coffee Value Chain in Lao PDR: Issues, Insights, and Strategies

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Abstract: Coffee is a major agricultural export product that generates foreign currency for Lao PDR. While several studies have been conducted on coffee in Lao PDR, none have focused on the value chain. This research seeks to fill that gap by analyzing the coffee value chain in Laos. The study uses both quantitative and qualitative methods, such as interviews, value chain mapping, and value-added estimation, to examine the structure, roles, activities, and performance of the value chain actors. The study finds that coffee farmers have the highest value-added, but they are facing various issues of pests and disease, low productivity, and limited access to finance. Laos has a high export potential for coffee, especially to European markets, but also faces constraints such as limited market access, transportation costs, and non-tariff measures. The study provides recommendations for improving the coffee value chain in Laos, such as strengthening farmer groups and cooperatives, enhancing quality and certification standards, and diversifying markets and products.

Keywords: Value chain; Export potential; Non-tariff measures

1. Introduction

Coffee is one of the significant agricultural production and exports of the Lao PDR. It is the third largest agricultural export product for Laos following cassava and banana, which the main export country is China. Coffee is the dominant farming system on the Bolaven Plateau, known by volcanic fields in the southern part of the Lao PDR. This area covers about 500 sq. km, ranging across altitudes of 600 to 1,300 meters above sea level, at about latitude 15°North, and produces about 80% of Laos cof-

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fee.

The Ministry of Agriculture and Forestry (MAF) aims to increase coffee production to 280,000 tons by 2025 and improve quality along the value chain [1]. To meet the goals, many activities must be improved. Coffee producers must expand the plantation area and production. Production groups should be established in many areas. Market price should be determined among the middlemen. The government should negotiate with trading partners for export quota and remove Non-Tariff Measures (NTM) for coffee export.

Little research has discussed the agriculture value chain in the Lao PDR [2-4]. Some research focuses on coffee production and export [5-7]. The value chain analysis includes quantitative and qualitative approaches which qualitative method is suggested to be used prior to the quantitative one [8]. According to Boehlje [9], there are six dimensions for value chain analysis: processes; product flow; financial flow; information flow; incentive systems; and governance. The value chain analysis is helpful in studying the industry, particularly the supply-side constraints. As in most research utilizing value chain analysis, progressive policies, and effective interventions, especially by the government, were indicated as necessary in addressing issues faced by the industry [10]. In Kaplinsky and Morris's study [11], Value chain analysis addresses the weaknesses of traditional analysis, which tends to be static and limited in identifying factors for success Value chain analysis focuses on the dynamics of complex linkages within a network.

The agricultural commodity value chain was primarily used in developing countries for agricultural development areas. It is found that value chain analysis is a tool for improving productivity, competitiveness, and business performance in general, especially for SMEs. Furthermore, the study by Kanhgile et al. [12], highlights that there is a gender imbalance in the coffee value chain in Tanzania but, gender equality empowerment in accessing land and credit and offering trade facilitation services will help to reduce the gender gap. Salam M., et al. [13] analyze the coffee value chain in Toraja, Indonesia using the qualitative method to identify total cost, revenue and margin in each actor. The result shows that house whole processing industry and collectors who sell coffee outside the district have the highest margin while the main issues are farmers' limitation of capital, knowledge, cultivation, and management skills.

There are few studies on the agricultural products value chain in Laos including the coffee value chain. The study on the commercialization of the rice and vegetable value chain found that low farm productivity causes high consumer prices for both rice and vegetables [4]. Specifically, the profit of rice is high, but the transaction cost affects the margin. While the price of coffee at the farm-gate of vegetables is low, the low-value chain management skill, marketing management system, as well as wet market management, causes high consumer price for vegetables.

The value chain of strategic sectors of Lao PDR including rice, coffee, maize, livestock, and wood furniture showed growth potential and market structure. Household participation in the agricultural products value chain can improve household income and well-being. The study of the coffee market in Laos shows that coffee production is threatened by cassava plantations, market access barriers, low labor efficiency, and climate change [7].

Understanding the value chain of coffee would help the Laos government to develop policies supporting actors, especially smallholders of the value chain. This research aims to address some questions as follows: (1) what is the structure of the coffee value chain, (2) what the roles and activities of actors are, (3) what are value added of each actor, and (4) what are the issues and challenges for the coffee value chain. The overall objective of this research is to analyze the coffee value chain in the Lao PDR. The specific objectives are to analyze the coffee value chain's structure, explain the roles and activities of members, and estimate the value added by each member.

2. Materials and Methods

In order to achieve the objectives data collection and data analysis are identified as the following. Five different sets of interview guides were developed for key stakeholders in the coffee value chain, including producers, collectors, production groups, exporters, processing factories, and coffee shops. The main questions in the interview guides were about the respondent's characteristics, activities, production costs, revenue, and main problems and challenges.

A total of 26 interviews were conducted, including 8 farmers, 4 collectors, 2 cooperatives, 4 production groups, 2 exporting companies, 2 processing companies, and 4 coffee shops. The interviews were conducted in Champasak province from January to February 2023. In addition to the interviews with key stakeholders, the Department of Industry and Commerce, the Department of Agriculture and Forestry, the Department of Public Works and Transportation, and the Laos Coffee Association were also interviewed to identify policies that support the coffee value chain.

This study applies the Export Potential Indicator (EPI) developed by Decreux & Spies in 2016 to identify the potential export value for any exporter in each product and target market based on an economic model that combines the exporter's supply, the target market's demand, market access conditions, and bilateral linkages between the two countries [14]. The method calculates potential trade values based on a country's projected share in a given market and the market's projected demand.

$$EPI_{ijk} = \frac{x_{ik}}{x_k} \frac{x_{ij}}{\sum_k \left(\frac{x_{ik}}{x_k} m_{jk}\right)} m_{jk} \tag{1}$$

where EPI_{ijk} is export potential indicator of country i to country j on product k. x_k is export of country i on product k. x_k is the world export of product k. x_{ij} is total export from country i to country j. m_{jk} is import of country j on product k. A theoretical model of EPI consists of three components. Supply, $\frac{x_{ik}}{x_k}$, which is exporter i's world market share in product k. Demand, m_{jk}, is market j's imports of product k. Ease of trade, $\frac{x_{ij}}{\sum_k \left(\frac{x_{ik}}{x_k} m_{jk}\right)}$, bilateral trade divided by hypothetical trade.

A higher EPI indicates a higher potential for exporting more products. In other words, the exporting country can either expand its production or negotiate with trade-importing countries to reduce trade barriers. The difference between the EPI and the actual trade shows the unexplored export potential that can be realized by promoting targeted trade. This can be achieved by helping firms overcome non-tariff measures, meet the rules of origin or adapt to consumer preferences in the target market. By comparing the unexplored potential with potential trade losses, Lao PDR can prioritize either negotiating better tariff regimes or trade promotion strategies [14].

Three parts of the analysing value chain include a value chain map and value-added. Data from the interviews is used to draw a value chain map and identify the activities of each member. SWOT analysis is applied to the coffee value chain.

Total production value, intermediate input, and consumption of fixed capital are three items to estimate the value added. Total production value is estimated by net production multiplied by price per unit. The cost of intermediate inputs is obtained by pricing items at their purchase prices that prevail when they enter the process of production [15]. For example, intermediate production costs of farmers include seeds, pesticides, and fertilizer. The consumption of fixed capital is determined from the depreciation of equipment, machinery, vehicles, and buildings and structures.

3. Results

3.1 Coffee Export Potential

Laos coffee production contributes to job creation and income generation. There is a promising market opportunity for the Lao coffee sector, as the local and export market for coffee is increasing. In 2019, coffee production was 171,380 tons; however, coffee production reduced to 158,190 tons in 2020 and 161,200 tons in 2021. However, coffee exports increased from USD 6.43 million in 2019 to USD 8.99 million in 2021 due to the increase in the world market price.

Lao PDR mainly exports coffee to the ASEAN market. In 2021, Lao PDR exported coffee to Vietnam amounting to approximately USD 48.20 million. Total exports of coffee from Lao PDR to ASEAN amounted to approximately USD 20 million, including Thailand for approximately USD 14 million, Cambodia for USD 5 million, and Singapore for USD 0.03 million [16]. The export of coffee to the EU market under GSP amounted to USD 11.39 million. Belgium imports coffee from Lao PDR worth approximately USD 5.92 million while Germany imports approximately USD 3.1 million. Under the GSP, Japan and the USA also import coffee from Lao PDR amounting to USD 2.67 million and USD 1.22 million, respectively [17].

Table 1. Export potential of Laos coffee.

Unit: million USD

Country	Export potential	Actual export	Unrealized potential
Germany	27.0	8.1	19
Vietnam	21.0	49.0	0
Thailand	14.0	12.0	3.1
Sweden	8.7	0.5	8.2
Japan	6.6	8.4	0.04
Belgium	5.9	8.1	0.01
United States	4.7	2.1	2.6
Italy	3.3	1.2	2
China	2.7	0.98	1.8
France	2.2	1.9	0.22
World	116	103	54

Source: Export potential map, 2023.

Table 1 shows the export potential of Laos coffee. Lao PDR has an export potential of approximately USD 116 million while the actual export of coffee is USD 103 million. The unrealized export potential is USD 54 million which means Lao PDR has the capacity to export more coffee if there is a demand from a market. Lao PDR has the highest export potential to export to Germany, but the actual export of coffee is worth only USD 8.1 million. There is a huge potential to export coffee to Germany. Unrealized export potential for coffee is relatively high in Thailand, Sweden, and USA. However, Lao PDR has actual export more than export potential in Vietnam, Japan, and Belgium which means Lao PDR uses its full potential to export to these countries. In other words, it is difficult to export coffee to these markets.

3.2 Value Chain Map

The key members of the coffee value chain include farmers, collectors, coffee producers/cooperatives, processing companies, retail shops, coffee shops, and exporting companies (See Figure 1).

The roles and activities of each member are explained as follows. Coffee producers are individual farmers, farmer groups, and large-scale commercial coffee producers who were set up by foreign investors. Most coffee producers are smallholder farmers.

Coffee plantation starts by preparing the seed or buying from other farmers. Before plantations, farmers cleared their land using tractors. It takes an average of three years to get a coffee cherry. Farmers must clear grass 1-2 times per year and add fertilizers. The coffee harvest season is from October to February. Picking coffee cherry uses a lot of time and labor. Farmers must collect 15,000 cherries to get one pound of coffee. Many of them have insufficient labor; therefore, they hire other farmers or laborers to collect coffee. Most of the farmers sell red cherries to collectors. Some farmers do primary processing including washing, milling, and drying before selling dry parchment to collectors or exporting companies.

The farmer group in this study refers to a production group and cooperatives. The production group is relatively smaller than the cooperative in terms of members and production. Production group is an informal arrangement in the villages. They have the commitment to share knowledge, information, and machines and equipment among the members of the group. However, the members of the group prefer to sell their products individually. On the other hand, cooperatives collect production from members and sell it to exporting companies as a group. Some cooperatives have the capacity to operate the whole process from red cherries to green coffee for export and roasted coffee for the domestic market.

Coffee collectors are intermediaries between coffee producers and exporting or processing companies. They can access the production area through information on the source of production and their relationship with coffee farmers and companies. They sometimes have a contract with farmers or production groups. The contract is based on the trust between coffee producers and collectors. Coffee collectors sell red cherries or dry parchment to exporting companies or processing companies depending on their network. They are also the first screening of the defects.

The processing companies produce finished products such as roasted coffee, instant coffee, ready-mixed coffee, and the like. They buy red cherries and dry parchment from farmers, production groups, and collectors to produce finished products. They target both domestic and foreign markets.

Exporting companies are trading companies that mainly export green coffee to Vietnam, Thailand, Japan, and EU countries as they have access to those markets. They

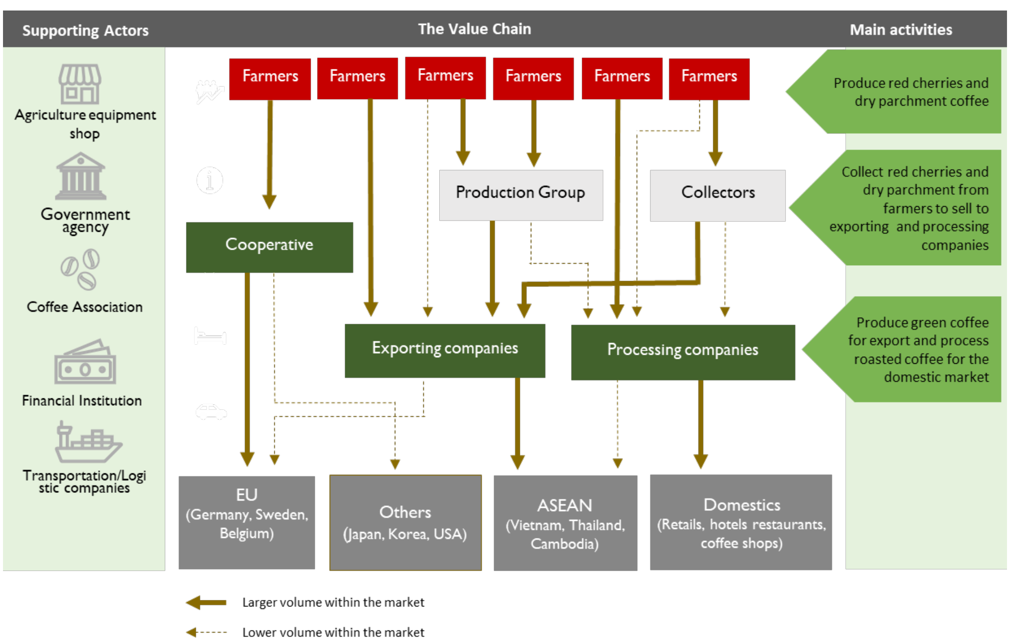

Figure 1. Coffee value chain.

buy red cherries or dry parchment from farmers. Exporting companies can do the entire process from red cherry to green coffee. They invest in advanced machines such as milling, gravity separator, optical sorting, etc.

The domestic consumption of coffee is a tiny proportion of total production. Most of the coffee used in the domestic market is in processing companies, retailers, and coffee shops. Retail shops sell roasted coffee, instant coffee, ready-mixed coffee, and the like. There are many coffee shops serving local and tourist customers. Coffee shops buy roasted coffee to brew varieties of coffee such as espresso, americano, cappuccino, café late, and the like. Some coffee shops have roasting machines while many of them buy roasted coffee from roasters.

Government agencies involved in supporting the coffee industry such as the Ministry of Industry and Commerce (MoIC), Ministry of Agriculture and Forestry, Ministry of Public Work and Transportation, Ministry of Finance, Ministry of Planning and Investment, Bank of Lao PDR, Ministry of Information, Culture and Tourism and other related organizations. These governmental agencies have different roles and responsibilities but collectively in promoting Lao coffee production, and access to the market. MoIC, for example, provides regulatory frameworks and relegations regarding trading, market access, and other supporting activities. MAF provides technical support on the plantation, producing natural pesticides and fertilizer processing and other ministries work in a similar way.

Financial institutions provide loans to farmers, producers, and companies as well as providing other financial services such as money transfers, and other transactions for coffee industry participants. These institutions are important for both domestic coffee trading and exporting. Currently, there are 43 commercial banks in Laos and many of them provide services for agriculture and trading. Besides banking institutions, there are several microfinance institutions that offer loans and financial services to farmers, collectors, exporting companies and processing companies. One way to obtain financial resources is through the Small and Medium Enterprises (SMEs) funds, which are managed by SMEs Promotion Fund under MoIC. These funds give preference to agriculture and agriculture processing SMEs, granting them access to loans with an annual interest rate of 3%. Additionally, the Lao government supports other SMEs funds, which provide loans to agriculture SMEs with an interest rate of 6-9% per year. Commercial banks charge interest rates of over 9% per year, depending on the borrower's credit rating.

Lao National Chamber of Commerce and Industry (LNCCI) is an independent agency that works as a representative of business groups. LNCCI supports its members to grow stronger and problems that its members face will be raised to the government. It works as a connecting point between the business units and the government which aims to facilitate the businesses to operate in a friendly business environment. LNCCI mainly supports the coffee sector by arranging coffee events, workshops, and business matching. They also work closely with the Lao Coffee Association (LCA) to support the coffee sector.

LCA is a Non-Profit Association established in 1994 with the aim of promoting Lao coffee and improving the quality and efficiency of coffee production. Its main role is to support the members to access the market, improve competitiveness, and enhance technical necessary skills and knowledge. LCA members gain benefits from information sharing and access to information about the coffee industry and market. In recent years, the LCA has been very active in participating in national and international trade fairs. LCA is one of the members of LNCCI.

Transportation agencies, both public and private, are important for delivering products from producers to consumers. Logistic companies support exporting companies to transport coffee from Lao PDR to seaports in Vietnam and Thailand. However, exporting companies use the services of foreign logistics companies because of competitive prices.

Agriculture equipment shops sell tools, machines, fertilizer, and pesticides to farmers. Most of the products in the shop are imported from neighboring countries such as Thailand, China, and Vietnam. Agriculture equipment shops also provide credit to farmers through machine leasing.

3.3 Value Added

This section discusses value-added along the coffee value chain. Several assumptions are set here. Arabica is used in the analysis because of the volume of production and demand from the market. The wash processing is assumed here. The exporting price of green coffee refers to the market price in Thailand because most of the green coffee is exported to Thailand. The output value, intermediate input cost, gross value added, consumption of fixed capital, and net value added are estimated in USD per kg. Coffee shops sell various menus of coffee such as espresso, latte, cappuccino, etc. It assumed the price of espresso as it is the base form of other coffee recipes.

The results showed that the farmer's net value added from selling red cherry and dry parchment is approximately USD 0.27 per kg and USD 2.18 per kg, respectively. Dry parchment has a higher value-added both absolute value and the share to the output value than red cherries,

Table 2. Value added along the value chain.

Unit: USD/kg

Description	Farmers		Collectors		Exporting companies	Processing company	Coffee shop
	Red cherry	Dry parchment	Red cherry	Dry parchment	Green coffee	Roasted coffee	Espresso
Output value	0.67	4.00	0.69	4.33	6.00	18.67	51.92
Intermediate input cost	0.40	0.73	0.67	4.00	4.74	12.00	18.67
Gross value added	0.27	3.27	0.02	0.33	1.26	6.67	33.25
Consumption of fixed capital		1.08	0.00	0.03	0.13	4.00	10.38
Net value added	0.27	2.18	0.02	0.31	1.13	2.67	22.87

Note: The exchange rate is 15,000 LAK/USD.

Source: Field survey, 2023.

Table 3. Share of value added to the output value.

Description	Farmers		Collectors		Exporting companies	Processing company	Coffee shop
	Red cherry	Dry parchment	Red cherry	Dry parchment	Green coffee	Roast coffee	Espresso
Output value	100%	100%	100%	100%	100%	100%	100%
Intermediate input cost	60%	18%	97%	92%	79%	64%	36%
Gross value added	40%	82%	3%	8%	21%	36%	64%
Consumption of fixed capital	0%	27%	0%	1%	2%	21%	20%
Net value added	40%	55%	2%	7%	19%	14%	44%

Source: Filed survey, 2023.

but it requires investment in machines and equipment. Collectors make an average of USD 0.02 per kg value added from selling red cherries and USD 0.31 per kg for dry parchment.

Exporting companies buy red cherry and dry parchment coffee beans from collectors to process the green beans. They gain approximately value added of approximately USD 1.13 per kg. Processing companies earn approximately a value-added USD 2.67 per kg from selling roasted coffee. Coffee shops earn the highest absolute value added per kg accounting for USD 22.87.

Table 3 shows the share of value added to the output value. Farmers gain the highest share of value added to output value on dry parchment coffee. Recently, farmers invested in machines and equipment to produce dry parchment. Collectors gain the lowest percentage of value added. However, they benefit from the volume of buying and selling coffee.

4. Discussion

The coffee value chain in the Lao PDR has improved in recent years due to public and private support for training. This has led to an increase in both the quality and quantity of coffee produced in the country. Some Arabica varieties are now considered to be of speciality grade, which commands a higher premium [18].

The market environment surrounding the Lao coffee sector is also quite promising. The demand for coffee is growing rapidly in neighboring Asian countries, and China has emerged as a new potential market opportunity. Exporters and processing companies have the opportunity to enter these markets and capitalize on the growing demand for Lao coffee.

Domestic demand for coffee has been increasing as well. The launch of many new coffee shops or cafés as well as small-scale roasters in recent years is an indicator of the increasing popularity of Lao coffee among locals. Some established coffee brands such as Sinouk Coffee, Saffron Coffee, Yuni Coffee, and Dao Coffee are marketed locally, hoping that booming tourism can boost their sales.

Farmers in Laos have solid knowledge and skills in coffee production. This knowledge has been passed down from generation to generation, and it is also supported by various training programs from the public and private sectors. As a result, farmers have a low cost of production and a high profit margin. This is similar to the findings of a study on the supply chain of premium coffee in Thailand [19].

Many coffee farmers face challenges that affect their livelihoods and the quality of their products. One of these challenges is the shortage of labor, especially during harvest seasons, when many workers migrate to neighboring countries in search of better opportunities. Another challenge is the lack of knowledge and skills to cope with pests and diseases that can reduce yields and quality. Furthermore, some farmers are reluctant to produce high-quality coffee because they perceive certification as too costly and time-consuming. Moreover, coffee farmers have limited access to low-cost finance because they lack collateral which is consistent with the rice farmers by Wongpit and Sisengnam [20]. This prevents them from borrowing money to invest in their businesses, such as expanding their production or processing facilities. Consequently, they are unable to increase their productivity or improve the quality of their coffee.

The demand for cassava has significantly increased in recent years. Casava is easy to grow with a low cost of planting and harvesting. In addition, casava produces 86.25% value-added which is higher than the 44% value-added of coffee [7,21]. Many farmers change from coffee to casava which will reduce coffee production in the long run.

The Laos government has prioritized policies to support production groups and cooperatives, which provides many advantages. Information, skills, knowledge, and resources such as machines and equipment can be exchanged and shared among members. This helps to improve the efficiency and productivity of production groups [22]. The quality of coffee can be controlled and guaranteed. This is important for ensuring that coffee produced by production groups meets international standards. Production groups have more negotiation power than individual farmers. This means that they are better able to bargain for better prices for their coffee. The lack of legal documents for production groups makes it difficult for them to access credit from banks, which can hinder their ability to invest in quality improvement [20]. Cooperatives shorten the value chain member and connect to the export market.

Exporting companies have an advantage in accessing foreign markets. They apply advanced technology to produce a large volume of products that benefit from the economy of scale. Processing companies have their own brand but not exporting companies do. They have various market segments to serve consumers. They own a supply chain from coffee plantations to coffee shops. They sell products in both domestic and foreign markets. Exporting and processing companies are facing volatility in coffee prices and exchange rates. They also pay the high cost of transportation and services. The export procedure requires many documents from related government offices and high cost of fees. Graduation from the Least Developed Countries (LDC) in 2026 will be a challenge for Lao PDR. The export of coffee will face high tariffs from developed and developing countries as the Generalized System Preference is terminated [14].

Non-tariff measures have become more challenging for the export of coffee. Importing countries impose various NTMs to protect local producers and consumers. Sanitary and Phyto-sanitary Technical Barriers to Trade are the most common measures used for coffee export. The more NTMs the higher the cost of export and the result in losing competitiveness [23,24].

5. Conclusions

Coffee is one of the strategic agricultural products of the Laos government. Many opportunities for exporting coffee to the world market due to the increasing coffee demand in domestic and foreign markets. However, there are many challenges to overcome. The coffee value chain in the Lao PDR has improved in both quantity and quality in the last decade. The production group is the key member in the value chain to increase skills, share information, link farmers to the market, and access finance. Farmers seem to have the highest value-added along the value chain. With a small scale of production and volatility of market price, the total income of farmers is not secured for expenditure. Exporting and processing companies benefit from large-scale production, but the lack of an in-house brand means that the world coffee market does not recognize Lao coffee.

The coffee sector has good opportunities in the global market. The demand in regional countries is growing. However, the coffee sector is facing challenges. NTMs are increasing in the coffee sector pushing the cost of export. Climate change, diseases, and pests impact the quality and quantity of coffee. To improve the coffee value chain in the Lao PDR, some policies should be implemented.

In the short term, the protection of coffee plantation areas, especially the Bolaven Plateau, through the implementation of policies on agriculture zoning and the enforcement of land management agreements. It suggests encouraging farmers to replace old coffee varieties with new ones to increase productivity and promote speciality coffee. The article also emphasizes the need for promoting and certifying coffee standards such as organic, good agriculture practices, and fair trade with support from relevant organizations. Additionally, it mentions that promoting speciality coffee requires significant efforts in changing mindsets, improving skills, and marketing strategies, implementing standards, and identifying geographic indications. Finally, the article suggests that the MoIC can assist farmers in accessing the speciality coffee market by promoting different market positions for coffee through exhibitions, trade fairs, and websites.

In the medium term, financial institutions should develop financial products tailored to farmers' unique requirements, such as group loans. It also proposes the establishment of a Lao coffee promotion fund by organizations such as CCCI and LAC, which can provide low-interest loans to cooperatives. MoIC should disseminate information on market access to exporters and producers through social media, posters, and the website of laotradeportal.gov.la. MAF should provide training to farmers on using natural fertilizers and pesticides and support the development of new innovations aimed at increasing productivity and reducing production costs through partnerships with universities and research institutes. The article emphasizes the importance of embedding capacity building for research and development of agriculture products within universities and research institutes to ensure continued progress and advancement in the field.

In the long term, to promote modernization in the local transportation sector, the MoIC and MPWT should collaborate with the private sector to streamline processes and encourage efficiency by reviewing and revising unnecessary procedures and documents. Additionally, a national logistics database should be established to enhance coordination and improve communication between exporters, importers, and domestic and international transportation companies to reduce the cost of inland transportation and cross-border transportation.

To promote coffee as a key export product, the MoIC, MAF, and LCA should establish trade relationships with potential partners such as Germany, Sweden, and China. The article also emphasizes the need to improve market access in these high-potential markets through trade policy negotiations. To meet the requirements of importing countries and graduate from LDC status, identifying a quality standard for coffee and supporting farmers and cooperatives to improve their quality and meet international standards is crucial.

This study has some limitations that should be considered. The sample size of the survey was small, but there was no significant difference in the cost and margin between the different groups of respondents. However, the study only focused on the domestic market, so it is recommended to conduct further analysis of the coffee value chain in the foreign market to understand who the customers of Lao coffee are in the international market.

Author Contributions

The first author as well as corresponding author Piya Wongpit took the lead in research design, analysis, interpretation and writing of the manuscript while co-authors including Pakaiphone Syphoxay, Bounthom Sisoumang, and Sengsulixay Sykhanthong, support the first author in the writing and analysis.

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Data Availability

The data are available upon request from the corresponding author.

Conflict of Interest

The authors disclosed that they do not have any conflict of interest.

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RESEARCH ARTICLE

Comparative Analysis of Price Forecasting Models for Garlic (*Allium sativum* L.) in Kota District of Rajasthan, India

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Abstract: Garlic is a well-known spice in India, and Rajasthan is the country's second-largest producer of garlic after Madhya Pradesh. Accurate price predictions are crucial for agricultural commodities, as they significantly impact the accessibility of food for consumers and the livelihoods of farmers, governments, and agribusiness industries. Governments also use these forecasts to support the agricultural sector and ensure food security. A study was conducted in Rajasthan's Kota district to analyze the wholesale price of garlic using data from July 2021 to July 2023 from the Kota fruit and vegetable market. The study used simple moving average (SMA), simple exponential smoothing (SES), and autoregressive integrated moving average (ARIMA) models to forecast garlic prices. The models were validated through mean absolute deviation (MAD), mean squared error (MSE), mean absolute percentage error (MAPE), root mean squared error (RMSE), correlation coefficient (r), and coefficient of variation (CV). The research was conducted utilizing Microsoft Excel and R Studio version 4.2.2 for Windows, and the results showed that the ARIMA (1,0,0) with a non-zero mean model had a strong correlation coefficient ($r = 0.91^{**}$) and accurately predicted the variation in garlic prices. Based on the analysis, it is recommended to use this model for forecasting and making informed decisions.

Keywords: Agricultural commodities; ARIMA model; Garlic; Informed decisions; Market intelligence; Price forecasting models

1. Introduction

Garlic, scientifically known as *Allium sativum* L., is a vital member of the onion (Alliaceae) family. This plant has been used in traditional medicine and cooking since ancient times [1]. The bulb of the garlic plant is the most commonly utilized part, consisting of several fleshy sections called cloves. These cloves have a distinct spicy

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flavor that becomes milder and sweeter when cooked [1,2]. Garlic can be used in various forms, such as raw, paste, tablet, powder, or oil extracted from cloves, depending on individual needs [1,3].

1.1 Area, Production, and Productivity of Garlic in India

India is a well-known leader in the global spice industry, producing almost every variety of spices available worldwide. The spice sector plays a significant role in driving the growth of the Indian economy [4]. As the world's largest producer, consumer, and exporter of spices, India's spice cultivation occupied an estimated 4.49 million hectares [5] of land during the 2022 fiscal year, resulting in a production volume of approximately 11 million metric tons (MT) [6]. India produces 75 of the 109 varieties listed by the International Organization for Standardization (ISO), including garlic, turmeric, coriander, cumin, and cinnamon [4]. India is renowned for its diverse range of spices that are produced and exported worldwide. The states that contribute the most to spice production in India are Madhya Pradesh, Rajasthan, Gujarat, Andhra Pradesh, Telangana, Karnataka, Maharashtra, and Kerala [4]. The area, production, and productivity of garlic in India are presented in Figures 1, 2, and 3.

In Table 1, it was found that garlic productivity varied significantly among different states and Union Territories (UTs). Telangana, Haryana, and Punjab have high garlic productivity (MT/ha) at 13.86, 11.69, and 10.93, respectively. Mizoram, Jammu and Kashmir, Bihar and Himachal Pradesh have lower productivity rates at 0.53, 0.73, 1.56, and 1.96, respectively. Madhya Pradesh has become a notable producer of garlic, with a sizeable area of 204.68 thousand ha dedicated to its cultivation. The state has achieved a commendable productivity rate of 10.29 MT/ha, making a significant contribution to the total garlic output of the country. However, regions like Mizoram and Telangana have limited garlic cultivation, leading to lower production and productivity rates. The table gave important information on how garlic production is distributed throughout India. The provided data compares the highest and lowest values of garlic productivity across various states. Additionally, the national average of garlic productivity is 8.17 MT/ha.

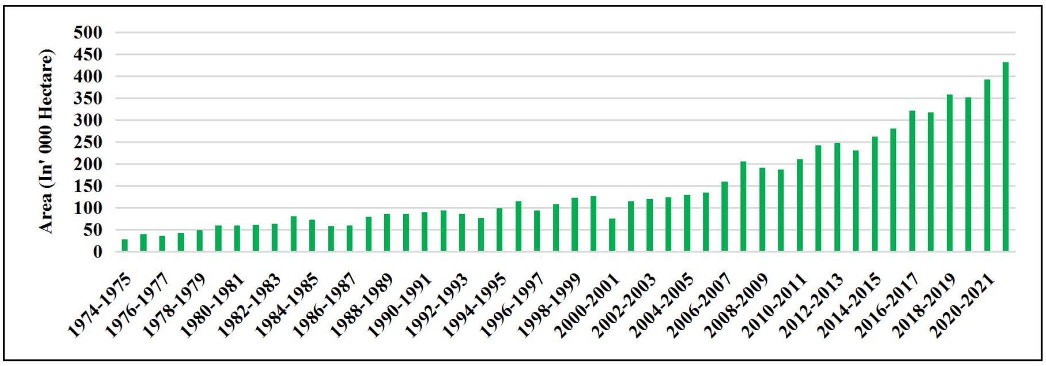

Figure 1. Area of garlic in India (In'000 hectare (ha)).

Source: Indiastat [8].

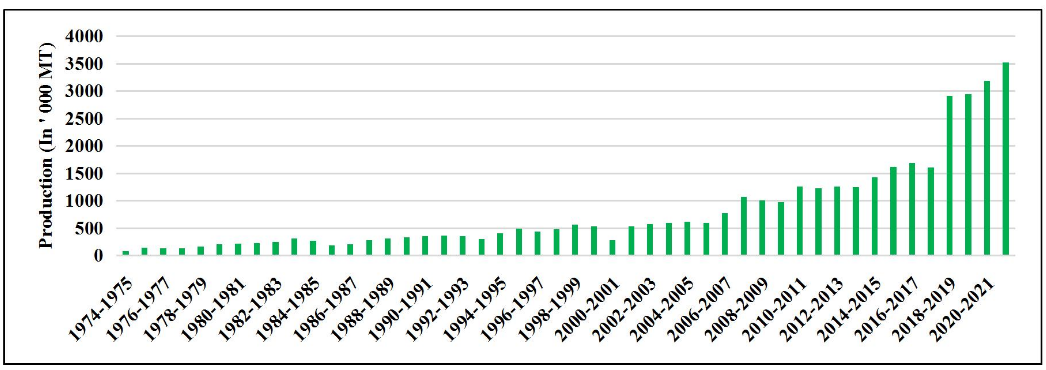

Figure 2. Production of garlic in India (In'000 MT).

Source: Indiastat [8].

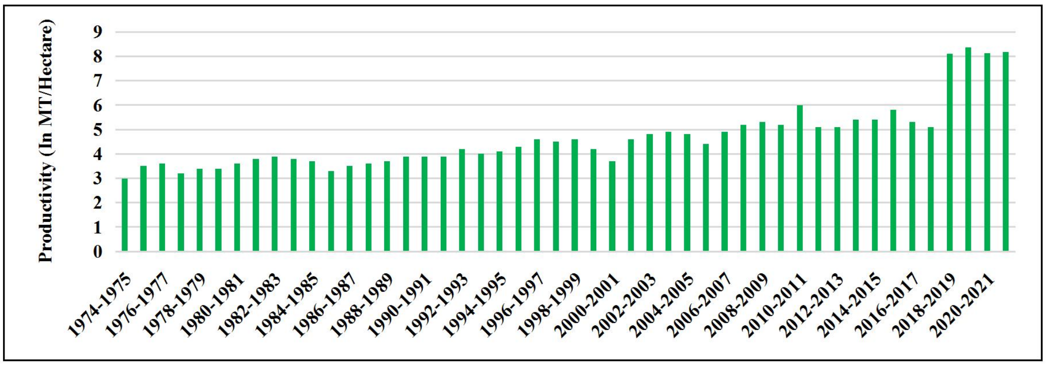

Figure 3. Productivity of garlic in India (In MT/ha).

Source: Indiastat [8].

Table 1. State-wise area, production, and productivity of garlic in India (2021-2022).

States/UTs	Area (In'000 ha)	Production (In'000 MT)	Productivity (In MT/ha)
Madhya Pradesh	204.68	2106.63	10.29
Rajasthan	98.34	592.52	6.03
Uttar Pradesh	40.96	242.24	5.91
Gujarat	26.01	202.83	7.8
Odisha	11.03	39.51	3.58
Assam	10.81	69.42	6.42
Punjab	8.88	97.04	10.93
Himachal Pradesh	6.94	13.58	1.96
Karnataka	4.28	24.54	5.73
Maharashtra	4.05	24.35	6.02
West Bengal	4.04	38.15	9.45
Haryana	3.42	39.91	11.69
Tamil Nadu	1.93	11.18	5.78
Uttarakhand	1.92	11.27	5.86
Bihar	1.41	2.21	1.56
Chhattisgarh	1.17	3.02	2.57
Jammu & Kashmir	0.78	0.57	0.73
Nagaland	0.28	2.32	8.35
Kerala	0.19	1.02	5.25
Telangana	0.08	1.12	13.86
Mizoram	0.02	0.01	0.53
India	**431.22**	**3523.44**	**8.17**

Source: Indiastat [9].

The data presented in Table 2 display the information on garlic cultivation in the Rajasthan region from 2008-2009 to 2021-2022, including the area, production, and productivity. The table highlights the fluctuations in garlic cultivation over 14 years. In 2008-2009, garlic was grown on 21.60 thousand ha, producing 101.90 thousand MT, with a productivity of 4.70 MT/ha, and the following year witnessed a slight increase in the cultivation area to 24.70 thousand ha. However, the production decreased to 98.40 thousand MT, leading to a 4.00 MT/ha lower productivity.

The land used for growing garlic has increased recently, reaching 112.89 thousand ha in 2017-2018. The production of garlic fluctuated, reaching its highest point at 727.50 thousand MT during 2016-2017. The production of garlic per hectare has remained consistent, with yields ranging from 3.40 to 6.73 MT.

Table 2. Area, production, and productivity of garlic in Rajasthan (2008-2009 to 2021-2022).

Year	Area (In'000 ha)	Production (In'000 MT)	Productivity (In MT/ha)
2008-2009	21.60	101.90	4.72
2009-2010	24.70	98.40	3.98
2010-2011	25.00	150.00	6.00
2011-2012	59.50	236.00	3.97
2012-2013	59.50	236.00	3.97
2013-2014	45.00	218.40	4.85
2014-2015	50.20	172.00	3.43
2015-2016	69.10	377.49	5.46
2016-2017	107.97	727.50	6.74
2017-2018	112.89	582.08	5.16
2018-2019	74.83	452.94	6.05
2019-2020	68.01	416.30	6.12
2020-2021	87.66	517.09	5.90
2021-2022	98.34	592.52	6.03

Source: Indiastat [10].

1.2 Trend Analysis of Garlic Productivity, Production, and Area in India

During the study period (1975-2022), garlic productivity increased by 1.63% per ha, resulting in a total output rise of 6.61%. The area under garlic cultivation also expanded with a compound annual growth rate (CAGR) of 4.90%. The increase in garlic production and productivity results from the timely supply of planting materials, improved irrigation facilities, credit availability, and better market infrastructure [4-7].

Table 3 shows highly significant observed relationships between garlic productivity, production, and area. The probability of achieving these results by chance is very low. The high R-squared values indicate strong correlations between the variables, meaning that the factors studied significantly impact garlic productivity, production, and area.

Table 3. CAGR of area, production, and productivity of garlic in India.

Variables	CAGR (%)	*P-value*	Regression statistics (R Square)
Productivity (In MT/ha)	1.63	< 0.001	0.82
Production (In'000 MT)	6.61	< 0.001	0.94
Area (In'000 ha)	4.90	< 0.001	0.95

1.3 Exports Trend of Garlic from India

India is the top exporter of spices and spice products worldwide [4]. In 2022-2023, exports were worth $3.3 billion, with a 44% increase in February 2023 alone [4]. The most commonly exported spices are chilli, cumin, turmeric, and ginger. India exported 1.53 million MT of spices [4] in 2021-2022, with a CAGR of 10.47%. Value-added products like spice oils and curry paste also saw growth in both value and volume [4]. Overall, India exported $4.1 billion worth of spices, with core spices and mint products being the biggest contributors [4]. In the spice export market of India for the year 2022-2023, garlic has been the leading performer [7], surpassing other major shipments. This can be attributed to the high demand and prices of garlic and the reduced availability of Chinese garlic in global markets [7]. Garlic shipment volume increased by 165% from April 2022 to January 2023 [7]. In contrast, as per the Spices Board data, other major spices such as chilli, cumin, mint products, and spice oleoresins have all declined. The export of garlic has reached 47,329 MT in the span of 10 months, which is higher than the peak of 46,980 MT in 2017-2018. With two more months of data, garlic export is expected to surpass 50,000 MT. In terms of value, garlic export has seen a rise of 34% at US$ 2.47 crore in the span of 10 months. In the previous year, 2021-2022, India's garlic exports were at 22,181 MT, valued at US$ 2.24 crore [7].

1.4 Major Export Destinations

As of 2022, India has exported spices and spice products to 180 destinations globally [4]. The top ten export destinations include China, USA, Bangladesh, Thailand, UAE, Sri Lanka, Malaysia, UK, Indonesia, and Germany, accounting for over 70% of the total export earnings in 2020-2021 [4]. China imported spices worth US$ 813.81 million in 2021-2022 (Estimated), while the USA imported spices worth US$ 618.34 million during the same period. Bangladesh imported spices worth US$ 212.64 million, and the UAE exported spices worth US$ 227.39 million from India in 2021-2022. India's most exported spice is chilli, with China importing US$ 382.15 million of chilli during 2021-2022 and the USA importing US$ 115.02 million of chilli in the same period. The USA's main spice imports from India include celery, cumin, curry powder, fennel, fenugreek, garlic, chilli, and mint products [4].

1.5 Application of Forecasting Models

The volatility and fluctuations in garlic prices have made garlic price forecasting a crucial study area. Several models have been explored to predict garlic prices accurately. Feng [11] discovered that a combined empirical mode decomposition-gated recurrent unit (EEMD-GRU) model was the most effective in predicting garlic prices in China as compared to ARIMA, autoregressive integrated moving average and feedback support vector regression (ARIMA-SVR), and long short-term memory (LSTM) models. The EEMD-GRU model decomposed the garlic price series into different frequencies and used a GRU neural network for prediction. Wang et al. [12] applied an ARIMA model to forecast garlic prices in Shandong, China, and found it useful for short-term predictions. The model predicted rising and then falling garlic prices in early 2018. Lianlian et al. [13] studied the impact of COVID-19 on garlic prices. They found the complete ensemble empirical mode decomposition with adaptive noise (CEEDMAN-LSTM) model suitable for predicting weekly garlic prices during the pandemic. The model showed that COVID-19 had a significant impact, keeping garlic prices low. A study by Al-Mamun et al. [14] found seasonal autoregressive integrated moving average (SARIMA) models effective in predicting Bangladesh's potato, onion, and garlic prices. The best models were SARIMA (1,0,0) (0,1,2)12 for potato, SARIMA (2,0,0) (0,1,1)12 for onion, and SARIMA (2,1,3) (0,1,3)12 for garlic. Wu et al. [15] analyzed factors influencing garlic price fluctuations in Shandong, China, using Hodrick-Prescott (HP) filtering. Key factors were planting area, natural conditions, market speculation, and following the arrival of the commodity. The papers analyzed various time series models for predicting garlic prices, including ARIMA, SARIMA, EEMD-GRU, autoregressive moving average and generalized autoregressive conditional heteroscedasticity (ARMGARCH), and autoregressive with exogenous inputs models (ARXM). The most accurate models varied, but common factors influencing garlic price fluctuations were identified.

Accurate agricultural production and pricing forecasts [16-19] are essential for assisting farmers, governments, and the agribusiness industry. As food production is critical for a country's security, governments are significant suppliers and users of agricultural forecasts. They rely on internal forecasts to enact policies that offer technical and market assistance to the agriculture sector [20]. The government often publishes forecasts for commodity prices and output at regional and national levels and various time frames for private decision-makers. The study's primary objective was to identify the most reliable and precise method of predicting the fluctuating prices of garlic in the market.

2. Materials and Methods

2.1 Study Area

The Kota region in Rajasthan was selected for its significant garlic cultivation, particularly in Kota, Baran, Bundi, and Jhalawar districts (Figure 4). Other factors considered were its import and export status, price changes, and contribution to the state's economic development. The Kota fruit and vegetable market was selected, as it had the highest rate of garlic arrivals. Kota is a city in the southeast of Rajasthan [21], located on the banks of the Chambal River and about 240 kilometers south of the state's capital, Jaipur. Its population is over 1.2 million, making it the third most populous city in Rajasthan and India's 46th most populous city [21]. The primary crops grown in Kharif are soybean (77%), black gram (9%), Paddy (8%), and others (6%). In Rabi, the crops are wheat (46%), mustard (24%), coriander (21%), garlic (6%), and others (3%). The total cultivated area of the district is 340,000 ha, of which 210,000 ha (61.76%) is irrigated [22].

2.2 Sources of Data

The study's objectives were accomplished through the use of secondary data. Monthly garlic prices from July 2021 to July 2023 were collected from the agricultural marketing information network (AGMARKNET) website, a reliable secondary source. Other valuable sources, such as books, magazines, journals, reports, and the websites of various departments and institutions, were also consulted to identify the factors that determine garlic prices.

2.3 Data Analysis

i. Simple Moving Averages: The simple moving averages (SMA) method was used in this study to predict future values based on historical data over specific time intervals. The technique was calculated using MS Excel and employing three different SMA windows, namely 3 months, 6 months, and 12 months. The calculation of SMA involved computing the average of garlic prices over the last three months, six months, and twelve months for the respective SMA windows. This was done at each data point.

ii. Simple Exponential Smoothing: Simple exponential smoothing (SES) is a time series forecasting method that assigns exponentially decreasing weights to past observations. The alpha (α) value determines the weight given to recent data. This study used the SES method with alpha = 0.3 [20,34] to forecast garlic prices. Using a lower alpha (α) value will result in more forecast stability. SES was initialized with the actual value for the first month and then used the following formula to forecast subsequent months:

$$F_{t+1} = \alpha\, y_t + (1 - \alpha)\, F \quad (1)$$

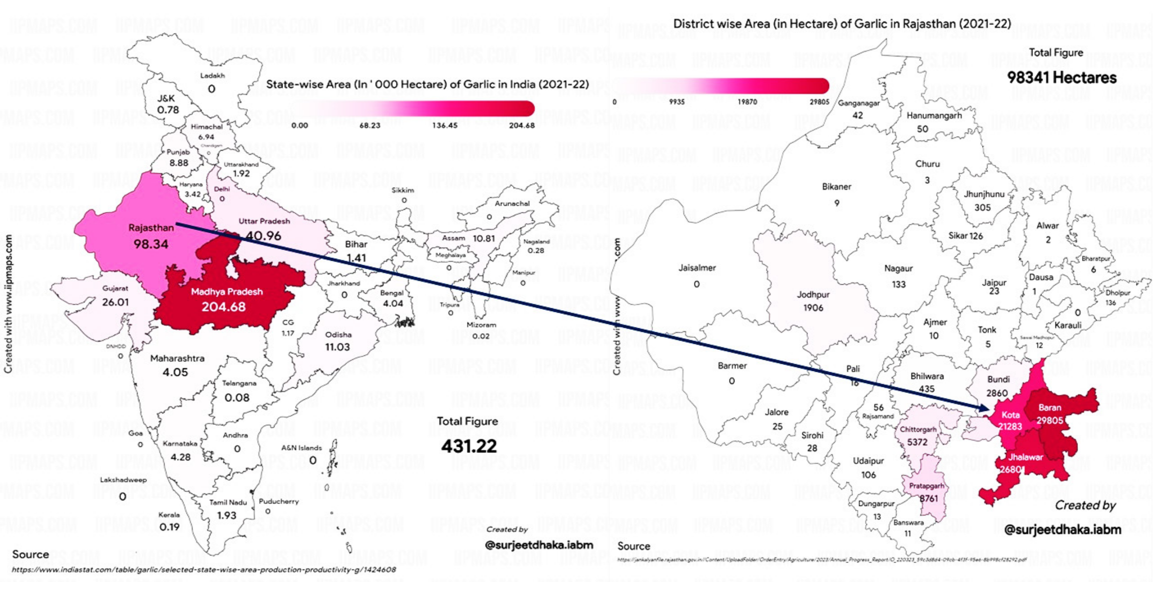

Figure 4. Geographical location of the study area.

where y_t is the actual, known series value at the time t; F_t is the forecast value of the variable Y at the time t; F_{t+1} is the forecast value at the time $_{t+1}$; α is the smoothing constant [22,35].

iii. Autoregressive Integrated Moving Average (ARIMA): ARIMA is an automated version and widely used for time series forecasting. The Ljung-Box test is a statistical test employed to check if the residual errors in the ARIMA model are independent and do not exhibit any serial correlation. R Studio version 4.2.2 for Windows was used to implement the Auto ARIMA model on the 25-month monthly garlic price data from AGMARKNET. The Auto-ARIMA function automatically identifies the optimal ARIMA parameters (p, d, q) based on minimizing the Akaike Information Criterion (AIC) or Bayesian Information Criterion (BIC). After fitting the ARIMA model, Ljung-Box test was conducted on the residuals to detect serial correlation, which is a statistical test for autocorrelation in a time series. ARIMA stands for Autoregressive (AR) Integrated (I) Moving Average (MA), which means that an ARIMA model has three parts [23]. There are two types of ARIMA models: non-seasonal models and seasonal models [23-25]. In non-seasonal models, the order is expressed as (p,d,q), with 'p' representing the number of autoregressive terms, 'd' representing the number of non-seasonal differences, and 'q' representing the number of moving average terms [23-25]. Autoregressive models (AR): Autoregressive models are similar to regression models. However, in auto-regressive models, the dependent variable is the regressor with a specific time lag [23-25]. Differencing (I): To optimize the performance of ARIMA, it requires the data to be stationary, which implies that the mean and variance must remain constant throughout the set. Differencing alters the data and renders it stationary [23-25]. Moving average (MA): Moving averages are widely known and commonly used in time series analysis. It entails calculating the average of the data points in a series for a specific time lag [23-24].

Steps for forecasting using an ARIMA model in R [24-26].

1) Plot the data and identify any unusual observations [25].

2) If necessary, transform the data (using a Box-Cox transformation) to stabilize the variance [25].

3) If the data are non-stationary, take the first differences of the data until the data are stationary [25].

4) Examine the ACF/PACF: Is an ARIMA(p,d,0) or ARIMA(0,d,q) model appropriate [25]?

5) Try your chosen model(s), and use the AICc to search for a better model [25].

6) Check the residuals from your chosen model by plotting the ACF of the residuals and doing a portmanteau test of the residuals. Try a modified model if they do not look like white noise [25].

7) Calculate forecasts once the residuals look like white noise [25].

The Augmented Dickey-Fuller (ADF) test [26] was performed on the dataset "garlic time" to investigate the stationarity of the data. The ADF test is commonly used in time series analysis to determine whether a given time series is stationary or not.

iv. Garlic ARIMA R Codes

```
Library (readxl)
Garlic <- read_excel ("garlic") ("see Appendix A").
View (garlic)
Class (garlic)
Garlic time = ts(garlic$Prices, start = min (Prices$Month), end = max (Prices$Month), frequency = 1)
Class (garlic time)
Library (forecast)
Library (tseries)
Plot (garlic time)
Acf (garlic time)
Pacf (garlic time)
adf.test (garlic time)
Garlicmodel = auto.arima (garlic time, ic = "aic", trace = TRUE)
acf (ts(garlicmodel$residuals))
pacf (ts(garlicmodel$residuals))
Mygarlicforecast = forecast (garlicmodel, level = c(95), h = 12*1)
Mygarlicforecast
Plot (mygarlicforecast)
Box.test (mygarlicforecast$residuals, lag = 5, type = "Ljung-Box")
Box.test (mygarlicforecast$residuals, lag = 15, type = "Ljung-Box")
Box.test (mygarlicforecast$residuals, lag = 25, type = "Ljung-Box")
```

v. Model validation: The best price forecasting models were validated based on the predicted price series' correlation coefficient and coefficient of variation.

vi. Forecast Accuracy: For the identification of the best forecasting model in garlic, the accuracy of forecast models was carried out using different error measures, i.e., MAD, MSE, MAPE, and RMSE. These metrics are helpful to assess the performance of forecasting models, understand the accuracy of predictions, and make informed decisions based on the quality of the models' outputs [36].

3. Results and Discussion

3.1 Price Forecasting of Garlic Using Various Forecasting Models

Simple Moving Averages

Garlic is the major spice crop of Rajasthan. The harvesting of garlic started during the month of October. Therefore, the price forecasting for the harvesting period based on its pre-harvest price using 3 months, 6 months, and 12 months simple moving averages are shown in the following Table 4 and Figure 5.

MAD, MSE, MAPE, and RMSE for 3 months, 6 months, and 12 months SMA are shown in Table 5.

After analyzing the MAD, MSE, MAPE, and RMSE of all the moving averages, the 3-month SMA is the most effective method for forecasting due to its lowest values for all metrics, indicating higher accuracy.

Simple Exponential Smoothing

The actual price and forecasted prices of garlic using simple exponential smoothing are shown in the following Table 6 and Figure 6.

Table 4. Actual and forecasted prices of garlic using 3 months, 6 months, and 12 months SMA (Indian Rupee (₹)/quintal).

Month	Actual prices	Forecasted price with 3 months SMA	Forecasted price with 6 months SMA	Forecasted price with 12 months SMA
Jul-21	6138			
Aug-21	6167			
Sep-21	5747			
Oct-21	5534	6017.33		
Nov-21	4076	5816.00		
Dec-21	5050	5119.00		
Jan-22	2859	4886.67	5452.00	
Feb-22	2598	3995.00	4905.50	
Mar-22	3125	3502.33	4310.67	
Apr-22	2973	2860.67	3873.67	
May-22	2402	2898.67	3446.83	
Jun-22	1921	2833.33	3167.83	
Jul-22	1857	2432.00	2646.33	4049.17
Aug-22	1934	2060.00	2479.33	3692.42
Sep-22	2119	1904.00	2368.67	3339.67
Oct-22	2134	1970.00	2201.00	3037.33
Nov-22	2756	2062.33	2061.17	2754.00
Dec-22	2439	2336.33	2120.17	2644.00
Jan-23	2618	2443.00	2206.50	2426.42
Feb-23	2209	2604.33	2333.33	2406.33
Mar-23	4135	2422.00	2379.17	2373.92
Apr-23	4623	2987.33	2715.17	2458.08
May-23	4730	3655.67	3130.00	2595.58
Jun-23	5118	4496.00	3459.00	2789.58
Jul-23	8396	4823.67	3905.50	3056.00
Aug-23		6081.33	4868.50	3600.92

Note: 1.00 Indian Rupee (₹) = 0.012 US Dollars (US$) as on 10.09.2023 Available from: https://www.xe.com/currencyconverter/convert/?Amount=1&From=INR&To=USD

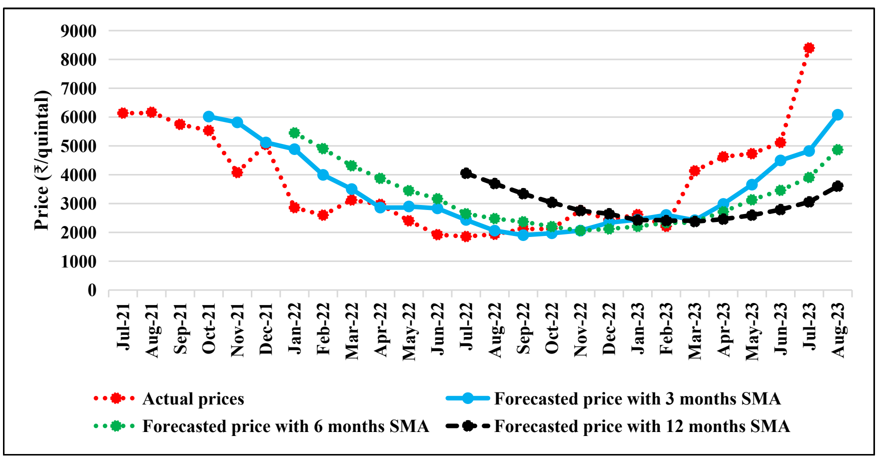

Figure 5. Actual and forecasted prices of garlic using 3, 6, and 12 months SMA.

Table 5. Forecasting accuracy of garlic using SMA methods.

Error measures	3 months SMA	6 months SMA	12 months SMA
MAD	849.08	1257.50	1569.18
MSE	1435168.53	2677243.59	4354036.39
MAPE	23.86	37.10	44.41
RMSE	1197.99	1636.23	2086.63

Table 6. Actual and forecasted prices of garlic using SES (₹/quintal).

Month	Actual prices	Forecasted price with SES (alpha = 0.3)
Jul-21	6138	2811.16
Aug-21	6167	3809.21
Sep-21	5747	4516.55
Oct-21	5534	4885.68
Nov-21	4076	5080.18
Dec-21	5050	4778.93
Jan-22	2859	4860.25
Feb-22	2598	4259.87
Mar-22	3125	3761.31
Apr-22	2973	3570.42
May-22	2402	3391.19
Jun-22	1921	3094.43
Jul-22	1857	2742.40
Aug-22	1934	2476.78
Sep-22	2119	2313.95
Oct-22	2134	2255.46
Nov-22	2756	2219.02
Dec-22	2439	2380.12
Jan-23	2618	2397.78
Feb-23	2209	2463.85
Mar-23	4135	2387.39
Apr-23	4623	2911.68
May-23	4730	3425.07
Jun-23	5118	3816.55
Jul-23	8396	4206.99
Aug-23		5463.69

Price forecasting error measures like MAD, MSE, MAPE, and RMSE for SES are shown in Table 7.

Table 7. Forecasting accuracy of the SES method.

Error measures	SES
MAD	1158.72
MSE	2319642.01
MAPE	29.88
RMSE	1523.04

Autoregressive Integrated Moving Average (ARIMA)

The ADF test result for the "garlic time" dataset showed a test statistic (Dickey-Fuller) of 1.1834 with a p-value of 0.99 (Table 8). The null hypothesis of the ADF test is that the data is non-stationary. The null hypothesis cannot be rejected in this case since the p-value is greater than the significance level of 0.05. Therefore, the data is considered non-stationary based on the ADF test [26].

Table 8. Augmented Dickey-Fuller test [26].

Parameter	Value
Dickey-Fuller	1.18
Lag order	2
P-value	0.990

Source: The R Project for Statistical Computing [26].

To further analyze the data and find a suitable model for forecasting, the "auto. arima" function was used [26]. This function automatically identifies the best-fitting ARIMA model for the data based on the AIC. The selected model was ARIMA (1,0,0) with a non-zero mean, as shown in Table 9. The coefficients of the chosen ARIMA (1,0,0) model were estimated, with an autoregressive coefficient (ar1) of 0.90 and a mean of 5233.75. The estimated sigma squared value was 1060487, and the log-likelihood of the model was –208.69. The model's AIC, AICc, and BIC values were 423.39, 424.53, and 427.05, respectively [26].

Table 9. Results of auto.arima function in R.

Garlicmodel = auto.arima (garlic time, ic = "aic",trace = TRUE)
ARIMA (2,0,2) with non-zero mean: 428.5072
ARIMA (0,0,0) with non-zero mean: 446.9979
ARIMA (1,0,0) with non-zero mean: 423.3899
ARIMA (0,0,1) with non-zero mean: 437.1901
ARIMA (0,0,0) with zero mean: 489.0769
ARIMA (2,0,0) with non-zero mean: 425.3286
ARIMA (1,0,1) with non-zero mean: 425.349
ARIMA (2,0,1) with non-zero mean: 426.7006
ARIMA (1,0,0) with zero mean: Inf
Best model: ARIMA (1,0,0) with non-zero mean

Source: The R Project for Statistical Computing [26].

Next, a forecast was generated using the selected ARIMA (1,0,0) model with a 95% confidence interval for 12 time periods ahead (h = 12*1). The values forecasted along with the lower and upper bounds of the confidence interval are presented in Table 10.

To evaluate the forecast accuracy, the Ljung-Box test [26,27] was performed on the forecast residuals, and the results are presented in Tables 11, 12, and 13. The Ljung-Box test is used to assess whether there is any significant autocorrelation in the residuals, which would indicate that the

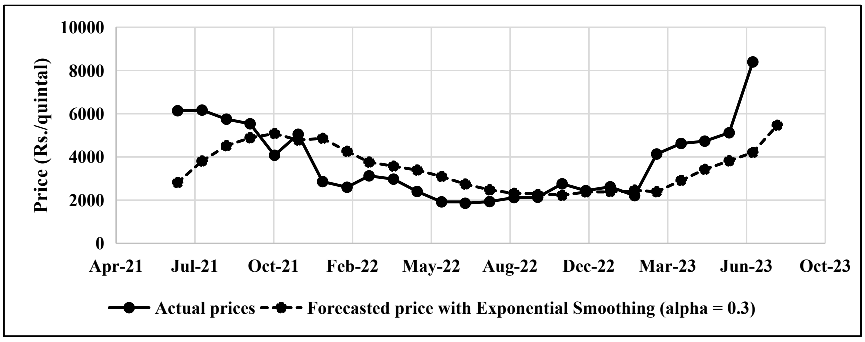

Figure 6. Actual and forecasted prices of garlic using SES.

model may be missing some important information [26,27]. The Ljung-Box test was conducted with different lag values (5, 15, and 25), and their respective p-values were reported. The interpretation of the Ljung-Box test results indicates no significant autocorrelation in the residuals at different lag levels, as the p-values were greater than the significance level of 0.05.

Table 10. Price forecasting results of ARIMA (1,0,0) model (₹/ quintal).

Month	Point forecast	Lo 95	Hi 95
Aug-23	8083.36	6064.99	10101.73
Sep-23	7801.63	5084.66	10518.60
Oct-23	7547.75	4374.70	10720.80
Nov-23	7318.98	3819.03	10818.93
Dec-23	7112.82	3368.35	10857.29
Jan-24	6927.04	2995.19	10858.90
Feb-24	6759.63	2681.94	10837.32
Mar-24	6608.77	2416.39	10801.16
Apr-24	6472.83	2189.57	10756.09
May-24	6350.33	1994.66	10705.99
Jun-24	6239.94	1826.35	10653.52
Jul-24	6140.46	1680.40	10600.52

Source: The R Project for Statistical Computing [26].

In conclusion, based on the research conducted on the "garlic time" dataset, it was found that the data is non-stationary according to the Augmented Dickey-Fuller test. The best-fitting ARIMA model for forecasting was determined to be ARIMA (1,0,0) with a non-zero mean. The forecasted values were obtained with associated confidence intervals. The residuals of the forecasted model did not exhibit significant autocorrelation according to the Ljung-Box test.

Table 11. Results of Ljung-Box test at lag = 5.

Parameter	Value
Chi-square (X^2)	3.94
Degrees of freedom (df)	5
P-value	0.557

Source: Box, G.E.P., et al. [27].

Table 12. Results of Ljung-Box test at lag = 15.

Parameter	Value
X^2	10.58
df	15
P-value	0.781

Source: Box, G.E.P., et al. [27].

Table 13. Results of Ljung-Box test at lag = 25.

Parameter	Value
X^2	24.75
df	25
P-value	0.966

Source: Box, G.E.P., et al. [27].

3.2 Suitable Price Forecasting Model for Garlic

Determination of the suitability of a price forecasting model can be validated using measures such as the correlation coefficient and coefficient of variation. The model with the highest correlation coefficient is considered suitable at a significance level of 0.01. Additionally, forecast accuracy is also a criterion for validation. The model with the lowest MAPE and RMSE [30] among the analyzed models is considered the most suitable price forecasting model.

Model Validation

Table 14 presents the results of validating the best price forecasting models, which were determined based on the correlation coefficient and coefficient of variation of the predicted price series.

The ARIMA (1,0,0) with a non-zero mean model showed the highest correlation coefficient (r = 0.91) with a coefficient of variation (27.14%). Therefore, it can be concluded that most of the variation in the predicted series was captured by this model [28-32]. Hence, the ARIMA (1,0,0) with a non-zero mean model is best validated, as shown in Table 14.

Table 14. Validation measures of various forecasting methods for garlic price series.

Forecast methods	Validation measures	
	Correlation coefficient	Coefficient of variation (%)
Actual price series		46.44
3 months SMA	0.66**	39.62
6 months SMA	0.23	32.61
12 months SMA	–0.26	18.31
SES	0.49**	29.44
ARIMA (1,0,0) with a non-zero mean	0.91**	27.14

** Correlation is significant at the 0.01 level (2-tailed).

Figure 7 shows Rplots for price and time, ACF, PACF lags for "garlic time" and "garlicmodel residuals" and forecast from ARIMA (1,0,0) with a non-zero mean model.

Forecast Accuracy

In order to determine the most effective forecasting model for garlic, we assessed the accuracy of various models using different error measures, including MAPE and RMSE [31-33]. The findings can be found in Table 15.

A comparison was made between various forecasting models using the minimum values of MAPE and RMSE [28-32]. It was found that for garlic, the ARIMA (1,0,0) model had the highest accuracy with a minimum MAPE value of

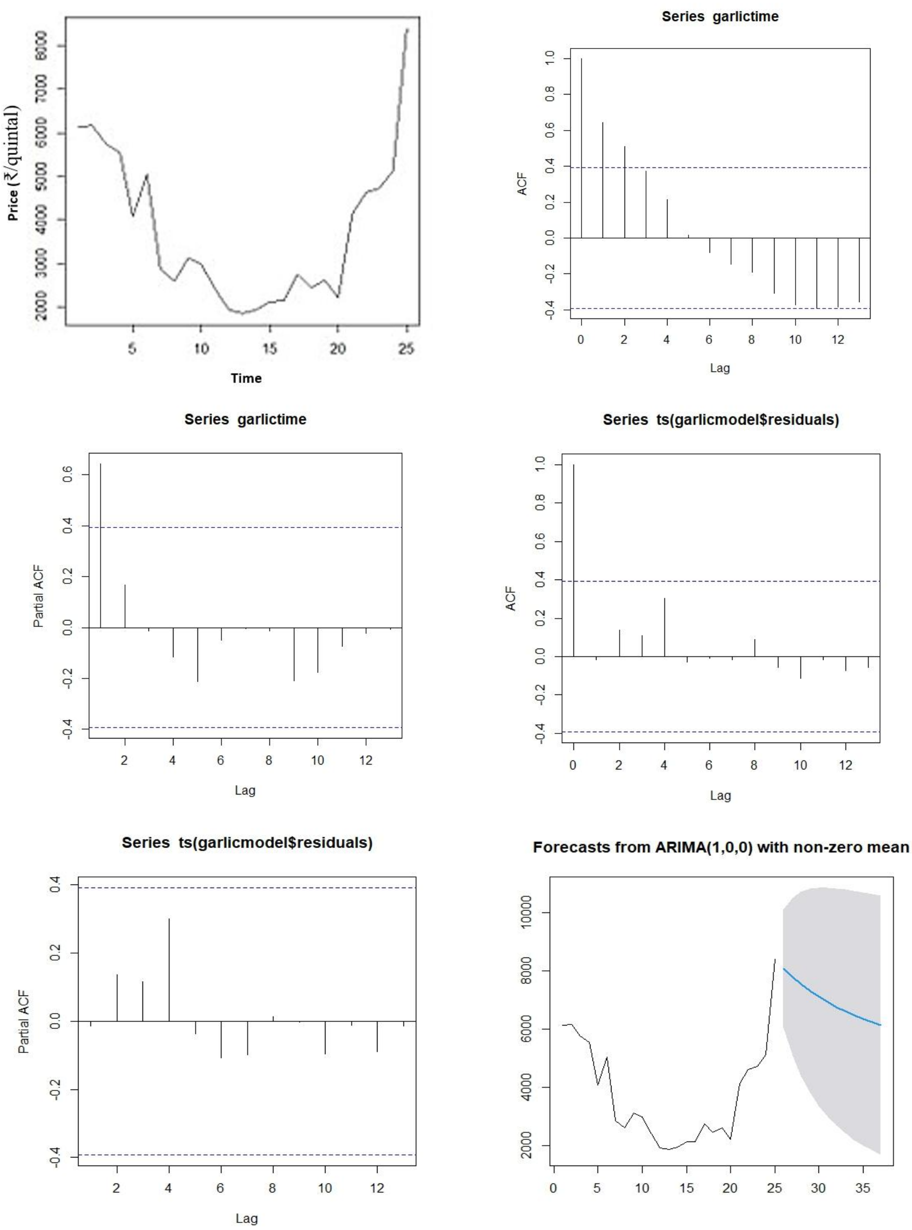

Figure 7. Rplots.

Source: The R Project for Statistical Computing [26].

20.15 percent and a RMSE value of 1007.72.

Table 15. Error measure of various forecasting methods for garlic price series.

Forecast methods	Error measures	
	MAPE	RMSE
3 months SMA	23.86	1197.99
6 months SMA	37.10	1636.23
12 months SMA	44.41	2086.63
SES	29.88	1523.04
ARIMA (1,0,0) with a non-zero mean	20.15	1007.72

4. Conclusions and Recommendations

This study aimed to determine the most appropriate price forecasting model for garlic crops in Rajasthan. Garlic is a significant spice crop in the region, and its production increases yearly. The study aims to help farmers, consumers, agribusiness firms, and policymakers make informed decisions regarding production and marketing. Farmers can benefit from the predicted prices, which are disseminated before the harvest. The study found that the predicted prices were close to the actual market prices in most cases. Time series and causal models were used to forecast garlic prices, and the ARIMA (1,0,0) model with a non-zero mean was found to be the best fit. This was determined by model validation and accuracy measures. The price of garlic is expected to decrease in the next 12 months, ranging from 8083.36 to 6140.46 ₹/quintal. Farmers and policymakers should allocate resources optimally and consider other crops to avoid oversupply and lower prices in the market, which can be detrimental to farmers' income. To ensure market stability and mitigate negative impacts on farmers' income, policymakers should incentivize crop diversification and crop rotation and educate farmers on anticipated price changes. Implementing price stabilization mechanisms like future contracts and exploring export markets can reduce domestic price fluctuations.

Further research is needed to identify the most effective approach for predicting the prices of major commodities both locally and globally. Such a forecast method could enhance market intelligence in agricultural commodity marketing. To reduce errors, it would be useful to investigate more advanced models with a greater number of years. It is important to note that this study did not consider certain factors that influence prices, such as lagged prices, rainfall, or the arrival of commodities in the mandi. Therefore, a more thorough study is necessary that considers these factors.

Author Contributions

The research article was a collaborative effort by Dr. Surjeet Singh Dhaka, Urmila, and Dharavath Poolsingh. Dr. Dhaka formulated the empirical models and drew statistical inferences, while Urmila and Dharavath collected secondary data from various sources, including https://agmarknet.gov.in/PriceTrends/SA_Month_PriMar.aspx, and reviewed the literature. All authors jointly wrote the final draft of the article.

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Data Availability

The data presented in this research article can be obtained upon request from the corresponding author.

Conflict of Interest

The authors disclosed that they do not have any conflict of interest.

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Appendix A

Table A1. Month-wise garlic prices for forecasting.

Month	Prices (₹/quintal)	Month	Prices (₹/quintal)
Jul-21	6138	Aug-22	1934
Aug-21	6167	Sep-22	2119
Sep-21	5747	Oct-22	2134
Oct-21	5534	Nov-22	2756
Nov-21	4076	Dec-22	2439
Dec-21	5050	Jan-23	2618
Jan-22	2859	Feb-23	2209
Feb-22	2598	Mar-23	4135
Mar-22	3125	Apr-23	4623
Apr-22	2973	May-23	4730
May-22	2402	Jun-23	5118
Jun-22	1921	Jul-23	8396
Jul-22	1857		

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RESEARCH ARTICLE

Parasitic Behavior and Separation Countermeasures in Large-scale Farming: Insights from Shijiazhuang, China

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Abstract: A significant number of young and middle-aged farmers are migrating to urban areas, which could facilitate farmland transfer and large-scale farming in China. While there has been active exploration in achieving large-scale farming, a replacement model has not yet been developed. The primary challenge does not stem from the modes themselves, but rather from agricultural stakeholders' parasitic behavior on farmland transfer. This parasitism takes the form of farmers' continued reliance on farmland, village cadres leveraging their power for rent-seeking from farmland, and the virtual parasitism carried out by agricultural intermediaries. Drawing from an investigation conducted in Shijiazhuang, the capital city of Hebei in the North China Plain, this study asserts that the key to promoting orderly farmland transfer lies in establishing a compensation standard founded on principles of social justice. The article culminates in the exploration of the specific compensation standards for farmland transfer.

Keywords: Large-scale farming; Shortage of agricultural labor; Urban-rural income; Agricultural parasitism; Farmland transfer; Compensation standard

1. Introduction

The main driving force of large-scale agricultural production is the improvement of productivity, which expands farmers' living and production radius. To analyze the driving force of agricultural production, different scholars give different answers from different perspectives. With the rapid development of urbanization and industrialization, many rural workers quit the farms and

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migrate to cities, which leads to a shortage of agricultural productivity [1] and promotes farmland transfer and large-scale production [2,3]. Modern agricultural technologies such as mechanization [4], informatization [5], chemical fertilizers and pesticides have improved agricultural production efficiency [6], saved a lot of labor force, and promoted the scale of agricultural production, which promotes the development of urbanization, industrialization and tertiary industry [7]. Some scholars believe that the scale of agricultural production can effectively save the input of agricultural production factors and resources, protect the soil, improve soil organicity and fertility, reduce carbon emissions [8], and be beneficial to the protection of climate and environment [4,9]. As a low-profit industry, agricultural production's low social recognition makes it universal for the breakage of farmers' inter-generational inheritance [10], especially in smallholder production areas [9]. This is a huge challenge for small-scale farming in China. China is also actively exploring ways to solve the dilemma of small-scale farming and large-scale farming suitable for China to improve food security and increase farmers' income [1].

Since the founding of New China, China has seen two major agricultural reforms. The first one is based on the People's Commune in the early days. Since productivity does not match advanced production relations, it is a failure. The second one is the household contract responsibility system—small-scale farming in the late 1970s. It is based on the unit of households, which achieves great success. In 1984, China's food production increased by more than 100 million tons over 1979 but decreased in 1985. And there is no improvement for the following four years in succession. So during this period, large-scale farming was proposed again.

In January 1983, the Central Committee of the Communist Party of China issued "Problems in Current Rural Economic Policy", which encouraged the gradual concentration of land for cultivation experts. In November 1993, the Third Plenary Session of the 14th Central Committee of the Communist Party of China adopted "the Decision of the CPC Central Committee on Certain Issues Concerning the Establishment of a Socialist Market Economy System", which clearly suggested forms of moderate large-scale farming, such as subcontracting and taking shares. In the early 1990s, Pingdu City, Shandong Province, experimented with the "two-field system". With this system, the cultivated land is divided into two categories: One is the ration land, which is shared by everyone to meet basic life security. The other category is contracted land. With this category, the land, except for the ration field, will be retrieved, planned and contracted to improve the agricultural income. This approach was widespread in developed coastal areas, but was soon halted by the Party Central Committee. Zhejiang Jiaxing's two-point and two-way model is based on the "two-field system" [11], but it has not been fully popularized. The "transfer of development rights" program in China—the Chongqing Land Quotas Trading program, might effectively address the farmland preservation and urbanization dilemma [12]. But it still hasn't been able to replicate in the rest of the country.

In the 21st century, farmland transfer and large-scale farming were actively explored in China [13,14]. Both of them have achieved some achievements, but so far reproducible and popularized mode has not been available. It has been focused on exploring reproducible farmland transfer and large-scale farming [9,15]. In fact, the main bottleneck of China's large-scale farming has been explained: With executive order instead of market mechanism, it is hard to ensure that large-scale farming can be carried out with objective conditions and farmers' wishes. If village cadres try to gain personal benefits from it, large-scale farming will eventually go astray [16]. "Executive Order instead of Market Mechanism" and "Village Cadres' Receiving Benefits" are essentially parasites of "rent-seeking with power" and "squeezing profit from agriculture". Agriculture is low-profit [17,18], therefore, when promoting farmland transfer and large-scale farming, parasitism of "squeezing profit from agriculture" can become the last straw that breaks agricultural reform. So it is of significance for this paper to objectively and fairly analyse the parasitism of squeezing profit from agriculture, and explore the stripping method, which is the most important factor in promoting farmland transfer and large-scale farming in China.

Based on the analysis above, we predict that China will experience an increase in farmland transfer and large-scale farming due to the significant migration of labor forces and students to urban areas. However, since 2018, there has been a decline in the scale of farmland transfer, and in some cases, a reverse flow of farmland. To understand this phenomenon, we conducted a survey and identified that parasitic behavior among agricultural stakeholders is impeding the progress of farmland transfer. Through theoretical exploration and on-site investigations, we propose that the key to addressing this issue lies in the establishment of a compensation standard for farmland transfer that upholds principles of social justice. Furthermore, we advocate for government intervention in creating a platform that disseminates relevant information to facilitate the organized transfer of agricultural land. Building on these findings, our research delves deeper into this topic.

2. Promotion of Large-scale Farming Resulted by Lack of Agricultural Labor Force in China

In rural regions internationally, populations are ageing more rapidly than in urban centres [19]. This phenomenon is also beginning to emerge in China. With the development of the social economy and the improvement of agricultural productivity, a large number of rural surplus labors have been swarming into various industries, which forms a large number of "migrant workers". From 1984 to 1988, rural surplus labors mainly flowed to local town enterprises, with "leaving home without leaving the hometown" as its characteristic. In 1986, the Chinese government began to allow state-owned enterprises to recruit rural labour, which stimulated farmers' migration to cities. At the end of the same year (1986), there were 4.8 million registered farmers in the city, and 15 million with estimated unregistered ones. With the rapid development of the economy in the southeast coastal areas of China, 1989 saw the first "migrant workers tide", and the number reached about 30 million. In 1992, Deng Xiaoping's talks during his Southern Tour played a key role in promoting China's economy, which changed farmers' migration into the new characteristic of "leaving home and hometown". In 1997, the number of migrant workers reached 100 million. Since the 21st century, there has been a growing number of migrant farmers [20]. In 2018, there were about 288 million migrant workers, an increase of 1.84 million over the previous year, and the annual growth rate fell to less than 1% for the first time, an increase of 0.6%. In 2020, there were about 286 million migrant workers, a decrease of 1.8% over the previous year, but also accounts for 20.25% of the total population [21]. A large number of farmers migrating to towns promotes urbanization, as well as farmland transfer and large-scale agricultural production [22].

The dominant factor of farmland transfer and large-scale agricultural production is migrating workers, while the breakage of farmers' intergenerational inheritance is the hidden factor [23]. In 2020, the proportion of students attending primary schools in rural areas accounted for 22.85 percent of the total number of students enrolled in primary schools in the whole country, while the proportion of students attending primary schools for rural left-behind children accounted for 34.68 percent of the students attending primary schools in rural areas [24]. After deducting left-behind children in rural areas, the proportion of students enrolled in primary schools in rural areas accounted for only 14.88% of the total number of students enrolled in primary schools. According to the logic of "father-son succession", which means left-behind children in rural areas will migrate to towns, it could be inferred that children born from 2007 to 2013 will have an urbanization rate of at least 85.12%. A large number of farmers, especially young and middle-aged, migrate to cities to work, and accordingly their children go to towns for education, which will accelerate the reduction of the number of farmers. Besides, there is the breakage of farmers' intergenerational inheritance, and there is little possibility that young and middle-aged adults will come back to agriculture [25]. Therefore, mechanization of agriculture and large-scale production will be promoted by the shortage of agricultural labor and farmland circulation has become an urgent issue for Chinese governments. Young and middle-aged rural workers migrate to cities and towns. Rural children have gone to school in towns. These are farmland transfer and large-scale farming driving forces in China.

According to the statistics of the National Bureau of Statistics of China, the area of farmland transferred under contract in 2004 was 58 million acres, and increased to 280 million acres in 2012, with an average annual increase of 21.6%. In 2016, the area of contracted land was 480 million acres, an increase of 200 million acres compared with 2012, with an annual increase of 14.6%. In 2018, the total area of farmland transferred under contract was over 530 million acres, an increase of 50 million acres compared with 2016, with an annual increase of 5.1%. The total area of cultivated land scaling (over 50 acres in southern provinces and over 100 acres in northern provinces) accounted for 28.6% of the total cultivated land area [26]. According to the data, the area of the contracted land transfer is increasing, but the increasing rate is decreasing. One reason for this is the decrease of speed of migrating into cities, the other important reason is the obstacles in farmland transfer. Related groups expect to get profit from farmland transfer, which results in serious parasitism of "squeezing profit from agriculture" [27,28]. Therefore, it should be recognized that agricultural operators are stimulated by agricultural scaling [29,30], it should also be recognized that agricultural scaling is pushed by a lack of farmers. The first factor to promote large-scale production is to make a scientific and reasonable farmland transfer plan, and the core of which focuses on getting rid of parasitism of squeezing profit from agriculture. Scientific judgment of parasitism and the countermeasures are the key to promoting orderly farmland transfer and forming stable, reasonable and moderate large-scale farming.

3. The Parasitism of Farmland Transfer in Large-scale Farming

According to the principle of distribution according to work in China, labors engaging in agricultural production could obtain agricultural income. However, some could also obtain income without participation, and this is regarded as parasitic behavior. Farmers, without participating in farming, transfer their land and obtain dividends, which is a parasitism of dependence on agriculture. Rural cadres' embezzlement of collective assets, corroding agricultural economy and hindering agricultural development, is a kind of power seeking agricultural parasitism with involution caused by unsound management of the rural grassroots [31]. Intermediary institutions like agricultural cooperatives and trusts, born with large-scale farming, obtain the price difference by repackaging and leasing it after retrieving the farmland, and maintaining management by intercepting agricultural financial subsidies [32]. The three major parasites can be displayed in Figure 1.

Based on the investigation of the Shijiazhuang areas, the capital city of Hebei in North China Plain, data analysis and logical reasoning, the three major kinds of parasitism are analyzed as follows.

3.1 Parasitism of Farmers' Dependence on Farmland Transfer

The main reason for farmers' dependence on parasitic can be attributed to two aspects. The first is the urban-rural income gap. The second is the block land price.

In China, the wealth accumulation of peasants is significantly lower than that of urban areas. When farmers migrate to cities, or their children migrate to cities, the original wealth accumulation of rural households is obviously little. This prompted farmers to seize the land contract rights and homestead use rights, hoping to exchange them for more wealth.

China is now imposing block land prices that make the compensation for land expropriation and relocation far higher in urban areas than in remote areas. This partial compensation gap sets a high threshold for farmers to migrate to cities, and also stimulates all land-use rights holders to seek high compensation. This is not conducive to promoting the orderly transfer of land. Farmers regard farmland transfer as a short-term behavior, which is not conducive to the long-term planning of farmland and the organization of agricultural production, and affects soil fertility.

The Income Gap between Urban and Rural Areas Encourages Farmers' Parasitism

The high income, high social welfare and high public basic services in cities attract farmers to leave the countryside and enter the cities [33]. Housing prices in cities are much higher than those in rural areas, which is the main obstacle to farmers' settlement in cities. Peasants look forward to going to the city, but the security of life there cannot be guaranteed. So farmers hold on to the farmland to get more wealth and social security. We could catch these data of disposable income, wage income and property income of urban and rural residents in 2000-2020, which come from the Statistical Yearbooks published by China Statistics Press [34] (Table 1).

The ratio of per capita disposable income has little fluctuation. The maximum value of the ratio of per capita disposable income appeared in 2007, and then decreased gradually. However the absolute gap in per capita disposable income between urban and rural residents is gradually widening. For the wage income, the maximum value of the relative difference was seen in 2004 and then decreased gradually (Table 1). The main reason is that the proportion of per capita disposable wage income of rural residents is increasing gradually, and the growth rate is obviously higher than that of urban residents. The per capita disposable income and wage income of rural residents in 2020 were 17131 yuan and 6974 yuan, an increase of 6.93% and 5.94% over the previous year. The per capita disposable income and wage income of urban residents

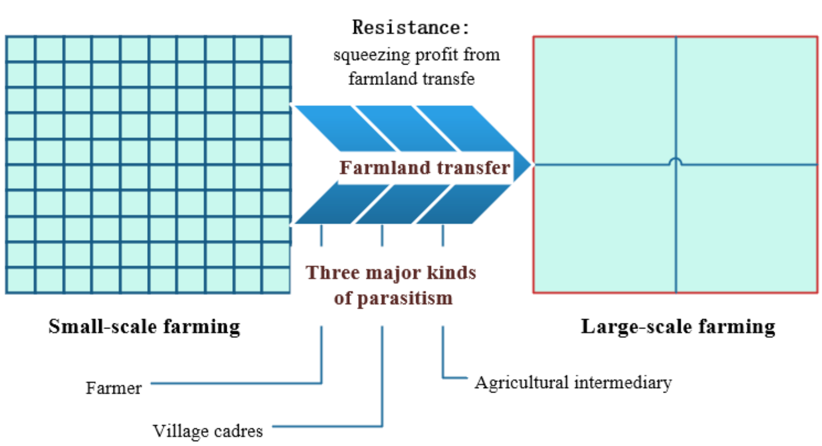

Figure 1. Three major kinds of parasitism in farmland transfer.

Table 1. Disposable income, property income and wage income of urban and rural residents from 2000 to 2020 (yuan).

Year	Per capita disposable income				Per capita wage income				Per capita property income			
	Urban	Rural	Rural-urban ratio	Urban-rural difference	Urban	Rural	Rural-urban ratio	Urban-rural difference	Urban	Rural	Rural-urban ratio	Urban-rural difference
2020	43834	17131	2.56	26703	26381	6974	3.78	19407	4627	419	11.04	4208
2019	42359	16021	2.64	26338	25565	6583	3.88	18982	4391	377	11.65	4014
2018	39251	14617	2.69	24634	23792	5996	3.97	17796	4028	342	11.78	3686
2017	36396	13432	2.71	22964	22201	5498	4.04	16703	3607	303	11.90	3304
2016	33616	12363	2.72	21253	20665	5022	4.11	15643	3271	272	12.03	2999
2015	31195	11422	2.73	19773	19337	4600	4.20	14737	3042	252	12.07	2790
2014	28844	10489	2.75	18355	17937	4152	4.32	13785	2812	222	12.67	2590
2013	26467	9430	2.81	17037	16617	3653	4.55	12964	2552	195	13.09	2357
2012	24127	8389	2.88	15738	15247	3123	4.88	12124	2231	165	13.52	2066
2011	21427	7394	2.90	14033	13673	2734	5.00	10939	1903	157	12.12	1746
2010	18779	6272	2.99	12507	12372	2278	5.43	10094	1414	144	9.82	1270
2009	16901	5435	3.11	11466	11333	1940	5.84	9393	1088	122	8.92	966
2008	15549	4999	3.11	10550	10438	1766	5.91	8672	905	112	8.08	793
2007	13603	4327	3.14	9276	9561	1543	6.20	8018	758	100	7.58	658
2006	11620	3731	3.11	7889	8305	1336	6.22	6969	484	81	5.98	403
2005	10382	3370	3.08	7012	7456	1147	6.50	6309	352	73	4.82	279
2004	9335	3027	3.08	6308	6900	980	7.04	5920	271	65	4.17	206
2003	8406	2690	3.12	5716	6224	905	6.88	5319	209	57	3.67	152
2002	7652	2529	3.03	5123	5610	829	6.77	4781	144	45	3.20	99
2001	6824	2407	2.84	4417	4723	764	6.18	3959	179	43	4.16	136
2000	6256	2282	2.74	3974	4405	697	6.32	3708	159	42	3.79	117

Note: Rural-urban ratio = Urban/Rural; Urban-rural difference = Urban-Rural. Data from China Statistical Yearbook.

were 43834 yuan and 26381 yuan, an increase of 3.48% and 3.19% over the previous year. The relative gap narrows, but because of the big difference between the base figures, the absolute difference is not narrowing but widening.

The growth rate of rural residents' income is higher than that of urban residents, and the income base of rural residents is less than that of urban residents. Therefore, it can be predicted how many years it will take for rural residents to catch up with urban income through the following Equation (1) by the data in Table 1.

$$\begin{cases} FI\{\prod_{i=1}^{m}[1+r_{FI}(i)]\}^{\frac{n}{m}} \geq UI\{\prod_{j=1}^{m}[1+r_{UI}(j)]\}^{\frac{n}{m}} \\ FI\{\prod_{i=1}^{m}[1+r_{FI}(i)]\}^{\frac{n-1}{m}} < UI\{\prod_{j=1}^{m}[1+r_{UI}(j)]\}^{\frac{n-1}{m}} \end{cases} \tag{1}$$

Solving the Equation (1), it can get n from Equation (2):

$$1+m\ln\frac{UI}{FI}\times\left\{\ln\frac{\prod_{i=1}^{m}[1+r_{FI}(i)]}{\prod_{j=1}^{m}[1+r_{UI}(j)]}\right\}^{-1} > n \geq m\ln\frac{UI}{FI}\times\left\{\ln\frac{\prod_{i=1}^{m}[1+r_{FI}(i)]}{\prod_{j=1}^{m}[1+r_{UI}(j)]}\right\}^{-1} \tag{2}$$

where FI is the income of farmers (rural residents), UI means the income of urban residents, $r_{FI}(i)$ reflects the growth rate of FI in ith *year,* $r_{UI}(j)$ represents the growth rate of UI in jth *year*, m means the selected observation period, n is the function of being solved, indicating how many years the income of rural residents will catch urban residents.

Take 2020 as the benchmark year, nearly ten years (m=10) as the observation period. By taking the per capita disposable income (DI) and per capita wage income (WI) of urban and rural residents as the research objects, it can be calculated $n^{DI} = 57$, $n^{WI} = 40$.

$n^{DI} = 57$ means that it will take 57 years for the disposable income of rural residents to have equal income with urban residents, in 2077. It is based on the average growth rate of the disposable income of urban and rural residents in the past decade.

$n^{WI} = 40$ means that it will take 40 years for the wage income of rural residents to have equal income with urban residents, in 2066.

The most obvious is the gap in income between urban and rural residents, which has seriously prevented farmers from settling down in cities.

From the perspective of urban and rural property values, the gap between them is very significant. In 2013, China's Bureau of Statistics unified the statistical standards for residents' property. Since then, the relative value of the gap has gradually narrowed, but the property gap by 2020 is as high as 11.04 times. Property income in the statistics only includes interest, rent, etc., but not premium income from transferring the ownership of the assets. If this premium income is included, the gap between urban and rural property income will expand to 30 times. For the Chinese traditional concept of buying houses to settle down, the gap in the ability to pay for houses, or the wealth gap brought by urban and rural real estate, is huge, and has gradually become difficult to straddle.

Besides, the wage income and property income difference, with absolute difference expanding, force the peasants to hold the land for survival, which is reflected in farmers' high degree of dependence on the contracting right to farmland and the use right of the homestead. Then, gradually, the right to land is applied to "become rich by relocation", which deviates from the economic system of distribution according to work.

ALCGVAP Encourages Farmers' Parasitism

At present, China's farmland expropriation compensation is based on the *Agricultural Land Classification Gradation and Valuation of Area Piece* (*ALCGVAP*). It is regularly issued by the province. *ALCGVAP* is calculated according to factors such as land category, output value, land location, agricultural land grade, per capita number of cultivated land, land supply and demand relationship, the local economic development level and the minimum living security level of urban residents. Its main factor is the land location. The land that is closer to the town center has more advantages, and has more farmland expropriation compensation. In fact, the expropriation of farmland is the government's redemption of land from farmers, which means farmers sell the right to use farmland to the government. Therefore, the gap between farmland transfer compensation and expropriation compensation can be judged by the farmland sale-to-rent ratio (*FSRR*). This ratio is the comparison between the compensation for the expropriation of a piece of farmland and the compensation for this land leasing. The calculation formula is as follows:

$$FSRR = \frac{FEC}{FTC} \tag{3}$$

where, *FSRR* is the farmland sale-to-rent ratio, *FEC* is the farmland expropriation compensation which is published by the provincial government through *ALCGVAP* regularly, *FTC* means the farmland transfer compensation, which is the price of leasing farmland.

In order to reflect the situation objectively, the plots with the same agricultural land output value but distinct land locations in Shijiazhuang area were selected for analysis. The fertility of farmland and the output value of crops in the main urban area of Shijiazhuang, Luancheng district and Zhao County are almost the same. The three regions are connected in turn. Their farmland is leased for agricultural production at similar prices. The locations of the three regions on the map are shown in Figure 2.

Through the investigation of the three regions in the North China Plain, the farmland transfer can be divided into three forms.

The first type neither depends on government subsidies, nor changes the nature of farmland production. It is farmland transfer by single leasing out (*SLO*). The annual leasing price is 3-12 thousand yuan/ha, about 1/4 of farmland output value. When the lease price is below 3 thousand yuan/ha, farmers will abandon leasing out and choose farming methods of "once and for all", such as planting trees, or idling of farmland.

The second type is farmland transfer by changing production leasing out (*CPLO*). It does not depend on government subsidies, but changes the nature of the original farmland production, such as cultivation of cash crops like medicinal herbs and vegetable sheds. The annual leasing price is about 15-24 thousand yuan/ha, more than 1/2 of the output value of common farmland.

The third kind is farmland transfer depending on subsidy leasing out (*DSLO*). It depends on government subsidies, and some agricultural land changes the nature of the original farmland production. For the farmland transfer that obtains special government subsidy, the annual leasing price is 9-18 thousand yuan/ha, about 1/2 of the output value of common agricultural land. There is timeliness for government subsidy, so it is easy to emerge a phenomenon of "abandonment of cultivation and break of the contract" when the government subsidy period is over and subsidy can not be enjoyed.

The interval feature of farmland lease price mainly depends on its fertility and the local agricultural labor force. In order to facilitate the calculation, the average value is used to represent the interval value of the farmland transfer compensation. This requires an emendation of Equation (3), which is as follows:

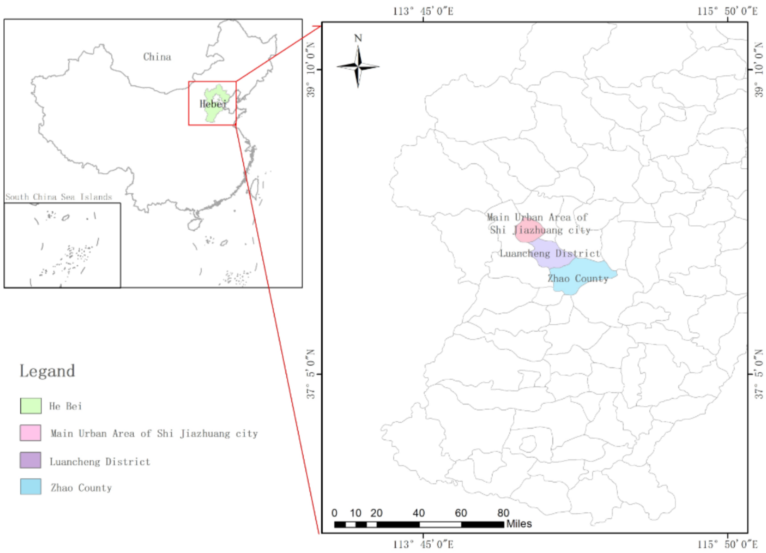

Figure 2. Map of Shijiazhuang area in North China plain.

$$FSRR' = \frac{FEC}{(FTC_{\min} + FTC_{\max})/2} \tag{4}$$

where, $FSRR'$ is the amended value of farmland sale-to-rent ratio, FTC_{min} is the minimum value of farmland transfer compensation, and FTC_{max} is the maximum value.

In 2020, Hebei Province published *Agricultural Land Classification Gradation and Valuation of Area Piece in Hebei Province* [35]. The land of the main urban area of Shijiazhuang city was divided into four classes. Luancheng district was divided into two classes. Zhao County was divided into five classes.

In order to perceive the block grade division more directly, the three observation regions in Figure 2 are enlarged and simplified to obtain Figure 3.

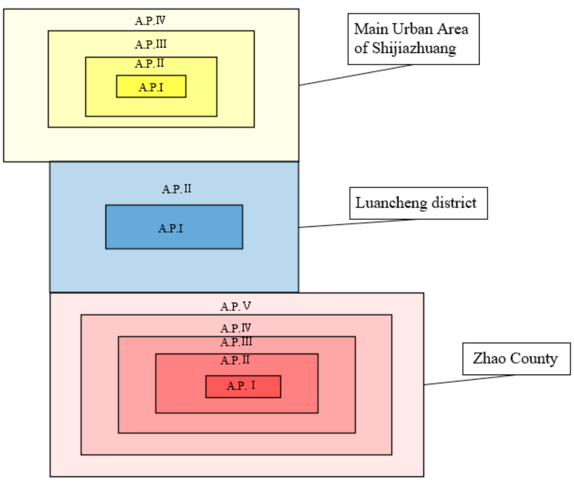

Figure 3. The plot of land price classification in three observation regions.

According to the block land prices of the three survey regions, and the data of farmland leasing prices were surveyed. **Table 2** is obtained by the Equation (4).

Table 2 indicates that the farmland expropriation compensation in *A.P. I* of the main urban area of Shijiazhuang city was 900 times higher than that of *SLO*. It means that the compensation for the expropriated farmland in *A.P. I* of the main urban area was equivalent to leasing the farmland for 900 years. There was relatively little agricultural land in *A.P. I* of the main urban area, most of which belonged to the *A.P. III* and *A.P. IV*. The compensations for the *A.P. IV* in the main urban area of Shijiazhuang city were 300 times higher than that of *SLO*, 167 times higher than that of *CPLO* and 115 times higher than that of *DSLO*.

A.P. II in the Luancheng district, the farmland expropriation compensation was 240 times higher than that of *SLO*, 133 times higher than that of *CPLO* and 92 times higher than that of *DSLO*.

As a traditional agricultural production area, except for *A.P. I* and *A.P. II*, the other lands in Zhao County are mostly farmlands. Even for A.P.V, the compensations were 159 times higher than that of *SLO*, 88 times higher than that of *CPLO* and 61 times higher than that of *DSLO*. This evidently reflected that the compensation for expropriation farmland was much higher than the farmland transfer compensation.

From Table 2 and Figure 3, it is easy to analyze the two reasons why farmers tightly hold the right of farmland and are unwilling to withdraw, and transfer farmland for a long time. One is the farmland sale-to-rent ratio, and the other is the gap in land compensation at regional boundaries.

Table 2. Sale-to-rent ratio of the three survey regions in Shijiazhuang area.

	Main urban area of Shijiazhuang city (thousand yuan/ha)				**Luancheng district (thousand yuan/ha)**		**Zhao County (thousand yuan/ha)**				
	A.P.I	A.P.II	A.P.III	A.P.IV	A.P.I	A.P.II	A.P.I	A.P.II	A.P.III	A.P.IV	A.P.V
	675	450	315	225	213	180	126	125	123	120	119
SLO	900	600	420	300	284	240	168	167	164	160	159
CPLO	500	333	233	167	158	133	94	93	91	89	88
DSLO	346	231	162	115	109	92	65	64	63	62	61

Note: A.P. is an area piece, which is a block of the city or county. The prices of different A.P. were published by *ALCGVAP in Hebei Province*, in 2020. 10.

Farmland sale-to-rent ratio makes farmers hope that farmland will be expropriated. Regional boundary compensation difference causes poor rich and poor. The social and economic value produced by a piece of farmland is the same, just because the regional affiliation is different, the compensation difference is very significant. When expropriating farmland, farmers hope that their farmland can be divided into high grade plots to obtain more compensation. When organizing farmland transfer, farmers prefer short-term farmland transfer.

According to the above analysis, it is known that the parasitism of farmers' dependence on farmland transfer mainly stems from the urban-rural income gap and the block land price (Figure 4).

The urban-rural income gap makes farmers afraid to give up the right to use farmland, and want to use farmland in exchange for more social security. Block land prices to widen the gap between rich and poor. When the gap is too large, would affect the enthusiasm of farmers to work, and affect the healthy development of the economy.

As the contracting right of farmland belongs to the welfare brought by the identity of collective organizations, farmers are reluctant to move out of rural collective organizations, which not only affects the orderly transfer of farmland, but also hinders the orderly promotion of urbanization.

3.2 The Involution Parasitism of Village Cadres' Rent-seeking with Power

Rent-seeking with power refers to an activity that seeks or maintains vested interests through the power of cadres. When there lack of effective restrictions and supervision, there will be rent-seeking with power. Because of the weak restrictions and supervision in rural areas, there is serious rent-seeking with power [36]. In 1997, in Pingdu City of Shandong Province, a "two-field system" was introduced, which improved the efficiency of agricultural production and the collective economy. In some developed coastal areas, the "two-field system" was promoted quickly but failed. The direct cause of the failure is that farmers' contract right to land is forcibly reclaimed, and the contract fee for land is increased at will, which increases farmers' burden and results in farmers' strong dissatisfaction. Therefore, this "two-field system" is not supported by the Central Committee. This is the typical failure of large-scale farming due to cadres' right to rent-

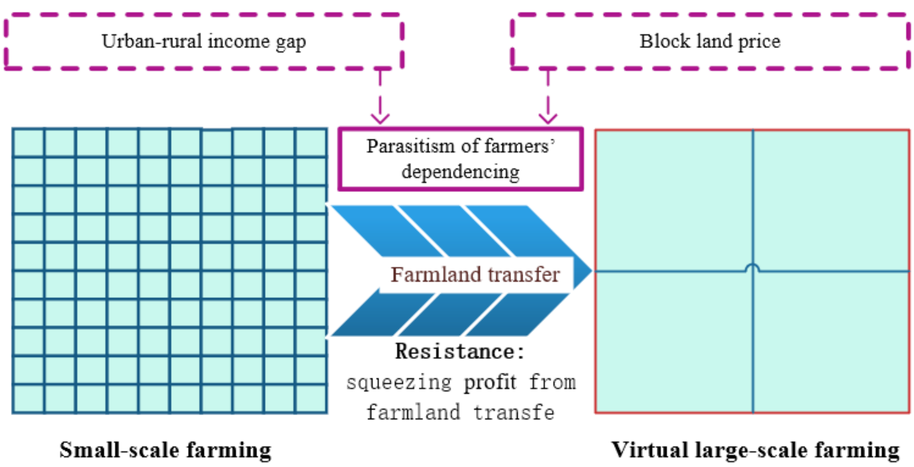

Figure 4. Two main reasons for parasitism of farmers' dependence on farmland transfer.

seeking. The more times farmland is transferred, the more space for power rent-seeking, and the higher the probability of failure. Based on this, some scholars propose marketization [37,38]. That means that land use rights are fixed [4] and land is transferred orderly [39,40] to balance cadres' right to rent-seeking.

In the 1970s, land transfer and large-scale farming with the form of market orientation and private ownership of land were practised in Japan [41]. In 1962, Japan's Agricultural Land Law stipulated that the top limit of the possession of farmland is moderated and eligible agricultural legal persons are allowed to buy farmland to expand agricultural production. Large farmer-households are encouraged to buy farmland from small ones. These reforms allowed for free trade of farmland introduced market mechanisms to expand the scaling, but it was not effective.

By 1970, its scaling had not increased but declined from 521 thousand in 1960 to 353 thousand. The reasons are as follows.

First, in the absence of integrated planning and management, it is difficult to form effective scaling management for the small scale of private land ownership. Second, with the development of industrialization and urbanization, the marketization and privatization of land increase the price of land, which increases the cost of land and weakens the scaling of land. From 1960 to 1973, the price of paddy fields in Japan increased nearly 14 times for non-agricultural land and 17 times for non-agricultural highlands. Land prices for agricultural paddy fields increased by 10 times, and for agricultural highlands by 14 times [42].

The marketization and privatization of land increase the farmland cost and make it difficult to realize the scaling of agricultural production. In 1975, the total area of idle land in Japan was 131 thousand hectares and it had increased to 218 thousand hectares by 2015. One of the important reasons for this is the high price of farmland. To get more compensation, the owners of farmland prefer idle land to transfer the land [43].

According to the historical experience of Japan, it is known that private ownership of land and marketization have not promoted orderly land transfer and large-scale farming, but have obviously contributed to the rise of farmland prices and the waste of land. It is not ideal to promote large-scale farming through marketization, and there is the risk of capitalization of agriculture. Based on the international experience, it is common that large-scale farming is governed, subsidized and supported by the government. For example, from 1962 to 1975, the French government bought 840 thousand hectares of agricultural land at high prices and sold 710 thousand hectares to 106 thousand farms at low prices. In 1967, the Agriculture Act of England provided £2,000 at most for people who gave up on small-scale farming; From 1966 to 1975, West Germany implemented a "bonus for change of occupation" to help small-scale farmers to change their occupation, which promoted the transfer of 37.13 million hectares of land [44].

Agriculture is a matter of national security, and all countries attach great importance to agriculture. When only the government or the market is used to promote the farmland transfer, it would lead to failure in the end (Figure 5). When village cadres use power on behalf of the government, it is inevitable to steal agricultural subsidies and use power to gain benefits for individuals. The invisible hand of the market will drive up land prices and eventually hinder the orderly farmland transfer.

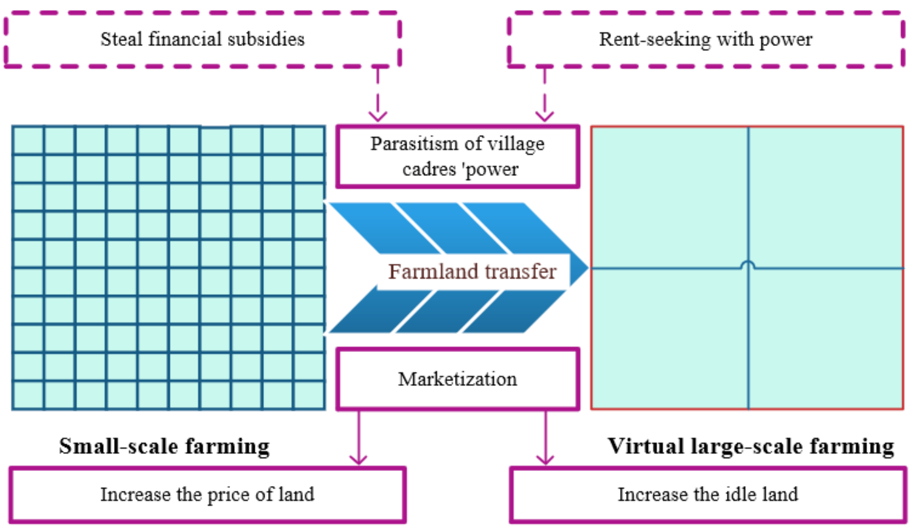

Figure 5. The inherent inadequacy of government and market in farmland transfer.

There is a risk for both pure marketization and cadres' rent-seeking with power. The only method to get rid of parasitism in large-scale agricultural production is to set up a policy of compensation with social justice for land transfer, which will make it open and transparent and achieve a balance between safety and efficiency.

3.3 Agricultural Intermediary's Virtual Parasitism

Most Cooperatives were Virtual Organization

In October 2006, the 24th meeting of the Standing Committee of the 10th National People's Congress adopted the Law of the People's Republic of China on Peasant Professional Cooperatives. It is stipulated that "On the basis of the contracted management of rural families, farmers' professional cooperatives are mutually supportive economic organizations that ally voluntarily and manage democratically." It operates the same agricultural production, or provides and utilizes the management services of the same agricultural production. Farmers' professional cooperatives, whose members are the main target of service, provide services such as the purchase of agricultural means of production, the sale, processing, transportation, storage of agricultural products, technology and information related to agricultural operation. Article 3, paragraph 3, provides that "It is free to join and withdraw from the cooperative" [45].

According to the China Bureau of Statistics, by the end of 2020, the number of agricultural cooperatives had reached 2.241 million [46], and 512,500 administrative villages [47], which means administrative villages have four agricultural cooperatives in China. Most agricultural cooperatives are in a virtual and parasitic state [48]. According to the investigation of some parts of North China, it is found that in most cooperatives in order to attract farmers to join the cooperative, some agricultural materials (a bag of fertilizer, a bottle of pesticide, etc.) are distributed as conditions for joining the cooperative. After joining the cooperative, farmers' activities are nothing but mainly submitting their identity cards and receiving prizes.

Cooperatives are voluntary cooperative organizations in which the working people join together voluntarily for cooperative production and cooperative operation. According to this definition, the cooperatives are not very different from production teams. That is to say, it is not different from village committees. Village committees cannot manage agricultural operations, and cooperatives could not be more effective. The core members of the cooperative are mostly the leaders of the village committee, or those who have nepotism with the village committee. Village committees cannot rejuvenate agriculture, and the efforts of cooperatives may be limited.

Most cooperatives were virtual organizations. It could not organize agricultural production. Its reasons could be attributed to the following two points.

First, farmers don't need co-production.

A Cooperative is a mutually supportive economic organization that provides services for farmers of the same agricultural products or servers of the same type of agricultural operation. With the increase in migrant workers' income, farmers have less and less labor power to engage in agricultural production. The mechanization and singularization of agricultural production are more and more obvious. Singlularization facilitates the purchase of farm products. At present, wheat harvesting in North China is accompanied by storage. Corn is saved for food, and can also be sold for storage conveniently. Sowing and harvesting are finished by employing an agricultural machinery service team. Harvesting and selling for storage can be carried out at the same time, and the whole process can be completely free of cooperatives. This is also one of the main reasons why most cooperatives are meaningless.

Second, cooperative organizations could not provide risk protection.

The benefits brought by small-scale farming are limited, and based on opportunity cost, most farmers are reluctant to invest too much time, energy and capital in agricultural production. Farming of singlularization with low input and income has become the best choice for farmers to engage in agricultural production under the over-decentralized mode of smallholder production, which is an important reason for the imbalance of the agricultural supply structure in China. If cooperatives do not agree with the farming of singularization and would change agricultural products, they need to provide risk management for farmers. Because cooperatives are non-profit organizations and lack financial support in guiding agricultural production, it is difficult to change farmers' farming. In addition, the popularity of e-commerce increases the convenience of doing with the means of production, and farmers can improve their efficiency without intermediaries. Cooperatives' value in helping to buy agricultural means of production is also diminishing.

Gaining benefit directly from selling their produce or further processing of the produce, which one do farmers choose? Farmers prefer the former. The reasons are as follows.

First, agricultural income is no longer the main source of income for farmers. So with guarantees of farmers' rations, to get cash by selling agricultural products is their best option.

Second, there are risks in further processing. The risk of market uncertainty and the risk of intermediary managers stealing benefits [49]. Because of the uncertainty factors, the ideal choice is not to participate in further processing to avoid risk.

Most cooperatives were in a virtual parasitic state mainly reflected in the stealing of agricultural financial subsidies issued by the government and could not really organize agricultural production (Figure 6).

Other Agricultural Intermediary Organizations are in a Virtual State

For land trusteeship, contract farming, land bank and so on, which were some enthusiasm to solve the problem of idle land and organize agriculture production, but most of them were in a virtual state.

Farmers, unwilling or unable to engage in agricultural production, lease their farmland to intermediaries (such as cooperatives, land banks, etc.) to obtain a certain amount of "fees for storage". Large-scale agricultural operators pay a certain amount of "fees for hiring" from the intermediaries. The difference between "fees for storage" and "fees for hiring", should be obtained by farmers or agricultural operators. But it was taken away by intermediaries. This is a kind of parasitism for squeezing profit from farmland transfer. For agricultural operators, agriculture is low profit industry and it can be guaranteed by intensive cultivation and government financial subsidies. Farmers receive low compensation for farmland transfer. In this circumstance, the intermediary organizations that organize large-scale agricultural production take some profits from farmland transfer. Eventually, it makes it difficult for all parties to obtain satisfactory benefits. This led to farmland transfer and large-scale farming was difficult to promote in China.

The main reason that agricultural intermediaries can not organize agricultural scale production is that some farmers are unwilling to transfer out of their land. They still want to work on their farmland. This makes agricultural land unable to organize effective scale production. It is difficult to bring the benefits from scale production. Therefore, agricultural intermediaries need to obtain agricultural subsidies and organize fragmented large-scale farming (Figure 7). The irregularly circled graphs in the fragmented large-scale farming of Figure 7 represent the large-scale production by agricultural intermediaries. Fragmented large-scale farming relies on local supportive policies. It is difficult to be fully promoted in the whole region.

Agricultural intermediary organizations play a more catalytic role in organizing agricultural production. But with the perfection of the mechanism of the agricultural market, this role will gradually decline, which is also the important reason for the weakening of of Japanese Agricultural Association in recent years [50]. With the improvement and stability of the agricultural market, the role of agricultural intermediary will focus on providing services for agricultural production rather than squeezing profit from farmland transfer. Paying attention to the role of agricultural intermediary services and getting rid of the parasitism of squeezing profit from farmland transfer is of positive significance for agricultural reform in China.

The intersection of three kinds of parasitism is the farmland transfer. To strip the parasitic behavior in the farmland transfer, it is necessary to establish the compensation standard of farmland transfer with social justice. Only by clarifying the compensation standard could we build an open and transparent farmland transfer system, and promote orderly farmland transfer and larger-scale farming. The specific framework is shown in Figure 8.

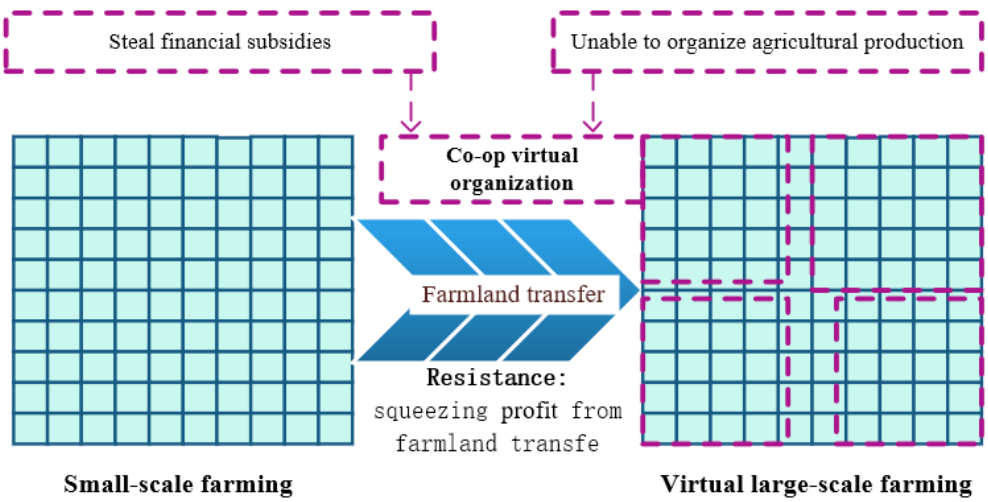

Figure 6. Virtual large-scale farming organized by cooperatives.

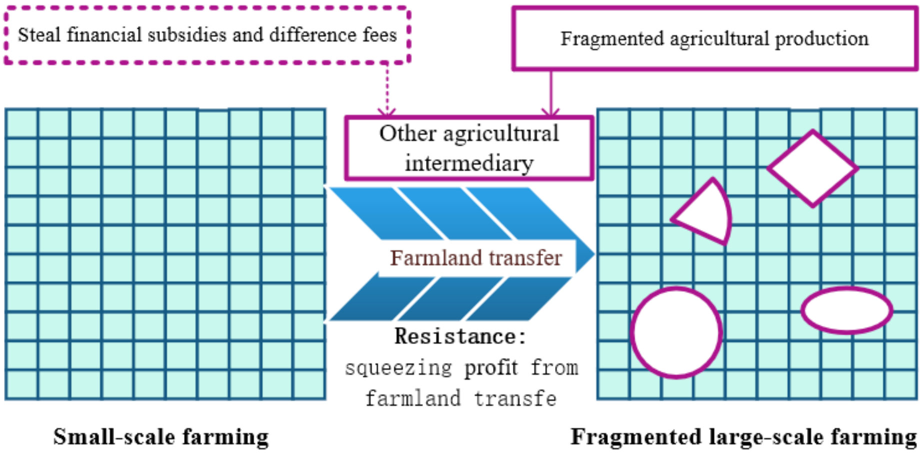

Figure 7. Fragmented large-scale farming organized by other agricultural intermediaries.

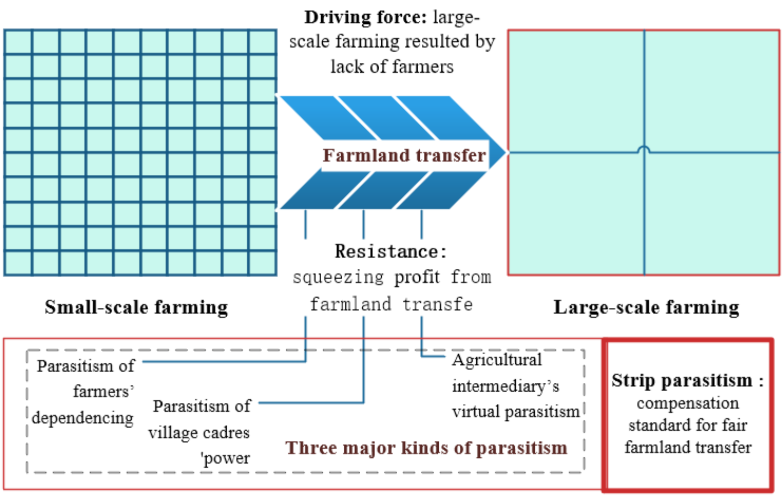

Figure 8. The driving force and resistance of farmland transfer and strip strategy.

A large number of young and middle-aged rural labor force entered the towns, and rural children entered the towns to study, which accelerated the breakage of farmers' intergenerational inheritance. A shortage of agricultural Labour is driving farmland transfers. The urban-rural income gap and block land prices would set a high threshold for rural residents to settle down in cities. This makes farmers hope that their land use rights could obtain more social security when the land is transferred. Village cadres used their power to gain more benefits for themselves. It is difficult for agricultural cooperatives and agricultural intermediaries to find profit points from the value of their providing services, so they inevitably need to steal benefits from the farmland transfer. Three kinds of parasitic behaviors interweave with each other, hindering the orderly farmland transfer. The only way to strip parasitism of farmland transfer is by setting up compensation standards with social justice and forming an open and transparent process for farmland transfer.

4. Theory and Realistic Basis for Compensation Standard for Fair Farmland Transfer

The first step of large-scale farming is the farmland transfer [51]. From the above analysis, it can be known that the intersection of the three kinds of agricultural parasitism is farmland transfer. Therefore, compensation standard for farmland transfer with social justice is the key to solving the bottleneck of large-scale agricultural production, and it also determines the breadth and depth of agricultural production scaling.

4.1 Theoretical Basis of Compensation Standard for Fair Farmland Transfer

Before discussing the fairness of compensation standard for farmland transfer, it is necessary to make it clear whether the farmland transfer belongs to the primary distribution or the secondary distribution. With the implementation of household contract responsibility system, cultivators begin to own their own farmlands. According to the distribution system, with contracting rights, farmers' income from farming belongs to primary distribution. The great success of the household contract responsibility system is attributed to the system of distribution according to work. Farmland transfer is a step in which farmers leave their farmlands and lease the farmland out to obtain corresponding compensation, which is definitely secondary distribution. So, the leasing out, transfer, expropriation of farmland and relocation of houses are all secondary distribution. Secondary distribution should reflect the social justice constructed by stability, justice and efficiency.

Based on secondary distribution, the social justice of farmland transfer should be reflected in two aspects. One is to prevent the occurrence of low compensation for the transfer of farmland, which will result in farmers' reluctance to participate in the transfer, idle lands, and the loss of basic (rations) security for farmers, thus forming "slums". Second, excessive compensation for farmland transfer should be avoided, because it will raise the feeling of unfairness for the non-compensation group and result in the rich and poor.

The Constitution of the People's Republic of China clearly stipulates that the foundation of the socialist economic system of the People's Republic of China is the socialist public ownership of the means of production, and the main distribution system is distribution according to work [52]. Rural collective economic organization is a kind of collective ownership system of working masses based on socialist public ownership, and should not be a tool of transferring land use to obtain huge social wealth. The exchange of land use rights for huge wealth artificially widens the gap between rich and poor, violates the basic economic system of distribution according to work and weakens citizens' enthusiasm for labor.

On the one hand, some exchange land use rights for large wealth, and their enthusiasm for labor weakens because of the wealth. On the other hand, when the wealth compensated by the land use right exceeds the wealth unavailable for a generation through labor, these people will lose enthusiasm for labor because they cannot become wealthy through labor. Because of this weakening of enthusiasm for labor, creativity for material wealth will inevitably decrease, which will lead to economic depression, inefficient or ineffective social governance.

Successful social governance requires ensuring an increase of economic efficiency and public service efficiency, striving to achieve complete equality of opportunities for development for members of society, guaranteeing survival at the bottom line, fairness on differences of salary, and achieving social stability by amplifying the law and promoting morality [53]. For a country, the standard of success in social governance revolves around social justice built by stability, efficiency and equality [54]. The principle of social justice regarding land transfer and compensation for relocation was issued by the State Council in October 2004 in the Decision of the State Council on Deepening Reform and Intensifying Land Management [55], which stipulates that "the life level of the farmers whose land have been expropriated shall not be reduced".

In August 2006, the State Council issued the Notice of the State Council on Strengthening the Control of Land [56] to improve the compensation for expropriated peasants, and put forward that "The original life level of the expropriated peasants will not be reduced and the long-term livelihood will be guaranteed". The implication of "the original life level will not be decreased" should refer to two levels. One is the original life level will not be decreased to guarantee the bottom line of compensation. Second, excessive compensation should be avoided to prevent artificial differences between rich and poor. At present, a new gap between rich and poor has resulted from compensation for relocation [57], and the idea of "becoming rich" through relocation has intensified people's dependence on the right to land use.

Land is the basis for the survival of the people of the country, and the right to land use should be more reflected in social security, rather than as a tool for citizens to seek huge wealth. Based on the rule of social justice, getting rid of the parasites in the farmland transfer means setting up the fairness of compensation standards for farmland transfer.

4.2 Status of Compensation for Farmland Transfer and Expropriation in Investigated Area

Through the investigation of the three regions of the Shijiazhuang area in the two-cropping areas of the North China Plain. The farmland leasing price was obtained in Table 2. Through communication with farmers, it could be known that the leasing price of farmland was 1/2 of the output value of agricultural land. When the value of agricultural land was about 9-18 thousand yuan/ha, farmers had high satisfaction. The output value of farmland is regarded as the base for the leasing price. Its main reason is to prevent the rising of price of agricultural products which will result in farmers' losing the security of their rations.

According to the data of the China Statistical Yearbook, in 2020, nationwide per capita consumption of grain (unprocessed) and vegetables in China is shown in Table 3 [34].

Table 3. Nationwide per capita consumption of grain and vegetable in China in 2020 (kg).

Grain (unprocessed)				Vegetable and edible mushroom	
	Cereals	Tuber	Beans and products		Fresh vegetables
141.2				103.7	
	128.1	3.1	10.0		100.2

The nationwide per capita consumption of grain (unprocessed) was 141.2 kg, and 103.7 kg of vegetable and edible mushroom (Table 3). According to the statistics bulletin in 2020, the agricultural household registrational population is little less than 777 million people, the annual grain cultivation area is 116.77 million hectares, and the annual grain output is 669.49 million tons [58]. According to this, it can be calculated that the agricultural household has a per capita of 0.15 hectares of a grain planting area, and the grain output per hectare is about 5733 kg. When the compensation for farmland transfer is 1/4 of the value of farmland output, the average agricultural household can get 215 kg of grain for farmland transfer, which can meet one person's grain (unprocessed) requirement for one year. When the compensation for farmland transfer is 1/2 of the value of farmland output, it will be about 430 kg of grain, which can meet the grain (unprocessed) needs of two persons for one year and the vegetable and edible mushroom needs of one person.

When the compensation of farmland transfer is 1/4-1/2 of the value of farmland output, the basic life of farmers who transfer out their farmland could be satisfied. Since there is no need to engage in agricultural production, this agricultural surplus labor force could earn wage income from other industries to improve their lives. This is the way to achieve urbanization.

5. Conclusions and Implications

In recent years, informatization and mechanization have significantly improved agricultural productivity, expanded the radius of farmers engaged in agricultural production and life, and consolidated the foundation for large-scale agricultural production in China. With the development of urbanization, a shortage of agricultural labor force leads to farmland transfer and large-scale agricultural production. The parasitism of "squeezing profit from agriculture" was declining the speed of farmland transfer.

Farmers' dependence on farmland stems from the urban-rural income gap and block land price. The greater the gap is, the stronger the dependence is. Farmers' irrational expectation for compensation interferes with farmland transfer and results in idle land. Village cadres' rent-seeking with power depletes the rural collective economy and hastens the decline of rural areas. The imperfect system of supervision and restriction on village cadres increases the possibility for village cadres to reap benefits from farmland transfer and large-scale farming. Intermediary institutions have promoted large-scale farming to a certain extent, but they rely on government financial subsidies and price difference of farmland transfer to maintain their operation. It organizes large-scale farming with loose structure and unsustainability.

Compensation standards for farmland transfer with social justice and fair, which can effectively resolve the parasitism of "squeezing profit from agriculture" in farmland transfer. Compensation standards for farmland transfer with social justice lay a foundation for the openness and transparency of farmland transfer, which is of positive significance to prevent cassette operation and rent-seeking with power. It can also make farmers treat farmland use rights in a rational manner and take part in the farmland transfer easily, and can promote the orderly implementation of agricultural production.

Based on the above conclusions, this paper has two implications:

(1) Based on logical analysis and investigation of the Shijiazhuang area in two cropping areas of North China Plain, the output value of farmland can be relied on to set compensation standards for farmland transfer.

First, the compensation standard for leasing-out farmland transfer does not change the nature of the land. Owing to the contract right of farmland, farmers can recall their land on expiration of the contract. Therefore, the leasing price in the market should be the compensation standard for leasing-out farmland transfer, that is, 1/4-1/2 of the original agricultural output value of the farmland. This compensation can meet farmers' basic food requirements after their farmland transfer and sustain their livelihoods. Because of this, it is necessary for landless farmers to actively engage in productive labor to improve the quality of life, which meets the requirements of distribution according to work.

Second, the compensation standard for expropriation and relocation through which the nature of farmland is changed. Farmers will lose their land and the right to contract. This kind of expropriation is usually in the suburbs of the city where the living cost is relatively high, and the whole income of farmland can be regarded as its standard of compensation. This enables these farmers to obtain all the farmland earnings without taking part in agricultural production, and undoubtedly ensures that there is no decrease in their living standard. After land expropriation, stable life can be guaranteed and quality of life can be improved through labor, which is beneficial for the sustainable development of the national economy. At the same time, the thought of "becoming rich" through expropriation and relocation can be prevented, and the social order of distribution according to work can be maintained.

(2) A farmland transfer platform can be built on the basis of government credibility. Constructing a unified transfer platform based on the government's credibility to guarantee the authenticity, openness and transparency of information. In recent years, all the provinces have built the agricultural land transfer platform. By clicking through these platforms, they were less than 15% really operating. Improving the platform construction and improving the platform operation supervision mechanism will have a positive significance in promoting the orderly circulation of agricultural land. The two parties of farmland transfer can publish information through the platform. Farmland can be handed over to the platform, which will transfer the land to the land operator through sorting and planning. With this platform, maximum integrity can be obtained for the two parties of transfer, which is beneficial for orderly land transfer and stable agricultural production. At the same time, the situation of land transfer can be awarded in time through the platform, which is convenient for the adjustment of supervision and policy.

Author Contributions

Jingqiang Geng is the first author and corresponding author of this paper, he is responsible for the research design and model design of this paper. Qingqing Huo is responsible for the research data analysis, and wrote this paper. Shanshan Jia helped to organize the survey and data collection, and gave many comments to revise this paper.

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Data Availability

The data are available upon request from the corresponding author.

Conflict of Interest

All authors disclosed no conflict of interest.

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RESEARCH ARTICLE

Assessing Land Use and Land Cover (LULC) Change and Factors Affecting Agricultural Land: Case Study in Battambang Province, Cambodia

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Abstract: This study analyzed land use and land cover (LULC) change from 1998 to 2018 in Battambang, Cambodia, and determined factors and constraints affecting agricultural production. Landsat satellite images in 1998, 2008, and 2018 were used to identify the changes in LULC. In combination, a social survey was conducted in August 2021 using purposive sampling, selecting a total sample of 200 from two wealth classes: the poor (65) and the better-off (135) based on the Cambodia poverty assessment by the World Bank, from uplands to lowlands of Battambang Province, Cambodia. Household characteristics, farm size, and constraints were compared between the classes. T-tests, the analysis of variance (ANOVA), and Likert scale analysis were adopted using the R Program and RStudio, while Pearson's correlation test was used to determine the factors affecting agricultural land. The results show that between 1998 and 2018, the forest cover decreased by 79%. In contrast, agricultural land expansion was the highest (54%). The average household size and age of the respondents were 5.0 persons/household and 50.1 years, respectively. Of all the interviewees, about 80% attended no higher than primary school. The total farm size of the better-off (7.0 ha/household) was larger than that of the poor (5.2 ha/household). The population growth, machinery use, and improved infrastructure were found to be positive and strongly related to agricultural land use. The highest constraints of the poor and the better-off households were the same: chemical fertilizer use. Then, drought and flooding were also challenges for all. In terms of land, credit, and labor, they were not the main constraints. Thus, it is recommended that the involvement of interdisciplinary stakeholders and policy frameworks is really important from both biophysical and social perspectives.

Keywords: Agricultural production; Chemical fertilizer; Drought; Flooding

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1. Introduction

Land use and land cover (LULC) change has been a heated topic discussed worldwide because of its adverse effects on farming systems, soil fertility, wildlife habitats, fauna and flora, water flow patterns, and humans as a whole [1-6]. The main drivers of the change stem from infrastructure development, population growth, urbanization, environmental and climate change, national policies, and related regulations [7-11]. In most developing countries, a majority of their populations rely heavily on natural resources and agriculture [1,12]. Similarly, approximately 13.6 million Cambodian people, or about 80% of the whole population, live in rural areas, while about 11 million (65%) depend on farming, fisheries, and natural resources [13]. In the global context, the supply of land resources for producing food, fiber, and biofuels is limited, so the land should be well-planned, developed, and used in a sustainable way [1,9,12,14]. According to [9,15-17], the conversion of forest land to farmland in Mexico, South America, and Cambodia is due to the land expansion for pastures, soybeans, cassava, corn, and fruit trees. In Cambodia, these changes have a negative impact on soil, causing soil erosion in Battambang Province, where the soil erosion rate on upland cassava fields ranges from 82.4 to 123.7 T/ha/year [18-20]. To address that issue, conservation agriculture (CA) is recommended as a mitigation measure against soil degradation caused by erosion [21]. Besides that, cultivated land for cassava, corn, and fruit trees is increasing at the expense of natural resources [9]. Among those crops, cassava is considered an industrial crop vital for socio-economic development and livelihood improvement [22]. Additionally, the factors that have led to agricultural land expansion are infrastructure development including significant development of double bituminous surface treatment (DBST), concrete, asphalt, laterite, and dirt road, economic growth, and the enhancement of agricultural technology [11,23]. Assessment of land use and land cover change (LULC) is considered extremely significant to determine plausible resource availability in the future and provide policy implications for the sustainable management of the landscape [26,27]. Meanwhile, the evaluation of factors affecting agricultural expansion is also crucial to explain how farmers' decisions affect their land use patterns, due to technological change, improvements in infrastructure, changes in agricultural practices, or population growth [11,28].

Over the last decades, LULC change experts have used multi-temporal high-resolution satellite images to analyze deforestation, urban growth, agricultural expansion, and other anthropogenic activities [29,30], but this technique could not explain the reason behind the changes [1]. Thus, combining LULC remote sensing techniques and ethnographic research is key to understanding why changes occur by assessing the perception of local people, experts, and relevant stakeholders with respect to their socio-economic conditions, farming activities, livelihood strategies, land use, socio-political consequences, culture, natural resources, and climate change [31-34]. In terms of comprehensive and scientific research on natural and social change, some tools such as key informant interviews (KIIs), in-depth interviews, and focus group discussions (FGDs) in studied areas should be applied to obtain past, present, and expected future information related to LULC changes [35,36]. Additionally, a qualitative approach is also applied to social surveys to deeply understand local residents' perceptions of land-use change [37]. This method was also used [1,35] to identify the relationship between LULC change and socio-economic conditions in Cameroon and Ethiopia. By using semi-structured interviews with local farmers to understand the relationship between national- and local-level perceptions of environmental change in central Northern Namibia, it is found that a combination of local and scientific knowledge can effectively assess LULC change and its impact on local land users and managers [38]. Therefore, combining data on LULC change acquired from remote sensing is important to enhance our understanding of the causes and processes of the change [1,34,39].

Some recent studies [9,40] have already been conducted in Cambodia to evaluate LULC change and its drivers in Battambang Province from 1998 to 2018 and to assess its relation with soil erosion using remote sensing, GIS, and universal soil loss equation (RUSLE) models. However, because of no integrated social survey, the reasons for those changes could not be well understood. Therefore, the objective of this study was (1) to analyze LULC change from 1998 to 2018, (2) to determine the factors affecting agricultural land, and (3) to determine constraints to agricultural production based on different wealth classes set by the World Bank. To address the objectives, the Landsat 5 TM and Landsat 8 OLI images to produce LULC maps and household surveys were used to understand the local people's perception of Battambang province. Interviews were conducted with those who had lived in the target area for more than 20 years, and their age had to be over 40 years.

2. Materials and Methods

2.1 Study Area

The study was conducted in Battambang Province northwest of Cambodia, covering over 1,203,628 ha (48P: 304461 mE, 1457098 mN) (Figure 1). The maximum and average elevation of the upland is about 1,333 and 118.1 m above mean sea level (MSL), respectively. The maximum and average elevation of the lowland is about 89 and 9 m above MSL, respectively [41]. Meanwhile, the average annual rainfall and maximum temperature are about 1,491 mm and 33.7 °C, respectively [18,42]. Because of the tropical climate, there are two seasons: the rainy season, starting from May to October; and the dry season, starting from November to April. There are nine soil types: acrisols, arenosols, cambisols, ferralsols, fluvisols, gleysols, lixisols, luvisols, and vertisols, while acrisols (loam) are predominant in this province, accounting for 42.1% (507,041 ha), followed by fluvisols (clay loam) equal to 30.7% (369,122 ha) [43].

Moreover, land use is categorized into seven categories: forest (evergreen, semi-evergreen, and flooded forest), shrubland, grassland, water, cultivated land, urban area, and barren land. According to the 2019 Provincial Agricultural Report [44], paddy fields and other crops covered 699,944 ha (58.2% of the total provincial land area) and 297,312 ha (24.7%), respectively and it was considered the agricultural hub of Cambodia. The province has 14 districts and a municipality. According to the National Institute of Statistics in 2019, its population increased dramatically from 793,129 in 1998 to 997,169 persons in 2018, excluding migrants working abroad (178,401 persons). The population in the uplands increased sharply, while the population in the lowlands decreased due to immigration.

2.2 Data Collection

LULC Change

The main data source for LULC change categories in the studied area was obtained from the Landsat image, including Landsat 5 TM and Landsat 8 OLI of scenes in 1998, 2008, and 2018 (Path: 128 and Row: 51). The Landsat images were derived from the United States Geological Survey website (https://earthexplorer.usgs.gov/), accessed on 3 August 2019. All Landsat data were acquired in the same dry season from December to April. Accuracy assessment was made using a total of 121, 163, and 317 validation points randomly selected in 1998, 2008, and 2018, respectively. This approach was adopted [47-50]. The reference data for 2018 of each LULC class were collected directly on the fields by using drones and handheld global positioning systems (GPS). However, the reference data for 1998, 2003, 2008, and 2013 were obtained from the existing maps of land use in 1993 from the Geographic Department, the Ministry of Land Management, Urban Planning, and Construction; the land use map in 2002 from the JICA; and the forest cover maps in 2002, 2006 and 2010 from the Ministry of Agriculture, Forestry, and Fisheries (MAFF). Meanwhile, the data also included Google Earth images supplemented by field visits, FGDs, and KIIs in the studied area. Overall accuracy, user accuracy, producer accuracy, and Kappa coefficient were defined as the common measures of classification accuracy obtained from the error matrix [48,51,52].

Household Survey

A well-structured questionnaire was used for the household survey, focusing on socio-economic profiles (household size, farmland size), and agricultural practices (farming size, land use type, land use change, perceptions of LULC change related to agricultural expansion, and fertilizer consumption). The survey was conducted in August 2021 by adopting purposive sampling to select a total sample of 200 households from two wealth classes: the poor (65) and the better-off (165) based on the Cam-

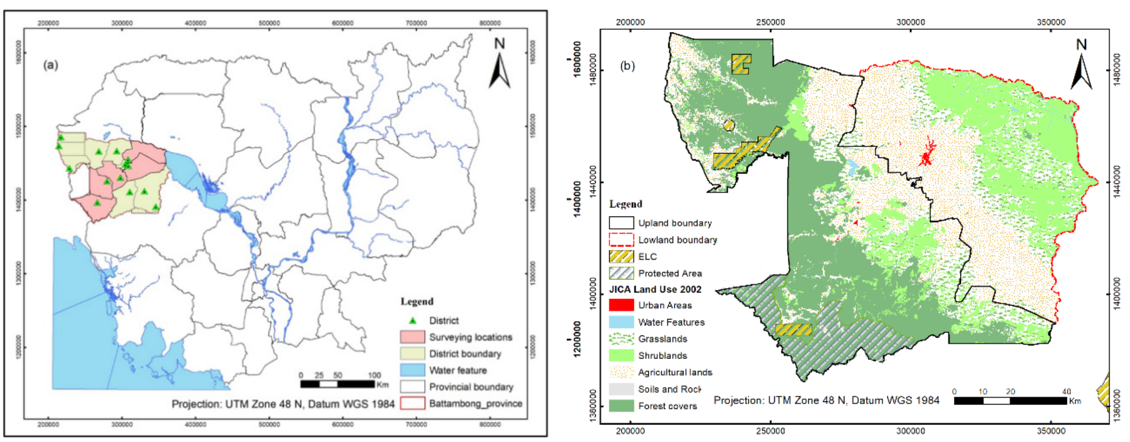

Figure 1. Map of the studied area: (a) survey areas and district headquarters [45]; and (b) protected areas (PAs) and economic land concession (ELC) in Battambang [46].

bodian poverty assessment, covering the upland area in Samlout and Rattanak Mondul Districts and the lowland area in Sangke and Ek Phnom Districts along the Tonle Sap River. After that, two more criteria were applied in order to obtain the right data for analysis: (1) the respondents must have their primary jobs as farmers and (2) they must be household heads living in two target areas since 1998. Twelve months of years 1998, 2008, and 2018 were used as reference periods for data collection and analysis. Therefore, the respondents were at least 40 years old.

The main reason for selecting Battambang Province as the study site is that this province is considered an agricultural hub and has the largest cultivated area in the country. Agricultural land expansion for cassava, corn, and fruit trees in the uplands of that province [19] was seen to boost agricultural products in line with the goal of the Cambodian agricultural sector development strategy plan (2019-2023), which aims to increase all types of agricultural production by 10% per year [53]. The consequence of such expansion in the uplands may lead to a decline in soil fertility [19]. To properly collect the data, the study was divided into two stages. In the first stage, field observations were made to contextualize agricultural systems and livelihoods to pretest and modify the questionnaire before the actual survey. In the second stage, the survey was carried out to gather both qualitative and quantitative data by using in-depth interviews, face-to-face individual interviews, four FDGs (two in the uplands and two in the lowlands), and KIIs.

2.3 Data Analyses

Data from Remote Sensing

All GIS data including reference data and remote sensing data were projected to the Universal Transverse Mercator (UTM) system, zone 48 N, and datum of World Geodetic System 84 (WGS 84). This can ensure that there was consistency between data sets during analysis. The images were analyzed by utilizing data image processing techniques in QGIS 3.10 and ArcGIS 10.3 software. To establish a map of LULC for each of the five-year images, a supervised classification method was used with the maximum likelihood algorithm [54]. This approach produces generally better results than the minimum distance approach [1,55]. Seven LULC categories, in accordance with the Cambodia land use map of 2002 produced by the JICA, were chosen for this study: urban/built-up area, water feature, grassland, shrubland, agricultural land, barren land, and forest cover. LULC classes were compared in three periods: 1998, 2008, and 2018. The values were illustrated in hectare (ha) and percentage (%). The percentage of LULC change was calculated using the equation [1]:

$$LULC\ change\ (\%) = \frac{A_1 - A_0}{A_0} \times 100 \quad (1)$$

where A_1 is the final-year land area (ha) and A_0 is the initial-year land area (ha).

Data from Household Survey

The data collected from the household survey were entered in MS Excel and analyzed using the R Program version 3.3.0+ and the RStudio version 2023.06.1+524, both of which are available for free online. Descriptive statistics such as cross-tabulation, frequencies, and percentages were employed to summarize the data. Two-sample t-tests were analyzed to compare all quantitative data between the two wealth classes. The graphics were created by using the ggplot2 package, which is powerful in dealing with complex graphs [56].

To determine the factors most affecting agricultural land use, Pearson's correlation was used to identify the relationship between agricultural land with variables: population, agricultural machinery, draft power source, and road infrastructure. The result of this test was presented with the correlation strength (R), lower and upper confidence interval (CI) at the 5% significant level [57]. To perform this task, the rstatix package is utilized [58].

Furthermore, a five-point Likert scale analysis was also used to determine the intensity of the constraints on land use in the studied area, based on the perceptions of the respondents. the process of performing the test is in accordance with Fielding et al. [49]. The data were collected by interviewing the respondents with some questions about their constraints: input constraints, including chemical fertilizer use and pesticide application; soil fertility declines; climate constraints, such as drought and flooding; and production constraints, such as labor, land, and credit. The scores were rated 1 (no constraint), 2 (little constraint), 3 (moderate constraint), 4 (big constraint), and 5 (very big constraint), and then compared by using the analysis of variance (ANOVA) following the guidelines [59]. When significant differences were detected, an adjusted least significant difference (LSD) following Bonferroni's test was used to separate mean scores among the identified constraints [60,61]. To perform this task, the agriculture package was utilized for the LSD test [62]. Then mean and total scores for each constraint variable were presented, while different alphabetic letters were used to signify their significant differences in intensity.

3. Results

3.1 Different Classes of LULC Change

The seven main LULC classes were compared using remote sensing and GIS data over three different periods in 1998, 2008, and 2018 (Figures 2 and 3). The comparison was made in two different scenarios: changes in land area (Figure 2A) and changes in the percentage of that land area (Figure 2B). In both scenarios, it can be seen that five LULC classes increased constantly over time from 1998 to 2018, and those include agricultural land, barren land, built-up areas, shrubland, and water features. However, sharp increases from 2008 to 2018 were seen with only two LULC classes: barren land and built-up area. In contrast, the forest cover decreased sharply in 10 years from 1998 to 2008 and continued to decline slightly until 2018. Meanwhile, grassland fluctuated over time because it increased from 1998 to 2008 and then made a sharp fall in 2018.

According to Figure 2, agricultural land increased by 54% in 20 years from 535.6 thousand ha in 1998 to 823.2 thousand ha in 2018. Meanwhile, barren land increased exponentially from just 16 ha in 1998 to 1.5 thousand ha in 2018, equivalent to an increase of 8,750%. Similarly, built-up areas also increased exponentially by 9,791% from 44 ha in 1998 to 4.7 thousand ha in 2018. Shrubland also increased moderately by 38% from 154.9 thousand ha in 1998 to 213.6 ha in 2018, while water features rose by 359% from 2.3 thousand ha in 1988 to 10.6 thousand ha in 2018. Due to the increase of these above-mentioned LULC classes, there was a negative impact on forest covers, while its reduction rate in a twenty-year period was 79% from 358.9 thousand ha in 1998 to only 74.5 thousand ha in 2018. Grassland experienced an increase from 1998 to 2008 and then a sharp fall in 2018. When compared to 1998, it decreased by 50%. A clearer picture of LULC change can be seen in Figure 3, showing that the green image that represents the forest covers in Battambang vanished greatly over the three periods.

The findings show that more agricultural activities may lead to an expansion of farmland and residential areas to support their daily livelihoods. In that regard, people in the studied area had to clear forest land to grow crops and build houses. Meanwhile, the increase in barren land may suggest that after forest clearance, some land was left uncultivated because the main purpose behind that was just to harvest timbers.

Figure 4 presents the agricultural and built-up areas, the GDP per capita, and purchasing power parity (PPP) in three periods in 1998, 2008, and 2018, and all of them increased constantly over the whole period. This may imply that increasing GDP and PPP have led to an increase

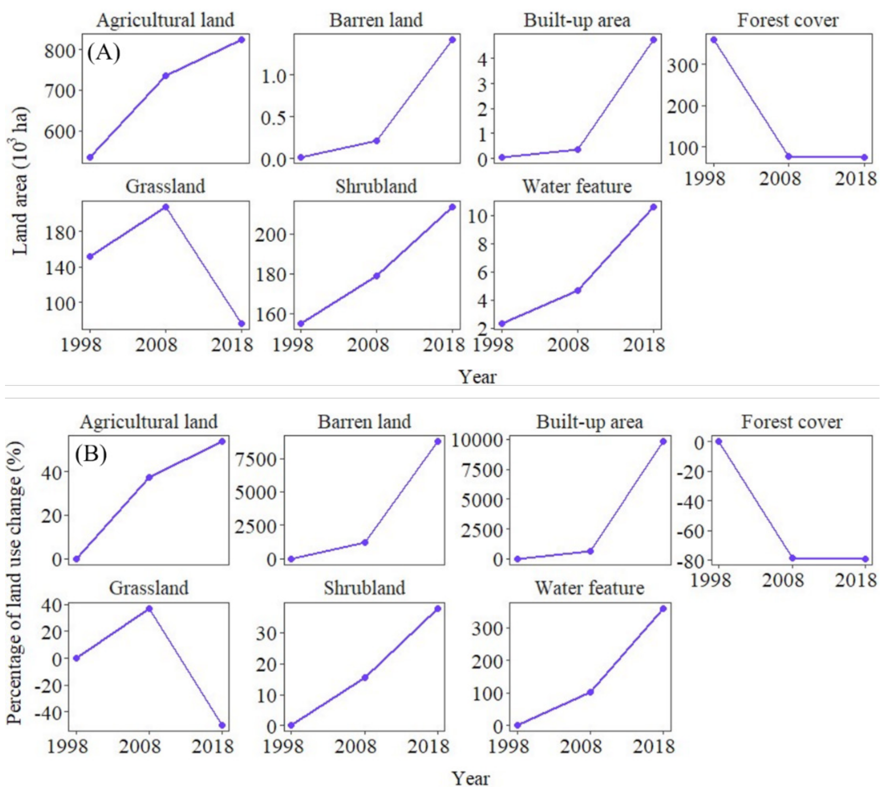

Figure 2. Comparison of LULC change among the seven land use types in the periods of 1998, 2008, and 2018, taking into account land area changes (A) and percentage of changes (the percentages of change in both 2008 and 2018 were compared to 1998) (B).

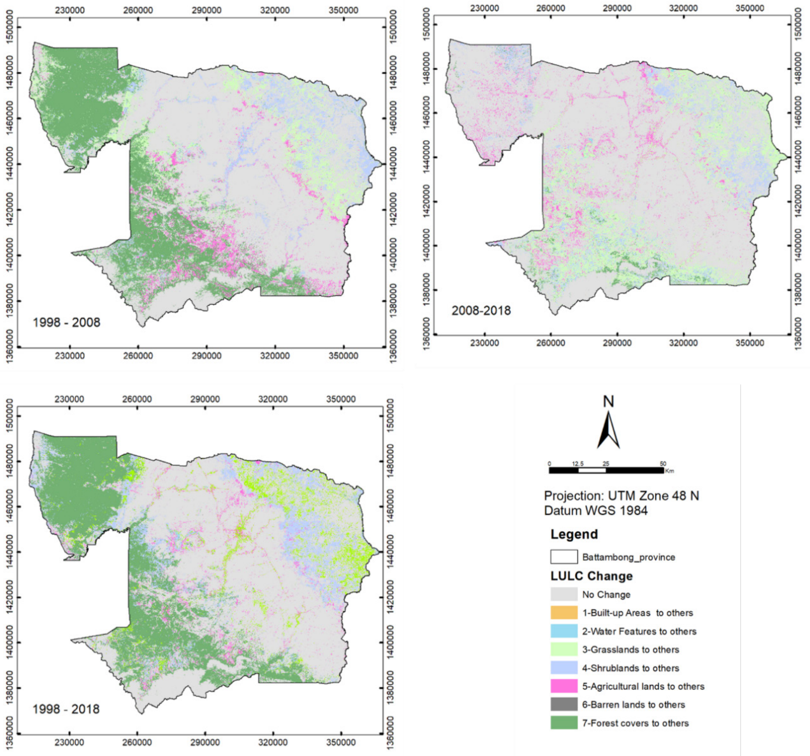

Figure 3. Spatial distribution of the LULC change in Battambang province for 1998-2008, 2008-2018, and 1998-2018.

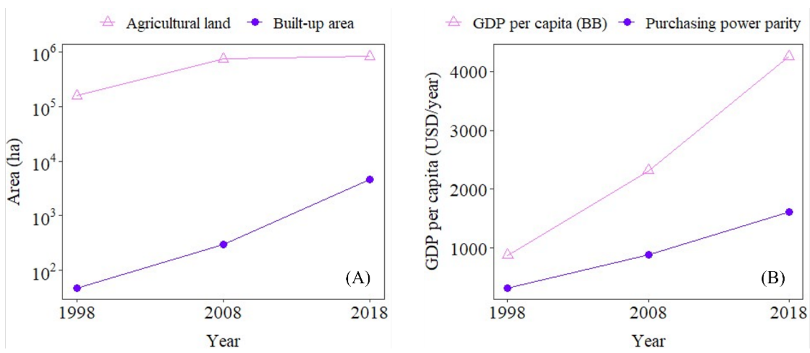

Figure 4. Comparison of Agricultural land and built-up area (A); GDP per capita and GDP per capita (PPP) (B) from 1998 to 2018.

in agricultural expansion and built-up areas over the past two decades. GDP per capita experienced an increase of around 462% between 1998 and 2018 [63]. The overall increase rate was approximately 23% annually. The increase rate of GDP per capita was the fastest during 2008-2018 (around 77 USD per year). Similarly, it was also noted that PPP increased year after year, equal to 3,383 USD from 1998 to 2018 [64].

3.2 Factors Affecting Agricultural Land

Table 1 shows correlations between agricultural land and a set of predictor variables: population, agricultural equipment, and infrastructure during the last two decades from 1998 to 2018. It is found that the population, power tillers, tractors, and infrastructure such as laterite roads, constructed earthen roads, and unconstructed earthen roads were significantly and positively correlated with agricultural land use (all P-value < 0.001), while the strength of the relationship was observed to very high, with R not less than 0.9. This means that when all these variables increase, agricultural land also increases because they are all important components to support farming activities. However, cattle draft power had a negative strong relationship with agricultural land, which means when farmland in the studied area increases, this leads to a reduction in cattle heads raised locally because farmers there prefer to use machinery as a means of land preparation and transportation instead. Meanwhile, rice threshers, bituminous roads,

Table 1. Pearson's correlation test between agricultural land and a set of predictor variables.

Dependent variable	Predictor variables	Correlation	Statistic	Pr (> t)	Lower CI	Upper CI
Agricultural land	Population	0.91	5.89	< 0.001***	0.63	0.98
	Power tiller	0.93	6.72	< 0.001***	0.70	0.99
	Tractor	0.90	5.34	< 0.001***	0.57	0.98
	Rice thresher	0.48	1.47	0.186 ns	–0.26	0.87
	Cattle draft power	–0.84	–4.12	0.004**	–0.97	–0.40
	Bituminous road	–0.53	–1.67	0.140 ns	–0.88	0.20
	Makadam road	0.58	1.87	0.104 ns	–0.14	0.90
	Concrete road	0.39	1.11	0.304 ns	–0.37	0.84
	Laterite road	0.87	4.69	0.002**	0.49	0.97
	Constructed earthen road	0.96	9.56	< 0.001***	0.83	0.99
	Unconstructed earthen road	0.95	8.19	< 0.001***	0.78	0.99

Note: Asterisks "**" and "***" denote statistically significant differences at 0.01 and 0.001, respectively. Meanwhile, "ns" means non-significant differences.

Makadam roads, and concrete roads had no relationship with agricultural land, denoting that the increase in rice thresher number and properly paved roads is independent of increased farmland.

3.3 Household Survey

Household Survey Based on Wealth Class

Household characteristics and different farm sizes were compared between the poor and the better-off in the studied area (Table 2). It can be seen that the household sizes between them were not significantly different and, on average, there were five persons in the household. Similarly, the age of the respondents between the two groups was not significantly different, and the average age was about 50 years. Regarding farm sizes, significant differences were observed in both non-rice fields and paddy rice fields between the two wealth classes. In all cases, farm sizes that belong to the better-off were larger than that of the poor. Non-rice fields for the poor and the better-off were 2.7 and 4.0 ha/household, respectively. Similarly, the poor had a rice field of 2.5 ha/household, while the better-off had 3.0 ha/household. It could be suggested the better-off had more chance to increase production because they had larger farm sizes.

Sex, Education, and Migration for Work by Wealth Class

The sex and educational level were compared in terms of percentage, regardless of the wealth classes (Figure 5). The main purpose was just to distinguish the differences within the whole sample. Of the 200 respondents, 56% were male and 44% were female. In terms of education, it can be seen that about 80% of the respondents could go higher than primary school, while 21% could attend secondary school, and another 8% went to high school. This finding may suggest the educational level of the respondents was very low, and that is why they made a living by practicing agriculture and selling labor through migration for work. When the population in the studied area started to grow, there was no other option, but to clear the forest land to pave the way for cultivation.

The respondents from the two wealth classes were also asked if they frequently migrated for work outside their province (Figure 6). Almost all of them reported that migration was important to make more income to support

Table 2. Comparison of household characteristics and all farm sizes between the two wealth classes in the studied area.

Variable	Wealth class (Mean ± SD)		Pr (> t)
	Poor	Better-off	
Household size (person)	4.9 ± 1.74	5.1 ± 1.59	0.632 ns
Age (year)	49.7 ± 14.97	50.4 ± 13.29	0.210 ns
Non-rice crop field (ha/household)	2.7 ± 2.06	4.0 ± 2.39	0.034*
Paddy rice field (ha/household)	2.5 ± 1.44	3.0 ± 2.85	0.025*

Note: Asterisks "*" and "ns" denote statistically significant differences at 0.01 non-significant differences, respectively.

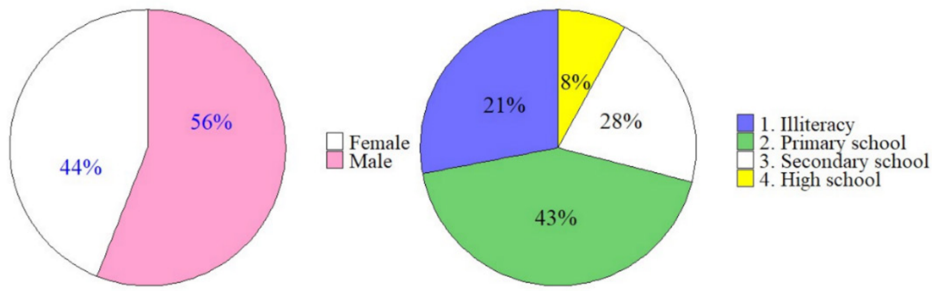

Figure 5. Distribution of household survey: (a) gender of interviewers and (b) level of education of interviewers.

their families when there were no agricultural activities available. This is the reason why the percentage of the respondents who migrated for work was very high among the two classes, at least 80% of the individual groups.

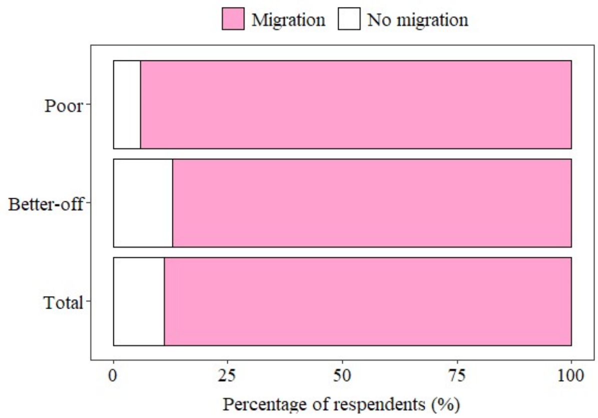

Figure 6. Comparison of migration rate between the poor and the better-off.

Constraints to Agricultural Production

The respondents from the two wealth classes were asked to rate potential constraints to their current agricultural production from 1 (no constraint) to 5 (very big constraint) based on their experience and perceptions, as illustrated in Table 3. In this context, the eight constraints, namely chemical fertilizer use, pesticide use, soil fertility decline, lack of credit, lack of land, flooding, drought, and lack of labor were identified as potential constraints. Regardless of the wealth classes, significant differences were observed among the constraints ($P < 0.001$). In terms of constraints, the two wealth classes had very similar perceptions, but what they thought the same was the price of commercial fertilizer which was rated as the biggest constraint to agricultural production. Similarly, the poor rated drought and flooding as the first and second biggest constraints, while the better-off thought that they ranked second and third. Regardless of the wealth classes, pesticide use and soil fertility decline ranked third in terms of constraints, followed by lack of labor and then lack of credit and land.

According to Table 3, the findings may suggest that farmers are very worried about the prices of commercial fertilizer because they may affect the yield if it is not used in sufficient amounts. Apart from that, irregular climatic patterns related to drought and flooding may also threaten their farming activities. They did not worry much about

Table 3. Comparison of constraints to agricultural production in accordance with the two wealth classes.

Type of constraints	Poor			Better-off		
	Mean	Sum	Rank	Mean	Sum	Rank
Chemical fertilizer use	3.9	249	a	4	536	a
Pesticide	3.1	198	c	3.5	474	c
Soil fertility decline	3.3	209	c	3.4	456	c
Flooding	3.5	222	b	3.5	473	c
Drought	3.8	242	ab	3.9	529	b
Lack of credit	1.6	100	e	1.9	262	e
Lack of land	1.6	103	e	1.9	251	e
Lack of labor	2.2	140	d	2.2	297	d
Pr (> F)	< 0.001***			< 0.001***		

Note: Asterisk "***" means statistically significant differences at 0.001, while different alphabetic letters denote different mean scores rated for different constraints.

pesticide use and soil fertility because they rated those constraints as moderate. In terms of labor, they may feel that there is no need to find more, as they thought that it was a little constraint. In terms of land, they had enough for their families, so it was not a problem. The same thing is found with a lack of credit. Rural credit is widely available in the studied area, so it is not hard to access that.

4. Discussion

The LULC change maps of the years 1998, 2008, and 2018 were produced by using the Landsat 5 TM and Landsat 8 OLI images with supervised classification and maximum livelihood, equipped with QGIS 3.6.29. Meanwhile, the household survey was conducted for the purpose of determining the perceptions of local residents. Overall, between 1998 and 2018, the agricultural area increased by 54% (287,600 ha) [65]. This shows that most past agricultural growth was due to the expansion of farmland from 2004 to 2012. The expansion was converted from forest and grassland [9,18,19]. The modernization of agricultural equipment, population growth, and the development of laterite roads, constructed and unconstructed earthen roads were key factors to caused agricultural land expansion, especially from forest covers. According to FGDs and the survey, agricultural practices have been transited to mechanized agriculture with the availability of tractors, power tillers, and other machinery since 2005. This is in accordance with the study of Mottet, A. et al. [66] who claimed that the agricultural land use change was also caused by modernization of agricultural machinery.

In this research, the combination tool between remote sensing and the social survey was conducted to significantly identify the correlation between LULC change and socio-economic conditions. This approach was also used by Desalegn, T. et al. [1] in the central highlands of Ethiopia and Toh, F.A. et al. [34] in the Western Highlands of Cameroon. Moreover, the priority constraints to agricultural production were also determined by using the Likert Scale analysis based on a five-point score to understand the perceptions of local farmers in depth. It was recommended by Joshi, A. et al. [67], who claimed that it is one of the most basic and widely used psychometric instruments in educational and social science research. Furthermore, the scales method was employed by other researchers to identify the constraints that varied by level [68-72]. Additionally, the results were compared using the analysis of variance (One-way ANOVA), according to the guidelines [59], while Toh, F.A. et al. [1,34] used only a percentage function to describe crop production constraints in their research.

The average total household size of the sample respondents was 5.0 persons, which was higher than the Cambodian average household size (4.3 persons) [73]. In Cambodia, the National Institute of Statistics [73] reported that the average household size decreased from 4.7 persons in 2008 to 4.3 persons in 2019. The mean household size of the better-off was not different from that of the poor, being 5.1 and 4.9 persons/household, respectively. This result was in contrast with the research finding [1,34], which reported that the average family size of the better-off was also higher. The total farm size, combining non-rice crop fields and paddy rice fields, was 5.2 and 7.0 ha/household for the poor and the better-off, respectively. This finding was higher than the average landholding size of an average rural household (only 1.3 ha) [74]. However, the average household farm size was smaller than the mean house farm size in the central highlands, Ethiopia [1] and in the Western Highlands, Cameroon, except for the average farm size of the poor (2.1 ha) [34].

Migration for work outside the province, either to other provinces or abroad, is common in the studied locations, regardless of the wealth classes. Additionally, according to KIIs and FGDs, if any families have their members migrate to work in other provinces, cities, or abroad, their livelihoods tend to be better. This finding was also in line with the result [75], which claimed that households that have members migrate to work may have much better livelihoods when compared to those staying at home.

In this study, eight constraints to agricultural production could be identified (Table 3), while only five similar constraints were identified [1] in the central highland, Ethiopia, and those include soil fertility decline, lack of land, lack of credit, crop pests, and crop diseases. Meanwhile, almost all constraints identified in this study were similar to the study [34] in the Western Highlands, Cameroon. The finding showed that chemical fertilizer use was the biggest constraint for both the poor and the better-off. According to the FGDs, chemical fertilizer use is increasing remarkably, and the local farmers spend more on it due to soil fertility decline [41]. However, in the northern uplands of Vietnam, Yen, B.T., et al[76] reported that the greatest constraint was a lack of credit, followed by the limitations of land and techniques. Furthermore, the poor and the better-off also faced the same constraints to their crop production, such as drought and flooding. It was also confirmed by ADB [44], which claimed 93,082 ha and 27,340 ha of agricultural land were damaged by flood and drought, respectively, in Battambang. HRF [77] reported that 66,088 households and 164,116 ha of agricultural land were affected by floods in Battambang in 2020. It is similar to the finding [72], who claimed that the farming systems practiced in South East Asia and Africa faced a similar natural disaster which was a severe drought.

5. Conclusions

The combination of remote sensing and GIS tools and a social survey is a very effective method to deeply understand the correlations between LULC change and socio-economic factors. The result shows that in 20 years between 1998 and 2018, the increase in the agricultural area was 54%. The increasing agricultural land with poor farming practices may lead to soil fertility decline. With this issue, farming households were forced to increase chemical fertilizer use to maintain high yields. The price of chemical fertilizer was rated as the biggest constraint among the eight identified constraints to agricultural production for both wealth classes. Possible approaches to soil fertility management in the region should involve the use of technology or agricultural practices that can add nutrients to the soil, such as conservation agriculture, while reducing nutrient losses through runoffs and soil erosion. Because the studied province is an agricultural hub, building public-private partnerships around market-oriented production can be an entry point to encourage investment in the use of external nutrient inputs to improve soil fertility and increase agricultural productivity.

In conclusion, the findings of this study provide considerable evidence that the local community in the study area faces a variety of social, economic, and environmental constraints to their agricultural production, so they must be properly addressed to reduce poverty and to contribute toward achieving the goal of the Cambodian agricultural sector development strategy plan (2019-2023), which aims to increase all type of agricultural production by 10% per year. Solutions should also adhere to the sustainable development goals (SDG) in 2030 and the goal of the Royal Government of Cambodia to become an upper middle-income country by 2030. Thus, it is recommended that the involvement of interdisciplinary stakeholders and policy frameworks is strongly needed to contain these dire situations from both biophysical and social perspectives. In particular, empowering and capacity-building local people with various agricultural techniques not only help them increase agricultural productivity but also contribute significantly to environmental protection in the future.

Author Contributions

Conceptualization: Taingaung Sourn, Sophak Pok, Nareth Nut; methodology: Taingaung Sourn, Sophak Po, Nareth Nut, Lyhour Hin; software: Taingaung Sourn, Lyhour Hin; formal analysis: Taingaung Sourn, Sophak Pok, Nareth Nut, Lyhour Hin; investigation: Phanith Chou, Dyna Theng; resources: Taingaung Sourn, Nareth Nut; data curation: Taingaung Sourn; writing—original draft preparation: Taingaung Sourn, Sophak Pok, Lyhour Hin, Nareth Nut; writing-review and editing: Taingaung Sourn, Lyhour Hin, Nareth Nut, Sophak Pok, Phanith Chou, Dyna Theng; visualization: Taingaung Sourn, Lyhour Hin; supervision: Sophak Pok, Phanith Chou, Dyna Theng. All authors have read and agreed to the published version of the manuscript.

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Data Availability

The data are available upon request from the corresponding author.

Conflict of Interest

The authors declare no conflict of interest.

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RESEARCH ARTICLE

Technical and Economic Efficiency of Vine Pruning: Results of Experimental Trials of Some Cultivars of Grapevine Grown in Sicily and Determination of Break-even Point

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Abstract: The research presents the results carried out on Sicilian viticulture in order to study the economic sustainability of the agricultural company. In particular, the author examined the operation of dry pruning and tying of the fruiting head in espalier vineyards with tools that facilitate the work. The economic analysis highlights that equipping yourself with mechanical tools that facilitate work is convenient for both large and small wineries. The results of the research highlight that the investment to facilitate pruning and tying in Guyot-trained vineyards can also be made by wine-growing companies and is increasingly convenient as the area under vines involved increases.

Keywords: Vineyard pruning; Production cost; Competitive advantage

1. Introduction

The Italian wine production structure, as evidenced by the statistical data, is highly fragmented. In fact, the 383,648 farms (ISTAT, 2022) with an average area of 1.6 hectares [1]. For micro-enterprises, which produce an undifferentiated product, achieving a level of total unit cost lower than that of competitors is the only way to achieve a competitive advantage. In fact, for the same selling price of the grapes, producing with lower average unit costs than competitors allows the company to improve the profit margin and be competitive in the market [2]. This situation is reflected in the company's financial structure and investment capacity. Furthermore, the increase in the net margin allows the firm to increase its self-financing capacity and consequently the remuneration of the production factors. An increase in sources of financing can, in any case, represent the driving force to start a process of growth in the

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size of companies, which in the long run allows them to establish themselves on the market with a new product compared to their competitors, also creating a differentiation advantage [3,4]. Today in developed economies the high production costs, first and foremost that of labour, do not allow wineries to be competitive. This situation also reflects the lack of generational turnover in the company, which sees the disappearance of the wine-growing companies where the work contributed by the farmer's family was the majority. Therefore viticulture without machines that facilitate some cultivation operations can no longer represent a source of competitive advantage. Our research question is: how to succeed in lowering production costs in vineyard management? To answer this question, we saw that one of the possible operations on which to intervene to lower costs is pruning and subsequent tying of the fruiting head. Today the mechanical industry makes available to winemakers a series of equipment and machines that allow a significant reduction in working times and therefore a reduction in production costs. This work aims to analyze how production costs change in wineries that introduce shears and electric tying machines into the company structure. These investments do not involve a large monetary outlay and can be made by the vast majority of wineries, even small ones. However, before their implementation it is important to know if the investment is convenient and, if so, the benefits deriving from the introduction of process innovation in the farm. Costs were estimated by comparing: a) pruning with shears and subsequent manual tying of productive shoots (manual pruning); b) pruning and tying of productive shoots using electric shears and an electric tying machine, respectively (facilitated pruning). Moving from hypothesis (a) to hypothesis (b) results in a reduction in costs.

2. Competitive Strategies to Reduce Production Costs

In developed economies, the achievement of a competitive advantage appears essential for companies and for the territory where they operate. Achieving this competitive advantage requires entrepreneurs to be innovators. In reality, in agriculture there are few innovative entrepreneurs and many imitators of innovations, i.e. they let others experiment with them and if they work, they imitate them. For small and medium-sized agricultural enterprises, which are the majority, it is difficult to implement innovations as they do not have sufficient means to carry out research and development. However, for those, who are subjected to the prices imposed by the operators downstream of the supply chain, it becomes of fundamental importance to achieve a cost advantage where by keeping revenues unchanged, profit margins improve [5]. Firms that innovate first achieve a competitive advantage and have a chance to be competitive until others imitate the innovation [6]. If the company reaches a cost advantage, it can decide to reduce the level of the selling price of its offer which, while remaining above the average cost, attracts customers from other farms. In the territory, competing companies that do not adopt innovation systems are destined to lose market shares in favor of companies that have innovated. These farms can have a cost of production equal to marginal revenue or a cost of production greater than marginal revenue. In the first case, they are marginal firms, in the second case, they suffer losses for each unit of production [7]. The advantage achieved by the leading cost company, if lasting, is capable of sweeping the others from the market in the medium-long term [8]. This situation has repercussions on the financial structure and investment capacity of the farm. The higher margin that the leading agricultural company reaches allows it, on the one hand, to have greater savings and therefore greater self-financing and, on the other hand, a higher return on the invested risk capital. In the first case, the firm increases the size of its equity capital and therefore, with the same leverage effect, the stock of debt capital it can acquire. In this case, banks will be more inclined to lend to these companies, as they have a high degree of self-financing and the ability to repay the borrowed capital. In the second case, the conditions are created for a possible acquisition of new risk capital and therefore to expand the production capacity of the farm or to renew the machinery. In general, in both conditions, process innovation allows for an increase in the profit margin which is reflected in an increase in the available financial resources of the farm. As previously mentioned, considering that in the rural world, the majority of farms are small in size and have high production costs and low selling prices for agricultural products (they are affected by the decisions imposed by operators downstream of the supply chain who often operate in oligopolistic markets such as in the case of wineries or large-scale retail trade) this situation could represent a way to achieve a cost advantage [9]. This aspect is important in those territorial contexts where agriculture represents the main economic activity and therefore the competitive advantage of companies represents a way to curb agricultural and rural exodus phenomena and therefore desertification phenomena. The extreme fragmentation of Sicilian wineries, which very often combines with corporate fragmentation phenomena, penalizes the achievement of competitive advantage and the degree of innovation. In fact, we are witnessing the fact that most of these wineries, unlike before when the production chain was closed within the company, deliver the grapes directly to the cellar, while less than a hundred (usually medium-large companies) transform and bottle their own products [11,12]. From an economic point of view, the productive specialization has determined that the low prices of the grapes imposed on the winegrowers do not allow to remunerate the factors of production. In the second case (large companies), having companies of a certain economic size that produce a bottled product, a differentiated product, such as wine, makes it possible to increase the added value of the farm.

3. Materials and Methods

Pruning, carried out in the month of January when the vine is in the dormant phase, involves the removal of all the shoots except the fruiting head which is subsequently tied to the galvanized wire of the espalier. The economic analysis, to identify the minimum optimal size that the company must have to invest, was carried out in Sicily considering the data on a winery located in the province of Trapani. The business reflects the majority of businesses in the area, both in terms of vineyard management methods and entrepreneurial orientation [12-14]. The data collection took place in March 2023 via questionnaire and direct interview with the entrepreneur. The cultivars taken into consideration are Nero d'Avola, Merlot, Syrah, and Chardonnay, trained on the espalier system with a density of around 5,000 plants/hectare and with Guyot pruning.

The test compared the costs of pruning in two different ways:

a) pruning with shears and subsequent manual binding of the productive shoots (manual pruning);

b) pruning and tying of the productive branches using respectively electric shears and an electric tying machine (facilitated pruning).

All the cost items that the winegrower must bear for pruning in the two execution methods (manual and facilitated) were therefore considered. The total cost for pruning is given by the sum of the fixed and variable costs. Fixed costs include the reintegration of agricultural capital and interest on it. Variable costs, on the other hand, are represented by maintenance, electricity, labor, the expense of twine or tube for tying, and interest on the advance capital [15,16]. The total unit cost is given by the fixed costs related to the number of hectares of vines on which the intervention is carried out, to which are added the variable costs referring to each hectare of vines that undergo the intervention. Subsequently, the minimum surface area was estimated—break-even point—which makes the cost of manual pruning equal to the facilitated one. By comparing the fixed and variable costs of the two pruning execution hypotheses, it is possible to find the break-even point, i.e. the vineyard area for which the cost of manual pruning (hypothesis a) is equal to that of facilitated pruning (hypothesis b). The break-even point is obtained by solving the following equation:

$$Cfa/x + Cva = Cfb/x + Cvb \tag{1}$$

from which:

$$x = (Cfa - Cfb)/(Cvb - Cva) \tag{2}$$

where:

Cfa = annual fixed costs assumption a;
Cfb = annual fixed costs hypothesis b;
Cva = variable costs per hectare of vineyard area hypothesis a;
Cvb = variable costs per hectare of vineyard area hypothesis b;
x = break-even point (hectares of vineyard area).

The break-even point refers to the choice of the pruning and tying operation of the fruiting head. This methodology allows us to determine and measure the cost advantage and to carry out the appropriate microeconomic assessments for companies in terms of production, sales, and marketing strategies [17-19].

4. Results and Discussions

The pruning and tying costs were calculated according to the methodology set out above, distinct for the two hypotheses examined. Comparing the two hypotheses, in the case of the Nero d'vola cultivar the total unit cost amounts to 1,046.33 euros/hectare for manual pruning (hypothesis a), against 1,127.62 euros/hectare for facilitated pruning (hypothesis b). For Merlot, the values are respectively 1,052.61 euros/ha compared to 1,149.21 euros/hectare. For Syrah, the values are 1,130.28 euros/hectare and 1,239.39 euros/hectare. Finally, for Chardonnay, values respectively equal to 992.86 euro/hectare and 1,113.59 euro/hectare are recorded. The differences between the four cultivars studied, considering that the density of plants per hectare is homogeneous, can be attributed to the greater vigor that the black berried cultivars have compared to the Chardonnay which translates into a greater need for work for cutting the shoots. Total unit costs for manual pruning decrease irrelevantly, as the hectares of vineyards increase since most of them are made up of variable costs which are constant for each hectare of surface subjected to pruning and binding. The total unit costs of facilitated pruning, on the other hand, undergo a significant reduction depending on the vineyard area pruned. In this case, the fixed costs—which in the case of manual pruning are equal to 7.07 euros—assume a certain importance, depending on the monetary outlay incurred by the entrepreneur to invest, and are equal to 401.00 euros. For the four cultivars examined, the break-even points, which justify the investment in the company, are respectively equal to 1.26 hectares for Nero d'Avola; 1.32 hectares for Merlot; 1.38 hectares for Syrah and 1.44 hectares for Chardonnay. In the latter case, the minimum optimal size is greater than in the other cultivars due to the lower work requirement. Given the break-even points, therefore, it is clear that the investment to facilitate pruning and tying in Guyot-pruned vineyards can also be made by companies smaller than 2 hectares in size. In the light of these results, we have measured the real decrease in pruning costs which derive above all from the reduction in working times and therefore from the relative cost. The transition from manual pruning (hypothesis a) to facilitated pruning (hypothesis b) in the case of vineyards equal to the minimum optimal size determined makes it possible to reduce the labor cost item by 32% in Nero d'Avola, by 30.6% in Merlot, 27.6% in Syrah and 29.3% in Chardonnay. This decrease is directly reflected in the item "interest on advance capital", resulting in an overall decrease in variable costs per hectare. As the vineyard area subjected to pruning increases, it will always be more convenient to operate with hypothesis b) compared to a). In fact, in companies with a vineyard area of 5 hectares for the Nero d'Avola cultivar, the reduction in the total costs of pruning and binding is 22.5%, for Merlot it is 20.9%, for Syrah it is 18.3%, while for Chardonnay there is a reduction of 19.7% (Table 1).

Table 1. Total costs for pruning of vineyards and tying of productive shoots in wine-growing farms with a vineyard area of 5 hectares.

	Nero d'Avola	Merlot	Syrah	Chardonnay
a) Manual pruning and tying hypothesis				
costs	5,203.27	5,234.77	5,623.12	4,936.02
b) Hypothesis of pruning and tying in a facilitated way				
costs	4,034.10	3,821.25	4,592.95	3,963.95
Variazione (%) b/a	–22.5	–20.9	–18.3	–19.7

Compared to previous studies, where we talk about bringing together different companies to make significant investments to reduce costs (purchasing machines together), this research highlights that even small wine-growing companies can make investments on their own that reduce production costs [20]. This work, compared to previous studies [21], is new as it is suitable for current cost conditions. In the validity of this research, one of the limits is the market conditions as the assessments were made according to the market conditions of 2023. As the conditions change, the indicators clearly change.

5. Conclusions

In viticulture, as well as in many sectors of Italian agriculture, the ability to contain production costs represents an indispensable choice for the company. The lowering of the average cost allows the company to arrive on the market with a price (always higher than the average cost) lower than that of its competitors, who are destined to lose market shares in favor of the company that produces at lower costs. The exploitation of economies of scale and the accumulation of experience allow the company that has managed to lower the total unit costs to activate a growth process which, in the medium-long term, leads it to cover an economic-productive position of leader in the sector in which it also operates from a supply chain perspective. In addition to creating a competitive advantage for the company, this condition promotes the development of the territory, encourages investment, and creates income and employment. The modest prices of the grapes, which in recent agricultural years have characterized the wine grape market, combined with high corporate fragmentation, determine a crisis in the wine sector. Intervening on pruning costs through the use of tools that facilitate the work represents a way forward both for large companies and above all for small and medium-sized wine-growing enterprises, which make up the vast majority of the production structures of Italian viticulture. Ultimately, process innovation allows the company to recover competitiveness margins and remain competitive in the market.

Author Contributions

The research was done by Filippo Sgroi and Federico Modica. Filippo Sgroi wrote Sections 2, 3, 4, and 5, and Federico Modica collected the data and wrote Section 1 (Introduction).

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Data Availability

The data presented in this study are available on request from the corresponding author.

Conflict of Interest

The author disclosed no conflicts of interest.

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RESEARCH ARTICLE

Promotion of Improved Onion (Nafis Variety) Production Technology under Irrigated Conditions in Nyangatom District, Low Land Area of South Omo Zone

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Abstract: Onion is an important cash crop that could enhance the income of agro-pastoralists in Nyangatom woreda as the area has huge potential for water availability from the Omo River and fertile land. However, access to improved onion variety is limited in the area. Thus, this study aimed to demonstrate the improved onion variety with its agronomic management in the production season. Onion growers were purposely selected and have taken training on onion production by using recommended doses of fertilizers, pesticides, irrigation, and suitable agronomic practices. Each agro-pastoralist covered 0.064 hectares of land by improved onion. The recorded data from the field experiment and agro-pastoral perceptions were analyzed through simple descriptive and preference ranking tools. From the result of the demonstration trial, the mean bulb yield of the improved onion (Nafis variety) was 125 qt/ha. The average return obtained from the sale of onion bulbs per hectare was 334,925 Ethiopian birr. Moreover, the benefit-to-cost ratio of improved onion production was 8.34:1, which indicates the benefits outweigh the costs, suggesting a positive return on improved onion production in the area. The agro-pastoralist's preference further showed that the Nafis variety was the best one or superior to the local variety in terms of its high-yielding ability, dark green leaf color, medium bulb size, and market preference. Therefore, the authors suggest the respective government and non-government bodies to further promote improved onion in the area.

Keywords: Promotion; Improved onion; Perception; Cost benefit ratio; Agro-pastorals

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1. Introduction

Onion is one of the major cash crops in Ethiopia and its production plays a significant role in the country's agricultural economy. It provides income and employment opportunities for thousands of farmers and laborers involved in its cultivation, harvesting, processing, and marketing [1]. Onion is a highly demanded culinary ingredient, making their production lucrative for farmers. They have a wide range of applications in the cooking and food processing industries, ensuring a constant market demand [2]. Onion is rich in essential nutrients, vitamins, and antioxidants and consumer awareness about healthy eating habits increases, and the demand for nutritious and organic onions continues to rise, thereby benefiting onion producers [3]. Onion can be grown in a variety of locations, but the optimum altitude range for its production is between 500 and 2200 m.a.s.l and the temperature ranges between 12.4 ºC to 31.3 ºC [4]. Onion production in Ethiopia is contributing to the country's agricultural sector. The economic stability and employment opportunities it provides are important for the country's development [5]. However, the productivity of onions is decreasing over time due to different production constraints such as lack of improved variety, disease and pest infestation, weak extension supports and soil fertility decline in the country [6,7].

The South Omo Zone is one of the zones in the Southern Nations Nationality and Peoples Region (SNNPR) and is known for potential large investment lands, irrigation water access from Omo, Woito, and other small rivers. Onion production is one of the significant agricultural activities which is dominated in Bena-Tsemay, Dasenech and Debub Ari woredas of the zone for domestic consumption to meet zonal demand and also supplied to other neighboring zones. Even though South Omo Zone has great potential for onion production with year-round irrigation water from Omo, Woito and other small rivers and fertile land, agro-pastorals were less involved in improved onion production and even most farmers/agro-pastorals in South Omo Zone use their own local varieties, which resulted in lower yield per hectare [8]. Thus, it calls for research efforts regarding improved variety and agronomic management to enhance the production and productivity. In an effort to address these issues, Jinka Agricultural Research Center (JARC) conducted a field experiment to select well-adapted varieties and the optimum blended fertilizer rate at Dasenech in 2019 and Bena-Tsemay in 2020 production seasons under irrigation conditions. Nafis variety with 100 kg/ha of NPSB blended fertilizer rate gave better yields in the field experiment. The onion (Nafis variety) yield obtained from the experiment was 23 to 28 t/ha in the area. Besides, agro-pastoralists and farmers are not in a position to use this improved onion variety (Nafis) because they lack awareness regarding this improved onion variety and its agronomic management. As of these and other production constraints, Jinka Agricultural Research Center conducted the agro-pastoral based field demonstration trial with the objective of demonstrating and promoting improved onion (Nafis variety) with its agronomic management to improve the agro-pastorals livelihoods. Besides, it was aimed at creating awareness among agro-pastoralists about improved onion production technologies to help them get a better income.

2. Materials and Methods

2.1 Description of the Experimental Site

A demonstration trial was conducted in Nyangatom Woreda which is located in the south Omo zone of the Southern Nations, Nationalities, and Peoples' Region (SNNPR) in Ethiopia. It is situated in the southwestern part of the country, bordering South Sudan to the west. It is located at 5°05'-5°21' North latitude and 35°55'-36°14' East longitude, and the altitude lies between 380 and 497 meters above sea level. The total population of the district is estimated to be 11375; of those 11187 were male and 22562 were female [9]. They are predominantly nomadic or semi-nomadic, relying on herding cattle, goats, and sheep as their primary means of subsistence. The Nyangatom people have a distinct culture, traditional practices, and a unique language that is a part of the Nilo-Saharan family. The woreda is characterized by a diverse landscape, including vast grasslands, arid deserts, and rocky hills. The Omo River, which flows through this area, provides a crucial water source for both human and animal populations. The natural resources and biodiversity in Nyangatom Woreda are significant, attracting visitors interested in exploring the diverse flora and fauna. Pastoralism in the woreda relies on livestock rearing for their livelihood. They raise cattle, goats, and sheep, and their lives revolve around herding and managing their livestock. Besides pastoralism, agriculture is also practiced, primarily in areas with suitable soil and adequate rainfall. The common crops cultivated by the Nyangatom people include sorghum, maize, millet, and beans.

2.2 The Research Site and Agro-pastoral Selection

Nabusmeria Kebele from the Nyangatom woreda was purposefully selected based on its onion production potential. The selection was done in consultation with the respective woreda and South Omo Zone Agricultural and Natural Resource Offices. In the Nabusmeria Kebele, community level awareness was created to select agro-pastoralists for the research experiment, and JARC identified one improved onion-producing group (PAPREGs) by giving due consideration to gender, which contained about 25 agro-pastoralist members (11 males and 14 females). The selected agro-pastoral areas for this research experiment were notified to the community. Then, the host agro-pastoralists, who have an interest in onion production technology, have access to irrigation water and are willing to manage and allocate land for the demonstration implemented the research experiment. Finally, from the members of the host agro-pastorals, one chairperson who is responsible for coordinating the group members was selected as a liaison between the group and the researchers, and one secretary who is responsible for record keeping was selected during this research experiment.

2.3 Planting and Agronomic Management

A high-quality onion seed (Nafis variety) was used for planting. The recommended seed rate of 4 kg/ha was sown. After 40 days, the sown seed was grown and ready for planting and uniform medium-sized seedlings were carefully transplanted in experimental fields at 3 or 4 leaf stages. Planting was done on 1.6 hectares of host agro-pastoralist fields. Agro-pastoralist planted the seedlings in 40 cm water furrows with 20 cm rows on beds and 5 cm between plants. 100 kg/ha of NPSB was applied at planting time, 150 kg/ha of Urea at 50% at planting, and the remaining 50% after 35 transplants. As per the recommendations of Ofga et al. [10] the experimental field was irrigated depending on the moisture condition of the soil (5-7 days). A total of 2.5 liter of Karate @5% and 2 kg Mancozeb were used. The weeding, hoeing, irrigating, pest management, harvesting time, and post-harvest handling was conducted timely by the pastoral/agro pastoral research and extension group with intensive follow-up of researchers and experts.

2.4 Training and Awareness Creation

Training materials such as production manuals that agro-pastorals can take home for future reference were provided and training was given to twenty-five agro-pastoralists who were members of PAPREGS, three development agents of kebele and two woreda agricultural experts to share their knowledge and experiences. Practical demonstrations were provided to give agro-pastorals hands-on experience with the onion production techniques which allowed them to see the benefits and implementation process directly. Moreover, the training was focused on nursery preparation, land preparation, sowing the seed, chemical application, fertilizer rate, irrigation frequency and time of application and all other agronomic practices for improved onion production.

2.5 The Role of Each Actor and Responsibility for Demonstration Trial, Follow-up, and Evaluation

In the early beginning, there was a discussion among the stakeholders on the roles and responsibilities for demonstration trial implementation, follow-up, and evaluation. Accordingly, the roles and responsibilities of each stakeholder were identified as follows (Table 1). Researchers discussed with agro-pastorals and identified their technology demand; developed a proposal, organized PAPREG members and delivered training, implemented demonstration trials with PAPREGs, provided appropriate technical information, and processed data to verify the recommendation. Besides, they analyzed the data collected during the demonstration trial and subsequent follow-up activities to evaluate the overall effectiveness, user satisfaction, and performance of onion production in the area. Low Land Livelihood Resilient Project (LLRP) and Southern Agricultural Research Institute (SARI) were the demonstration trial organizers who were responsible for planning and executing a trial phase where users could test and provide feedback on the improved onion production. They coordinate the logistics and collect feedback to evaluate the performance and usability of the system. The Woreda office has efforts to collaborate in site selection and follow-up of the implementation of the demonstration trial. Extension workers are responsible for mobilizing resources and facilitating the implementation activities. They create awareness for the PAPREG members, integrating it with the stakeholders, and ensuring its effectiveness in providing accurate and relevant information. They also maintained detailed records of inputs, practices, yields, and any observations throughout the onion production cycle.

Agro-pastorals are the participants in the demonstration trial. They are direct beneficiaries who get training on the onion production technologies and implement them on the trial site. Share information with each other keep a record of any activities in the field and provide to the researchers for further improvement of the onion production. They play a crucial role in performing field trials and providing feedback on its implementation and any issues encountered.

2.6 Field Day and Agro-pastoralist's Perception

At the end of the field activity (crop maturity stage), agro-pastorals field day was conducted to further promote

Table 1. Actors and responsibility of each stakeholder.

Stakeholders	Roles and responsibilities of each stakeholder
JARC (Researchers)	● Listened to what agro-pastoralist says and identified their technology demand ● Developed proposal and Organized PAPREG ● Delivered trainings and implemented project activity ● Provided appropriate technical information ● Processed data to verify the recommendation
LLRP and SARI	● Review and comment on proposal ● Released fund on time, monitored on-farm activity
District offices	● Collaborated in PAPREGS formation ● Site selection, planting and follow up of implementation
Extension workers	● Mobilized resource and facilitated activities implementation ● linked PAPRG member and Keep activity records
Agro-pastoralists	● Managed trials and discuss progress among PAPRG member ● Provided information to others and keep activity record etc.

the onion production technology. Field day events are a means of transferring new agricultural information like improved onion production technologies to agro-pastorals, farmers, development agents and key stakeholders. Consequently, a total of 50 agro-pastoralists (20 men and 30 women), 6 development agents and 4 experts from district agricultural offices, 6 researchers, and 34 different stakeholders from federal, regional and zonal were participated in the field day. Besides, the field day program was communicated on the news program by Debub television to disseminate information to the wider public view. A total of 120 leaflets were distributed to the participants which describe the production, agronomic practices, and overall management of improved onion varieties. Finally, at the end of the field visit, a group discussion was held to grasp agro pastoralists' feedback on the strengths and weaknesses of the improved onion variety. Additionally, socioeconomic and perception data was collected by face-to-face interviews with 25 PAPREGs members who produced onion and research extension groups using structured questionnaires prepared for this purpose.

2.7 Method of Data Analysis

Both qualitative and quantitative data were collected from early plantation to final harvesting. Qualitative data such as the agro-pastoral perception towards improved onion production was collected. Quantitative data such as the early maturity and bulb yield were collected. The collected data were analyzed using simple descriptive statistics like percentages and mean. A benefit-cost ratio was used to analyze the cost of production and profit from the business enterprise.

3. Results and Discussion

3.1 Yield Performance of Onion Production

The result of the study revealed that the productivity of improved onion (Nafis variety) with its technology packages gave better yield than the local variety with existing agro pastoralists' practice. Thus, the mean bulb yield of improved onion was 125 quintals per hectare (Table 2). This greater yield was achieved through the proper use of recommended technology packages such as the use of the improved Nafis variety with its proper agronomic management. This study by Tadesse [11] reported that the improved Nafis variety gave higher bulb yield among other onion varieties in Bena-Tsemay and Dasenech districts. Similarly, the better yield of Nafis as compared to Bombay Red and local was reported [12]. The better yield in the demonstration trail shows the production of onion in the area is feasible. The minimum and maximum bulb yield attained by each agro pastorals from a plot area of 0.064 ha were 6.3 and 9.7 quintals whereas the mean yield was 8 quintals.

Table 2. Yield data of onion produced by PAPREGs.

Beneficiaries	Land coverage (ha)	Average yield Q/ha	Total yield (Q)
Nafis variety			
25 agro pastorals	1.6	125	200
Per agro pastorals plot of 0.064 ha	Min	Max	Mean
	6.3	9.7	8

3.2 Agro-pastoral Perception of Improved and Local Onion Varieties

It is important to note that specific agro-pastoral perceptions of improved onion production can vary among individuals. Hence, on-ground consultations with agro-pastoralists would provide a more comprehensive understanding of their perception and facilitate the successful adoption of improved onion production methods. Agro-pastoralists might assess whether adopting improved techniques leads to higher onion yields, better bulb quality, or reduced post-harvest losses. This evaluation is crucial for economic viability and maintaining market competitiveness. As shown in Table 3, six criteria were set out in discussion with agro-pastorals to select the varieties in their traits with respect to the area they are producing. Accordingly, the important traits of onion used to select the Nafis variety were disease resistance, insect pest resistance, bulb size, bulb yield and marketability. Agro-pastoralists were interested and chose the improved onion in all traits provided as criteria but their first choice was in terms of bulb size as compared to their local practice. Accordingly, agro pastoralists' showed interest in the production of the Nafis onion variety mainly because of its uniformity in bulb size, disease and insect pest resistance, and other parameters. As indicated in the table, the weighted ranking matrix demonstrated that improved onion was preferred by agro-pastoralist in all traits as it showed better scores in bulb yield, bulb size, marketability, insect pest resistance and disease resistance. The study by Yesuf Sirba et al. [12] and Kitila et al. [13] demonstrated Nafis variety was selected by beneficiaries using similar selection criteria of improved onion variety used in this study.

3.3 Economic Returns and Costs of Onion Production

The economic returns and costs of onion production can vary depending on various factors such as location, scale of production, input costs, market demand, and productivity. Costs of production included in this study are expenses of labor, seeds, fertilizers, pesticides and irrigation. Yield per hectare is an important factor in determining economic returns. Higher yields can offset some of the production costs and result in increased profitability. The prices of onions fluctuate based on supply and demand dynamics, and seasonal variations, and to assess the economic returns of onion production, it's important to develop a comprehensive budget considering all costs and estimating potential revenues based on market conditions and projected yield (Table 4). The land was taken as a fixed asset in the assessment of its opportunity cost which is 2000 Ethiopian birr per hectare in the area at the prevailing land renting. Costs of irrigation, land preparation, weeding and chemical application, chemical, seed, fertilizer, and hired labor were calculated based on the existing market price of inputs during the experimental period which summed as 38075 Ethiopian birr per hectare. The total cost was estimated by adding up variable costs and fixed costs which was 40075 Ethiopian birr per ha.

The income from onion production per hectare was calculated as the multiple of an average yield of onions per hectare and the market price of onion at the time of harvesting. Thus, the average yield of onion per hectare in this demonstration trial was 125 quintal per hectare and the prevailing market price at the harvest was 3000 Ethiopian birr per quintal. The mean income from the sale of Nafis bulb yield was 375,000 Ethiopian birr per hectare. The profit of improved onion production in this case is the difference between the mean income of 375,000 Ethiopian birr per hectare and the total cost of onion production of 40075 Ethiopian birr per hectare. Thus, the profit is 334,925 Ethiopian birr per hectare and it implies that each household who engaged in improved onion production would get a profit of 334,925 Ethiopian birr per hectare. The benefit-cost ratio of onion production per hectare was calculated to see the importance of onion production in

Table 3. Agro-pastoral perception on improved and local onion varieties.

	Improved			**Local**		
Traits	Scores	Weights	Scores*Weights	Scores	Weights	Scores*Weights
Disease resistance	2	1	2	1	1	1
Insect pest resistance	2	2	4	1	2	2
Bulb size	2	4	8	0	4	0
Bulb yield	2	5	10	0	5	0
Marketability	2	3	6	0	3	0
Sum of (Scores*weights)			30			3
Rank			1			2

Note: Scores = (0 = Low 1 = Medium 2 = High) & Weight = (5 = Bulb yield 4 = Bulb size 3 = Marketability 2 = Insect pest resistance 1 = Disease resistance.

the area relative to the cost of production. The benefit-to-cost ratio of improved onion production was 8.34:1. This indicates that the benefits outweigh the costs, suggesting a positive return on improved onion production in the area. The benefit-cost ratio is useful in decision-making as it helps to assess whether onion production in the area is financially viable or not. Moreover, the benefit-to-cost ratio of improved onion production demonstrates that each household gets a benefit from onion production eight times the cost of production. This result would encourage new agro-pastoralists to start with onion production and area expansion to evaluate the costs and benefits of these profitable initiatives. This result is in agreement with the findings of Beshir & Nishikawa [14] and Koye et al. [5] who found the highest return from the production of improved onion variety (Nafis) as compared with the local variety.

3.4 Challenges in Onion Production in the Study Area

The challenging factors of onion production in the research site are presented in Table 5. As mentioned by agro-pastorals, the lack of onion seed is a serious problem for onion production. Improved onion seed varieties are often developed to possess desirable traits such as higher yield potential, disease resistance, and improved quality. Without access to these improved seeds, farmers or agro-pastorals may experience lower crop yields, affecting their livelihoods and food production [13,15]. Storage problems in onion production can arise due to various factors such as physical damage, lack of proper curing etc. Onions require proper curing and storage conditions to maintain their quality and extend their shelf life [1]. However, in the study area maintaining ideal humidity and temperature levels to prevent spoilage and sprouting can be challenging, especially lacking appropriate storage facilities. This problem is ranked as the second most challenging factor in the area. In the research site, agro-pastorals produce onion using a water pump for irrigation and it needs regular maintenance and timely repairs. However, the lack of skills in the maintenance of water pumps challenged onion production and ranked as third level as the smooth operation of water pumps in onion production is critical. Lack of irrigation water pump is the main challenging factor in onion production [7,6]. Agro-pastorals often face challenges in establishing direct connections with potential buyers and distributors. This can result in reliance on intermediaries, leading to lower profits and agro-pastorals ranked this problem as the fourth challenge in the research site. Lastly, they reported that seed preparation skills are another issue and need further. A well-prepared seedbed provides controlled conditions such as moisture, temperature, and protection from pests or diseases [16]. They allow for easier management of seedlings and facilitate proper root development before transplanting.

3.5 Lessons Learnt and Ways Forward

Onion production in agro-pastoral areas can be a rewarding venture and requires careful planning and management to achieve success. As it stands, the pastoral and agro-pastoral research and extension group established in

Table 4. Economic returns and costs of onion production.

Cost items per ha	Unit	Quantity	Unit cost (ETB)	Total cost (ETB)
Improved seed	kg	4	1500	4*1500 = 6000
NPSB	kg	100	25	100*25 = 2500
Urea	kg	150	22.5	150*22.5 = 3375
Karate @5%)	Liter	2.5	1200	2.5*1200 = 3000
Mancozeb 80% wp	kg	2	900	2*900 = 1800
Land preparation	Tractor rent per day	2	2500	2*2500 = 5000
Transplanting	Labor per day	40	100	40*100 = 4000
Weeding and chemical application	Labor per day	40	100	40*100 = 4000
Irrigation water application	Round/month/labor	9*3*2	100	9*3*2*100 = 5400
Harvesting	Labor per day	30	100	30*100 = 3000
Total variable cost				38075
Fixed cost				2000
Total cost				40075
Benefits (birr/ha)				
Bulb yield (Q/ha)	Quintal	125	3000	125*3000 = 375,000
Profit (birr/ha)				334,925
Benefit-cost ratio				334,925/40075 = 8.34:1

Table 5. The main challenges of onion production in the area.

Challenges of onion production	Extent of challenges on onion production					
	Low	Medium	High	Score	Index	Rank
Storage problem	3	6	16	38	0.187	2
Lack of hybrid seed of onion	2	9	14	37	0.182	1
Lack of market linkage and inaccessibility	4	8	13	34	0.167	4
Lack of seed beds	4	9	12	33	0.162	5
Water pump problem	5	4	16	36	0.177	3

Note: The values represent the extent of challenges: Low = 0, Medium = 1, High = 2.

the area hardly ever engaged in onion production.

However the formations of PAPREGs make them work together and learn from each other. This helped the PAPREGs members to undertake all the crop management activities.

This made it easier for the pastoral and agro-pastoral research and extension group members to carry out all of the onion production management. The competition among the participants to showcase their individual performances. So, the formation of the pastoral and agro-pastoral research and extension group is an essential task for technology adoption in the area.

4. Conclusions and Recommendations

The promotion of improved onion (Nafis variety) with proper agronomic management resulted in a higher bulb yield. Thus, it had shown 78.6% yield increments over the local onion production in the area by agro-pastoral field management. Moreover, the host agro-pastoralist preferred this variety its market preference. Additionally, agro-pastoralists have the highest financial returns from this onion production. Thus, it is advisable to use this improved onion variety (Nafis) with its proper agronomic management practice to enhance the production and productivity thereby improving the livelihoods of agro-pastorals in the study area. Further, it needs adequate support of inputs such as onion seed (Nafis), fertilizer, agro-chemicals, easy water lifting devices and agricultural mechanization technologies from respective stakeholders for sustainable production to improve household income for agro-pastorals in the area.

Author Contributions

Awoke Tadesse developed a proposal, conducted the field experiment, recorded all field data, and wrote the paper. Asmera Adicha was involved in data collection and wrote the paper. Atlaw Eshbel, Yibrah Gebre Meskel and Anteneh Tadesse participated in the field experiment and monitored the field activity.

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Data Availability

The data used for this field experiment were included in the main text and the corresponding author will avail the necessary data upon request.

Conflicts of Interest

The authors disclosed no conflicts of interest.

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RESEARCH ARTICLE

Examining the Linkages of Technology Adoption Enablers in Context of Dairy Farming Using ISM-MICMAC Approach

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Abstract: In the context of agribusiness, technology and innovation have led to major transformations in many countries. Precision dairy farming technologies enable cost optimization, quality control, waste reduction, achieving economies of scale, efficiency in dairy resource utilization, improvement in productivity, standardized processes, enhanced decision support system and overall farm management. Despite being an overall production-wise rich country, India's dairy sector lacks in terms of yield per cattle, overall dairy farm output, effective herd management and lack of effective technology acceptance and implementation. With the help of NGT based outcome, this research is an attempt to showcase the enablers of technology adoption in dairy farming and how these enablers interact with each other in a hierarchical form using ISM methodology. Experience in the dairy business, competitive pressure and digital literacy were found as the most crucial and driving enablers. However, agreeableness and managerial interest were found as the most dependent enablers of technology adoption. The interpretations drawn from the model can help the decision makers, policy makers and farmers not only in India but can serve as the base for other nations dependent upon agriculture to understand the inter dependency among enablers and suggestions to plan and channel technology adoption by focusing upon critical ones.

Keywords: Dairy business; Precision dairy farming; Technology adoption; NGT; ISM; MICMAC

1. Introduction

Dairy is a significant component of the Indian agricultural economy, and milk is a necessary consumable that helps rural and small-town households [1], generate revenue as well as a supplier for a number of other enterprises and activities. The livestock sector contributes about 6% of GDP and in the Indian economy; the livestock sector

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is a significant subsector of agriculture. It expanded at a 7.93% CAGR (Compound Annual Growth Rate) at constant prices from 2014-2015 to 2020-2021. Livestock now accounts for 30.13% of all agriculture and related sector GVA (Gross Value Added) at constant prices, up from 24.32% in 2014-2015. In 2020-2021, the livestock sector contributed 4.90% of the total GVA [2]. Animal husbandry, dairying, and aquaculture all significantly contribute to the country's socioeconomic development [3]. In such ways, dairy farming has contributed to uplift the poor farmers thus leading to a major portion of rural development. Global evidence shows that technology application improves cost optimization, quality control, wastage reduction, achieving economies of scale, efficient dairy resource utilisation, improved yield/productivity, standardized processes, enhanced decision support system, and overall management [4].

According to evidence from research studies, agribusiness has the ability to improve performance and bring about operational efficiency with the implementation of technology to ensure food safety and security, increase revenue, and achieve sustainability and regional development [5]. India is the greatest milk producer and consumer in the world, but it faces challenges with yield per unit, overall productivity, low rates of technology acceptance and implementation, health monitoring of milking units, documenting animal data, and the availability of dairy goods on the international market. India's milk market is still having trouble organising itself [6]. The unorganized market and the organised market are in competition over prices. Since clean milk from organised dairy farms is more expensive, a sizable segment of India's consumer base has not yet embraced it. The Amul model of cooperative milk supply chain originated in India during the operations flood programme in 1970 and is now adopted in many states and strengthened the rural and small farmers by enabling them to contribute and earn a livelihood. In this system, a farmer producing milk through its herd supplies to village-based milk cooperatives that are part of respective state-based milk marketing federations. This comprises 10% of the Nation's milk supply, the other 15% being supplied by private dairy farms, 5% going for self-consumption and the remaining 70% sector of India's milk supply is referred to as unorganized which means direct sales to consumers. With a constant rise in milk demand, other than the cooperative supply chain, dairy farms are also required to come forward to manage future demands [7].

The popular technologies available for dairy farming are artificial insemination, automatic milking systems, milk parlour, bucket/portable milking systems, robotic milking system, radio frequency identification (RFID) tagging in animals, information technology based database management system, enterprise resource planning (ERP), internet of things (IoT), using websites and other miscellaneous machinery for silage preparation, hydraulics for cleaning, etc. The government of India is active towards consolidating the milk cooperatives by attaching more and more farmers from villages to attach with this supply chain but has less focus on strengthening the dairy farms. Various technologies such as milk testers, collectors, and cold chain management technologies are part of these cooperative milk chains aided by government support at all village level milk collection centres.

In the presence of certain challenges of technology adoption, there is a second side of the coin which talks about certain enablers that facilitate the smoothness to adopt technologies. Whether somebody talks about enablers, challenges, determinants, consequents, facilitators or antecedents, the factors within these come from a variety of dimensions such as personal characteristics, organisational, micro or macro environmental, static or dynamic factors. The presence of these diversified factors creates a complex scenario since all cannot be taken at the same level. There are hierarchies, relationships, dependency, independence and interdependency among the factors that need to be examined to solve complexity, extract inferences and build strategic actions.

This paper analyses enablers of technology adoption in the case of dairy farming and analyses their interactions in the hierarchical based ISM (Interpretive Structural Modeling) model along with the MICMAC (Matrice d'impacts Croisés Multiplication Appliquée á un Classment) based analysis which divides the enablers into four categories based on driving and dependence power. These techniques are part of a systems approach to problem-solving. Systems thinking or systems approach is a way of looking at situations as a system which has a certain number of inside and outside sub-systems and numerous impacts of one on the other can be seen. This complexity needs to be resolved to plan action, solve problems and facilitate decision making. The findings of this study can serve policy makers, government, dairy farmers and service providers to get the idea about how enablers of technology adoption are related to each other and which enabler must be taken care of or targeted first on which the other enablers are dependent or help to drive it. The recommendations are solely based on the hierarchy that placed different elements at different levels and have the potential to significantly increase the rate of technology adoption and, ultimately, improve the social and economic well-being of Indian farmers at all levels of economic development, from micro to macro.

2. Literature Review

The impact of technology on the business sector has been quite enormous. As a result of the invention of technology, traditional business functions, models, and conceptions have been changed. That is because technology has provided a more innovative and effective way to do business. It has given a convenient, seamless, and efficient way of conducting business. Many businesses, regardless of their product or service focus, have discovered that technology adoption from procurement to delivery has resulted in a significant improvement in business operations, resulting in lower costs and higher profits [8].

The sustainability of the agro-food industry is significantly influenced by technological advancements in the fields of networking devices, sensors, and communication technology. As a primary type of technology under the roof of Precision Dairy Farming (PDF), the RFID ear tag or collar technology integrated with a database is used for the identification and record keeping of dairy cows [9]. The National Livestock Identification Scheme (NLIS) started using radio-frequency identification (RFID) tags in the year 2000. These tags have a microchip inside that can be electronically read in a split second by producers who have a suitable reader [10]. The advantages offered by RFID tags and related hardware and software include real-time monitoring, environmental sensing, tracing, and tracking. RFID tags can be incorporated into a variety of sensor types to collect data on various parameters. In addition, Eastwood et al. [11] identified a moral dilemma in the ethics of such precision technology devices that could spark societal discussions about animal welfare. Apart from the factors that influence the adoption of RFID like education of farmers, knowledge, age, farm size, business complexity, ownership, risk perception etc., Rathod and Dixit [12] highlighted several challenges in the adoption of such precision technology, like the incapability to assess cost-effectiveness, chances of technical failures due to high degree of automation, dependence upon technically sound and skilled workforce to access, interpret and analyze the generated data. Overall awareness, affordability and socio-cultural beliefs have been found the most prominent challenges in the adoption of digital devices such as RFID-based cow collars in India, because, most of the livestock is scattered by low-holding farmers in remote village areas where, even for the basic necessity, the population has to travel long distances. These areas do not have sufficient awareness and affordability to procure such high-end technology due to low herd size, leading to high fixed costs, training or access to after-sale support from the service provider. The livestock in India, primarily the indigenous cows, have a lot of religious beliefs attached to ancient mythology. Also, in some cases, the perception of farmers is more towards the ethical acceptability of such technologies and they feel like human touch, love and care are essential rather than treating animals like machines [13]. All these socio-cultural beliefs and economic constraints restrict the adoption of digital devices and PDF technologies in general.

The Internet and other technologies have ushered in a corporate revolution, demonstrating that technology is critical to the success of today's internet-based businesses. As a result, as tomorrow's managers, entrepreneurs, and business experts, one must learn how to use and manage a wide range of information technologies to revive dairy business operations [14] and obtain competitive advantages through improved managerial decision-making [15]. The enablers need to perform optimally in order to minimize the impact of challenges. Some of the major challenges are highlighted by Kaushik et al. [16] such as small herd size, unavailability of a trained workforce, high cost of adoption and maintenance, low awareness, huge investment requirements, inappropriate pricing policy of milk, shortage of funds, less number of course opportunities in dairy-based education, the low willingness of the market to pay against technology processed milk and milk products and less acceptance of the decision maker. While considering the listing of enablers, the challenges are also kept in mind to determine the scope to know where betterment is required or what must be the enabling factors to smoothly conduct the transition or change planning. Table 1 includes the list of enablers of technology adoption along with the references.

3. Problem Description

Agriculture has always been a prime pulse for the Indian economy and supports two-thirds of the total population in their livelihood, accounting for 18.3% of the GDP [38]. Dairy farming is an essential part of agriculture, since India is the largest producer as well as consumer of milk in the world. The credit goes to the white revolution when the cooperative milk movement came into the picture. With the advent of technology in agriculture, dairying has received support in the form of precision dairy farming technologies. Despite the largest production in which the large population of rural households has a role to play, India's 70% milk supply is through an unorganized sector and large dairy farms are not much motivated in the economy. The attention of the government is towards developing small holder farmers to maintain and operate technology-enabled dairy farms. Even in the existing private dairy farms, the level of technology adoption is not

Table 1. Enablers of technology adoption are indicated in previous research.

S. No.	Enablers	References
1	Access to financial and funding resources	Antwi-Agyei [17]; Galstyan & Harutyunyan [18]; Jharkharia & Shankar [19]
2	Government authorities support	Antwi-Agyei [17]; Stockdale & Standing [20]; Subba Rao et al. [21]
3	Technology infrastructure	LaLonde [22]
4	Awareness	Høyer et al. [23]; Quddus [24]; Jharkharia & Shankar [19]; Russell & Hoag [25]
5	Experience	Yadav & Naagar [26]; Abdullah et al. [27]
6	Accessibility	Antwi-Agyei [17]
7	Assertiveness	Van Akkeren & Cavaye [28]
8	Internal organisation culture	Abdullah et al. [27]
9	Absorptive capacity	Stornelli et al. [29]
10	Reliability	Jharkharia & Shankar [19]
11	Insurance facilities	Antwi-Agyei [17]
12	Willingness	Yengoh et al. [30]
13	Top Management commitment	Shoemaker et al. [31]; Jharkharia & Shankar [19]; Gallivan [32]
14	Perceived ease of use	McDonald et al. [33]
15	Perception of usefulness	McDonald et al. [33]
16	Competitive pressure	Ghadge et al. [34]; Wamba & Wicks [35]; Shoemaker et al. [31]; Zheng et al. [36]
17	Technology Self-efficacy	Venkatesh & Bala [37]

satisfactory.

There are several multilevel challenges in the adoption of technology, such as the low awareness, unaffordability, unavailability and promotion of such technologies that enable effective herd management like RFID, IoT, automatic milking, etc. Another important challenge is the yield per day of indigenous breeds, which does not provide much expected revenue to get the funds for technology adoption. These are the reasons why the presence of Indian dairy products is not impressive in the international market. This problem is solved by the use of artificial insemination (AI) technologies. Researchers indicate that India needs to strengthen its dairy farms in all respects to meet the constant rise in demand with the rise in the population.

Challenges and enablers are more or less the two sides of the same coin. While challenges are obstructions to achieve, on the other hand, enablers are requisites to not let obstructions restrict the achievement. Many studies have been conducted on the challenges of technology adoption in dairy farming as well as in other industries and sectors, but fewer studies are there in the context of enablers of technology adoption, specifically in the case of dairy farming. In the Indian context, the realization of the importance of technology adoption is vital to ensure the growth of farmers at the micro level and its impact on the nation's economy at the macro level.

This paper is an attempt to showcase that the enablers of technology adoption in dairy farming exist as a part of a complex system that needs to be resolved to have a suitable picture of how enablers impact each other. If enablers are not managed, they take the form of challenges. Thus, the results reflect how technology adoption can be maximized by focusing on the strengthening of crucial enablers identified as per the positions and linkages among enablers in the hierarchy.

4. Data Collection and Method

4.1 Nominal Group Technique

Delbecq et al. [39] and Delbecq and Van de Ven [40] created this technique. It is a cooperative process that primarily aims at problem-solving and decision-making. It can be utilized in groups of all sizes that wish to reach a conclusion fast, like by vote, but it also considers everyone's thoughts. In this study, a total of 10 domain experts involving 2 dairy farm owners, 3 academicians from dairy institutions, 2 dairy researchers, 2 dairy development board representatives and 1 owner of a technology service providing firm participated in the two NGT sessions given in Table 2.

4.2 ISM-MICMAC

The study has used ISM or Interpretive structural modeling [41] and MICMAC or Matrix of impacts cross multiplication applied to a classification [42] approach to develop a hierarchical model of enablers and divides the identified enablers into four categories based on the driving and dependence powers.

Table 2. Stages of NGT sessions.

NGT	Purpose	Outcome
Session 1	To finalize the list of enablers (elements) on the basis of literature review results and discussion	12 elements were finalized
Session 2	To define pairwise relationship among the finalized elements To make checks for any conceptual inconsistency in the software generated model result.	Construction of SSI matrix for ISM Development of final ISM and MICMAC.

5. Findings

5.1 Identification of Elements

On the basis of NGT led workshop sessions, the experts finalized the list of 12 elements (Table 3) to be taken forward in the study. The same order of elements (from E1 to E12) has been followed to carry out the ISM procedure.

Table 3. The final list of elements for ISM.

S. No.	Enablers of technology adoption in dairy farming
E1	Affordability to adopt and maintain technologies
E2	Awareness level of technologies
E3	Experience in the dairy business
E4	Technology maintenance ease
E5	Agreeableness of technology into dairy farming
E6	Managerial interest for technology adoption
E7	Availability of trained workforce to operate and manage technology
E8	Technology ease of use perception
E9	Perception of technology usefulness
E10	Competitive pressure for adoption
E11	Technology self-efficacy
E12	Digital literacy

5.2 Pairwise Contextual Relationship among Elements

The researchers have used freely accessible SmartISM software [43] to enter SSIM values. In SSIM, the elements are arranged row and column wise (see Figure 1) and experts are asked to choose the relation of influence by picking each pair of 'i' and 'j' intersections among V, A, X or O.

V → if row element influences column element

A → if column element influences row element

X → if column and row elements both influence each other

O → if there is no relationship of influence

After the SSIM, the ISM development procedure leads to the formation of the initial and final reachability matrix. The final reachability matrix (Figure 2) is formed after performing the transitivity checks. It means if experts have defined element 1 is related to 2 and element 2 is related to 3 but did not define that 1 is related to 3, and then

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12
E1		O	O	O	O	V	O	O	O	O	O	O
E2			A	O	V	V	V	V	V	A	V	A
E3				O	V	V	O	O	O	O	V	O
E4					O	V	A	O	O	O	O	O
E5						X	O	A	A	A	A	A
E6							A	A	A	A	A	A
E7								V	O	A	V	A
E8									V	O	V	A
E9										O	V	A
E10											V	O
E11												A
E12												

Figure 1. Image of the generated SSIM.

Variables	1	2	3	4	5	6	7	8	9	10	11	12	Driving Power
E1	1	0	0	0	1*	1	0	0	0	0	0	0	3
E2	0	1	0	1*	1	1	1	1	1	0	1	0	8
E3	0	1	1	1*	1	1	1*	1*	1*	0	1	0	9
E4	0	0	0	1	1*	1	0	0	0	0	0	0	3
E5	0	0	0	0	1	1	0	0	0	0	0	0	2
E6	0	0	0	0	1	1	0	0	0	0	0	0	2
E7	0	0	0	1	1*	1	1	1	1*	0	1	0	7
E8	0	0	0	0	1	1	0	1	1	0	1	0	5
E9	0	0	0	0	1	1	0	0	1	0	1	0	4
E10	0	1	0	1*	1	1	1	1*	1*	1	1	0	9
E11	0	0	0	0	1	1	0	0	0	0	1	0	3
E12	0	1	0	1*	1	1	1	1	1	0	1	1	9
Dependence Power	1	4	1	6	12	12	5	6	7	1	8	1	

Figure 2. Final reachability matrix.

this error is rectified after the initial reachability matrix. The transitivity check error rectifications are denoted by 1* in the final reachability matrix. The final reachability matrix also tells the driving and dependence power of each element which means the number of elements that it drives or depends upon, respectively. These powers are determined to perform MICMAC analysis.

The level partitioning is the next stage in which hierarchical levels of ISM are distributed among various levels. The levels are formed by performing separate iterations for each level by eliminating the already designated levels before making a new iteration for the next level. The first level indicates that the element is placed at the top and is the most dependent element followed by the drivers at lower levels. The final allotted levels of each element can be seen in Figure 3 in the form of a conical matrix. Once the levels are divided, then in order to reduce complexity, unnecessary or unrequired links are removed from multi relation portraying digraph without sacrificing or impacting the basic structural foundation. Then, through the reduced links, the digraph is converted into a final model.

Variables	5	6	1	4	11	9	8	7	2	3	10	12	Driving Power	Level
5	1	1	0	0	0	0	0	0	0	0	0	0	2	1
6	1	1	0	0	0	0	0	0	0	0	0	0	2	1
1	1*	1	1	0	0	0	0	0	0	0	0	0	3	2
4	1*	1	0	1	0	0	0	0	0	0	0	0	3	2
11	1	1	0	0	1	0	0	0	0	0	0	0	3	2
9	1	1	0	0	1	1	0	0	0	0	0	0	4	3
8	1	1	0	0	1	1	1	0	0	0	0	0	5	4
7	1*	1	0	1	1	1*	1	1	0	0	0	0	7	5
2	1	1	0	1*	1	1	1	1	1	0	0	0	8	6
3	1	1	0	1*	1	1*	1*	1*	1	1	0	0	9	7
10	1	1	0	1*	1	1*	1*	1	1	0	1	0	9	7
12	1	1	0	1*	1	1	1	1	1	0	0	1	9	7
Dependence Power	12	12	1	6	8	7	6	5	4	1	1	1		
Level	1	1	2	2	2	3	4	5	6	7	7	7		

Figure 3. Consolidated level partitioning of elements.

5.3 ISM Results

The ISM has been divided into 7 levels (Figure 4). The elements at level VI are the strong drivers that strive to drive the elements at subsequent levels above. Whereas, the level I elements are the most dependent elements. The arrows explain the association of influence from driver to dependent.

Level I: Agreeableness of technology into dairy farming (E5); Managerial interest in technology adoption (E6)

Level II: Affordability to adopt and maintain technologies (E1); Technology maintenance ease (E4); Technology self-efficacy (E11)

Level III: Perception of technology usefulness (E9)

Level IV: Technology ease of use perception (E8)

Level V: Availability of trained workforce to operate and manage technology (E7)

Level VI: Awareness level of technologies (E2)

Level VII: Experience in the dairy business (E3); Competitive pressure for adoption (E10); Digital literacy (E12)

5.4 MICMAC Results

The MICMAC divides the elements into four distinct categories on the basis of dependency and driving powers already derived in the final reachability matrix (Figure 5). The elements in the first quadrant are known as autonomous and possess low driving and dependence power. The second quadrant is composed of dependence, the one with low driving but high dependence power. The elements at the top levels of ISM are the dependents. Linkages in quadrant three are the interdependent elements that have both high driving as well as dependence powers. Lastly, in quadrant four, the high driving but low-dependent elements are placed and known as drivers or independents.

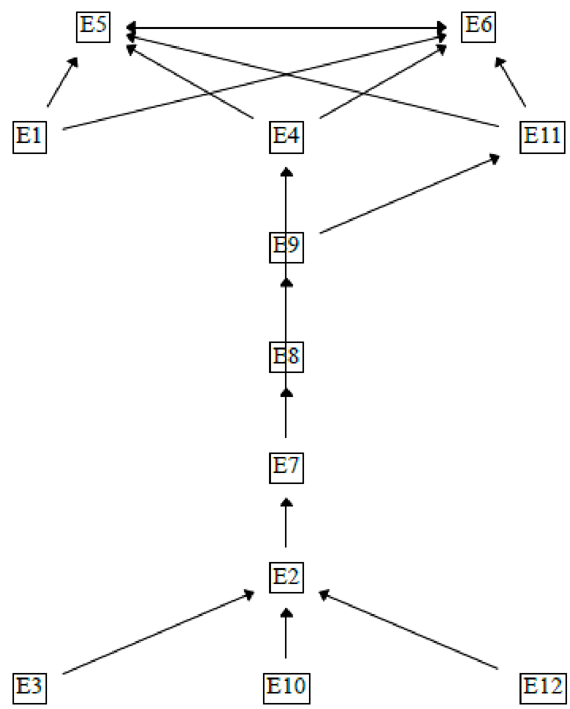

Figure 4. Interpretive Structural Modeling (ISM) for enablers of technology adoption in dairy farming.

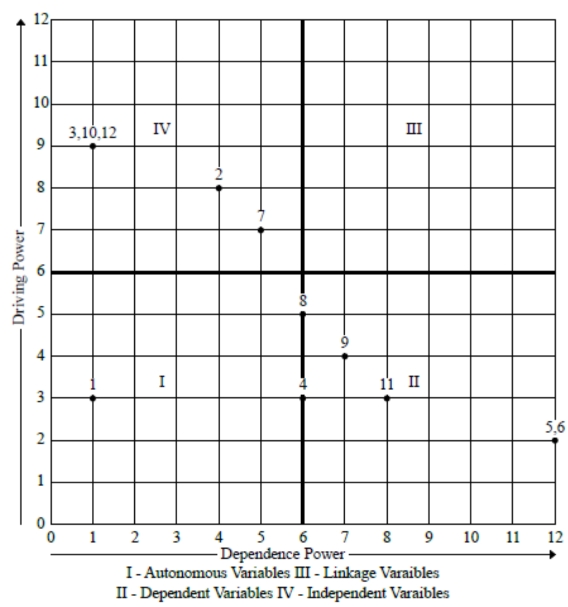

Figure 5. MICMAC.

Autonomous: Affordability to adopt and maintain technologies (E1).

Dependents: Agreeableness of technology in dairy farming (E5); managerial interest in technology adoption (E6); perception of technology usefulness (E9); and technology self-efficacy (E11).

Linkages: No element.

Independents: Awareness level of technologies (E2); experience in the dairy business (E3); availability of trained workforce to operate and manage technology (E7); competitive pressure for adoption (E10) and digital literacy (E12).

Exceptions: Technology maintenance ease (E4) and technology ease of use perception (E8) were found to be middle of the road elements between autonomous and dependent categories; and both have the same dependence power. Technology ease of use relatively has higher driving power than technology maintenance ease.

6. Discussion

On the basis of ISM and MICMAC results, the following points of interpretation can be drawn:

- Experience in the dairy business (E3), Competitive pressure for adoption (E10) and Digital literacy (E12) are present at the base level of the ISM, which means that they are the strong enablers of technology adoption and strong drivers in the given system of elements. It can be validated by MICMAC as all these are under the fourth quadrant that has high driving elements. All these three equally drive the element at level II. It is evident that farmers' experience in the dairy business or how much a farmer has invested in terms of years dedicated to dairy farming. It includes knowledge of all the ways to effectively perform activities related to herd management, procuring and processing. Next, competitive pressures also act as a strong driver for adopting technology. As technology gains popularity in dairy farming, other farmers also intend to adopt it in order to smoothly manage operations and ensure value deliverance in various tasks. Here, digital literacy or the knowledge of handling technology is also an important driver. If a farmer or any worker is aware of handling technologies and has a certain level of comfort, then the chances of a decision related to the adoption of technology become optimistic.
- All the above three enablers tend to drive the awareness level of technologies (E2). Experience in dairy farming enhances awareness as long tenure of service in dairying enables time to time updates in the field. In terms of technology, an experienced and informed farmer is aware of the technologies available for dairy farming. Competitive pressure also motivates farmers to stay aware and be in touch with the latest developments in the field of precision dairy farming technologies and other forms of innovative dairy technologies. Lastly, the digitally literate farmers or workforce get themselves regularly updated and aware of the technologies available.
- The availability of a trained workforce to operate and manage technology (E7) has been placed at level V. It means that the awareness of technology influences the availability of a skilled workforce to operate and manage technology. This link can be explained as digital literacy impacts awareness of technology and then it ensures that the workforce is aware of the chances of being capable of managing technology, primarily information and digital technologies.
- In the ISM figure, a continuous arrow can be seen crossing the element block. It means that this availability of a trained workforce to operate and manage technology (E7) has a direct impact on technology maintenance ease (E4) at level II. This can be interpreted as the trained workforce being capable of maintaining technology in case of minor issues or regular scheduled services.
- Technology ease of use perception (E8) at level IV is driven by the availability of a trained workforce to operate and manage technology (E7). If a trained workforce or an aware farmer is there, then it has an influence on the perception related to how easy a technology is to use. Since technology requires a certain level of awareness, knowledge and skills to operate and manage, it will be easy to use technology if technologically skilled workforce is there at the dairy farm.
- Technology ease of use perception (E8) influences perception of technology usefulness (E9) at level III. If the perception related to ease of using technology is favourable, then the perception related to the utility of engaging technology in one's dairy farm also moves in the positive direction. But if a farmer is not aware or tech-friendly, then he might not prefer to adopt it, thus affecting the unfavorable perception regarding the usefulness of technology in dairy farming and preferring to sustain with traditional farming methods.
- Perception of technology usefulness (E9) in the dairy farm business influences technology self-efficacy (E11) at level II. If the utility of technology is realised by the farmer, then it tends to encourage

the belief and motivation in a farmer's capacity to execute desired behaviour, which is in this case the adoption of technology.

- Technology maintenance ease (E4) and technology self-efficacy (E11) both directly influence the agreeableness of technology in dairy farming (E5) as well as managerial interest in technology adoption (E6) at level I. Here, the term managerial interest is referred to the decision maker in the dairy farm unit and can loosely be referred to as farmer also. If technology is easy to maintain, then both agreeableness and managerial interest can be positively influenced. As per the experts, the agreeableness and interest here differ in the sense that interest is somewhat related to the opportunity cost after comparing traditional farming methods versus technology enabled farming depending on farm size and other factors. Agreeableness is related to the acceptability of technology intervention in dairying. As some of the farmers did not find technology suitable to adopt, there is a perception that human touch and care are necessary and that maintaining technology is a burden. Most importantly, technologies like automatic milking can create harm to the animal's udders and further medical treatment for the cattle should be required. But it is assured now that there is no such harm due to more advanced forms of suction equipment.

There is another element present at level II; Affordability to adopt and maintain technologies (E1), which has no driving enabler at below levels and directly shows up. This is the reason why this enabler has been placed in the autonomous category in the MICMAC as it has almost no dependence power. In the end, technology is a cost-bearing decision. It involves one-time investment costs for adoption as well as maintenance costs, either regular or sudden. This enabler also directly influences agreeableness of technology in dairy farming (E5) as well as managerial interest in technology adoption (E6) at the level I. Cost versus benefit analysis is considered at this stage, which in turn develops interest among the decision makers in the dairy farm unit in whether to adopt any technology or not.

Also, it can be noted at level I, that a two-way relationship between agreeableness of technology in dairy farming (E5) and managerial interest in technology adoption (E6) has been explored. It means both have an impact on each other. The agreeableness to adopt technology influences the interest in adopting technology and interest developed in technology can influence the agreeableness to adopt technology. Both these enablers possess the highest dependence power and thus are placed in the second quadrant of the MICMAC.

7. Conclusions

This study has identified and established linkages among enablers of technology adoption specifically focused on dairy farming. The ultimate objective is to improve performance by enhanced or properly planned technology adoption and to aid stakeholders or decision makers in the Indian dairy farm business to develop strategic and action plans, and support policy planners in developing favourable policies based on an understanding of the contextual relationships between enablers. It is important that technology promotion, dairy related education and awareness of technologies of dairy farming must be enhanced first in order to ensure a trained workforce or trained farmers. This enabler can regulate other enablers such as perception regarding usefulness and ease of using technologies. Ultimately, the interest of the decision maker can be in the positive direction, but other important factors are also vital to play a role here, like affordability to procure and maintain technology, along with ease in the maintenance and constant technology management. Overall, the ISM and MICMAC as part of techniques under systems approach, are good ways to model poorly articulated problems within a system that has several sub-systems interlinked with each other in a proper interpretive form of hierarchical model that can help to resolve complexity and facilitate decision making. These techniques are backed by experts' discretion/opinion and ensure consensus building through discussion to get the maximum accuracy and closeness to the actual or real system. The NGT led discussion avoids bias and loudness of a single opinion. NGT ensures fair participation and a synergic impact on information gathering, building solutions and action plans.

This research shows the relationship among identified enablers along with their existence in the hierarchy and dependence and driving power, but it lacks the ability to statistically validate the findings using techniques like SEM. This can be taken as the future scope of this study, including fuzzy dominance considerations revealing the degree of association among identified elements. Also, this study can be taken as the basis to develop a modified model based on the dynamics of other nations than India. The model elements can be reworked, redefined and the contextual association may also be redefined as per the internal and external environment of the industry.

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The authors have contributed equally to this work.

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Data Availability

The data presented in this study are available on request from the corresponding author.

Conflict of Interest

The authors declare no conflict of interest in any form.

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RESEARCH ARTICLE

Understanding Factors of Households' Circular Economy Adoption to Facilitate Sustainable Development in an Emerging Country

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Abstract: A shift from a linear economy to a circular economy can help participants (i.e., enterprises and households) to cut expenses, stabilize supply chains for the long term, and lower manufacturing and operating costs. Although the circular economy can benefit both the economy and the environment, this topic has still been under-studied in developing countries. More specifically, there has been little known about conditions and/or barriers for stakeholders in adopting a circular economy. In this regard, the authors conducted a study among Vietnamese households to improve the understanding of the factors (both drivers and impediments) of a circular economy adoption. Specifically, the authors employed a questionnaire-based survey approach to collect data from 473 households operating in the agricultural sector in the Red River Delta, Vietnam. The PLS-SEM method was performed to unravel the complicated relationship between circular economy adoption, organizational innovation, and income of agricultural households. The results showed that the adoption of circular economy is widely influenced by many factors in Vietnam. For example, technology has a negative impact on the level of circular economy adoption while policy and regulation, management, customer, and society have the opposite effect. Furthermore, organizational innovation played a fully mediating role between circular economy adoption and households' income. The results of the study offer many policy implications for supporting and increasing the households' circular economy adoption for further sustainable development in Vietnam and beyond.

Keywords: Circular economy; Agricultural households; Households' income; Vietnam; Red River Delta; PLS-SEM

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1. Introduction

Circular economy (CE) has received significant attention from government, business, and society during recent years due to its environmental, social, and financial benefits [1]. The circular economy model is more efficient in utilizing and recycling resources, lowering emissions and wastes, than the traditional linear economy model, which collects raw materials and transforms them into goods that are utilized until they are eventually thrown as trash. It therefore helps to decrease the negative environmental consequences and to improve the economy, environment, and society's balance [2,3]. Moreover, according to a study conducted by Barros et al. [4], it was found that CE plays a crucial role in enhancing the sustainability of businesses through its positive impact on various aspects such as strategic planning, cost management, supply chain management, quality management, environmental management, process management, logistics and reverse logistics, service management, and research and development.

At the household level, moving toward the circular economy business model gives great potential for households to achieve higher market share, opening doors to new markets, lowering costs and risks, driving innovation, recruiting talent, and aligning company performance with public expectations. However, the transition from a linear economy to a circular economy business model is not an easy task. The move to a circular economy often requires a comprehensive adaptation of companies' business models or even the creation of new business models [5]. Companies shifting to the CE model must also create entirely new product conceptions, service offerings, reconsideration of suppliers and partners, and value chains that prioritize long-term efficiency over short-term efficiency [2].

The obstacles that businesses experience in applying circular economy principles as well as the elements that encourage the move to circular models are well-defined in the literature. According to the comprehensive review of Sarja et al. [6], most related studies are dominated by a few countries, mainly China and the United Kingdom. However, the determinants of CE adoption are very different across countries due to dissimilarities in culture, legislation, market, etc. [6]. Therefore, there should be particular studies for a specific country context.

Vietnam is an emerging economy with rapid and solid economic growth and governance. However, Vietnam is now confronted with numerous major issues, including resource depletion, pollution, and climate change [7]. Due to the concentration of a significant portion of the population and economic resources in coastal lowlands and deltas, coupled with the prevalent poverty and deprivation in rural areas, Vietnam has been identified as one of the top five countries most susceptible to the consequences of climate change. Specifically, the agricultural sector bears the burden of these impacts. The Red River Delta is a region with the highest Gross Regional Domestic Product among seven socio-economic regions in Vietnam. With its fertile alluvial soil and lush vegetation, it offers an ideal condition for cultivating rice, vegetables, and fruits as well as aquaculture with shrimp and fish. With existing strengths, the local government is trying to promote agricultural production in a circular direction for sustainable agricultural development. One of the most important forces in this goal is agricultural households (households engaged in agricultural production activities, including the production and distribution of agricultural equipment and supplies, as well as the processing, storage, and distribution of agricultural commodities).

Despite the undeniable long-term benefits of a circular economy, there are still numerous barriers to its widespread implementation at present [8]. In this case study, we focus on the determinants of CE adoption in agricultural households in the Red River Delta, Vietnam. Besides, we examine the impact of the CE adoption on households' income with the mediating effects of organizational innovations. There are many studies that assert the relationship between CE adoption, organizational innovations, and households' income separately [9-11]. However, no study before tried to figure out the joint interaction of these three factors. This research gap is the one addressed in this article. The research objectives of this study are (1) to provide insights into the key obstacles that need to be addressed and the incentives that can promote circular economy adoption in the context of Vietnam; (2) To find the indirect impact between circular economy adoption on households' income through the intermediary factor of organizational innovations; and (3) To propose solutions to help promote the adoption of circular economy in households and promote positive impacts of circular economy adoption on households' income.

Analyzing 473 collected questionnaires with Partial Least Squares Structural Equation Modeling (PLS-SEM), our results show that technology is the barrier to the CE adoption of agricultural households, while policy and regulation, management, customer, and society have a positive impact on the CE implementation. Besides, there is strong evidence that organizational innovation played a full mediating role in the positive effects of circular economy adoption on households' income.

The contributions of this study to existing literature are threefold. First, to the best of our knowledge, this is the first research that studies the mediating roles of organizational innovation on the relation between circular economy adoption and households' income. Second, We do not use binary variables for implementing CE as in other studies. Instead, we categorize it into four levels, which include applying at least one CE-related practice, incorporating at least one CE-related norm into the process, planning to implement any type of CE-related practice, and having no plans to undertake any CE-related activities. It helps to clearly define the specific level of CE adoption. Lastly, our empirical results could draw several managerial implications for local government and businesses.

The rest of this article runs as follows. Section 2 presents the literature review related to factors that influenced the CE implementation. Section 3 describes the data and methodology. Section 4 shows the results and discussions. Section 5 gives concluding remarks.

2. Materials and Methods

2.1 Factors Affecting the CE Adoption

In encouraging the shift from a linear economy to a circular economy at the household level, it is crucial to understand the motivations and barriers for the CE implementation of households. Only by recognizing the factors that impede or ease the transition can business policy and guidelines suggestions be established to efficiently and successfully support the transformation [14].

Urbinati et al. [12] conducted a comprehensive analysis of multiple case studies within the European manufacturing industry to explore the impact of environmental regulations on the establishment of a circular business model and the adoption of circular management practices. Their findings indicate that environmental legislation plays a crucial role in the development of a circular business model and the implementation of specific managerial practices. However, it is worth noting that although governments strive to create favorable conditions for transitioning to circular models through legislation, there can be a mismatch between regulatory measures and the evolving needs of businesses and emerging technologies [13].

Houston et al. [14] conducted a survey among European companies' stakeholders to identify key enablers and barriers to CE implementation. The authors underline that, if overcome, constraints might be transformed as facilitators of the move to circular economy business models. However, the classification of Houston et al. [14] only considers factors inside the company and the value chain. For a more comprehensive view, Xia and Ruan [15] study a sustainable circular economy in agriculture in China and build up a set of factors influencing CE implementation based on stakeholder theory [16]. This study divides barriers to CE in agriculture in China into three sources including government, farmers, and enterprises.

There are many studies that synthesize the factors affecting CE adoption through the literature review method. Werning and Spinler [17] list 29 potential barriers (including 27 factors from the literature and 2 more obstacles from their findings) that prevent organizations from transforming their business models to be more circular. The authors conclude that since the managerial and financial resources of each company are limited, a priority ranking for barriers of CE in order of their impact on the value chain and the difficulty with which business can be overcome is necessary. Galvão et al. [8] study 195 related articles from the Web of Science Core Selection and Scopus database and find out the main barriers identified in the literature are (i) technological, (ii)policy and regulatory, (iii) financial and economic, (iv) managerial, (v) performance indicators, (vi) customer and (vii) Social. Govindan and Hasanagic [18] extracted 5 drivers and 4 barriers to CE adoption from reviewing 155 articles, books, research reports, etc.

However, in the above studies, there are many factors that are both enablers and barriers to CE adoption. As explained in Sarja et al. [6], which provides a systematic literature review on obstacles, catalysts, and ambivalences of the transition to the circular economy in business organizations, some factors are not clearly motivations or barriers but ambivalences of CE transformation. Therefore, instead of developing any specific hypotheses, we comprehensively involve all impact factors mentioned by recent studies that may influence the CE adoption in agricultural households in Red River Delta, Vietnam into our model and figure out which one is the driver or barrier of the CE adoption in our study context.

Based on the summary of Galvão et al. [8] and Sarja et al. [6], there are five main factors that influence CE adoption including technology, policy and regulations, financial issues, management, customers, and society. We summarize the major factors and related papers in Table 1 below.

2.2 The CE Adoption, Organizational Innovations, and Households' Income

In an era where governments, industries, and academia are increasingly concerned about the circular economy and sustainability, innovating business models for circularity and sustainability is becoming increasingly important to maintain a competitive advantage for businesses [26]. Material circularity necessitates a set of organizational innovations that can help to greater resource utilization [27]. A new organizational strategy in the household's business procedures is projected to result in increased efficiency

Table 1. Summarize of factors that influence CE adoption.

Factors	Definitions	References
Technology	Technologies that support the adoption and development of circular economy	Su et al. [19], Pan et al. [20], Geng and Doberstein [21]
Policy and regulation	Policy and regulation of all level governments that support the adoption and development of circular economy	Su et al. [19], Pan et al. [20], Lieder and Rashid [22], Geng and Doberstein [21]
Financial issues	Household's current financial situation/issues	Su et al. [19], Pan et al. [20], Geng and Doberstein [21]
Management	Management direction towards circular economy	Bey et al. [23], Su et al. [19]
Customer	Customers' requirements and pressure on the CE adoption	Bey et al. [23], Ilić and Nikolić [24], Geng and Doberstein [21]
Society	Society's requirements and pressure on the CE adoption	Yuan et al. [25], Ilić and Nikolić [24]

Source: Galvão et al. [8]; Sarja et al. [6].

and cheaper expenses. New organizational approaches in the household's business processes can also result in increased work quality and better customer service. Besides, a new strategy for organizing the household's workplace is projected to boost employee productivity and happiness. According to the OECD [28], organizational innovation can enhance worker satisfaction/productivity and/or lower administrative/transaction costs, resulting in greater corporate performance. Zaied and Affes [29] find that organizational innovation improves corporate performance by enhancing work quality, information interchange, learning capacity, and the utilization of new knowledge and technology. According to Phan [10], two dimensions of organizational innovation, "innovation in business processes" and "innovation in workplace organization", are considerably positively related to company performance.

There are many studies examining the relations between CE adoption and organizational innovation, and between organizational innovations and households' income. However, none of the existing papers study the joint interaction between these three factors. We suspected that there is a mediating role of organizational innovations in the relationship between CE adoption and households' income. More specifically, the CE adoption will lead to organizational innovation, which in turn will increase households' income.

From the above literature review, we build a research framework for our study as in Figure 1 below.

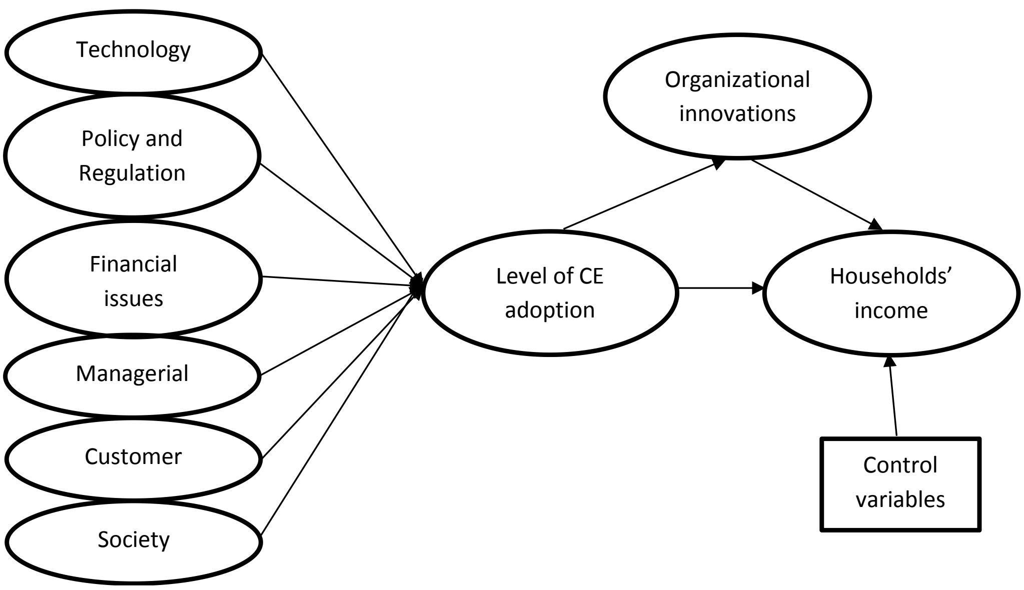

Figure 1. Framework for CE adoption.

3. Data Description and Methods

To understand the factors influencing households' adoption of circular economic practices in their business and the impacts of circular economy on households' income, we employ a questionnaire-based survey method to collect data on households operating in the agricultural sector in the Red River Delta, Vietnam. This survey targets assessing their awareness of circular economy concepts, motivations for adoption, and potential barriers they encounter. Specifically, we asked economic household representatives if they had ever heard of the concept of the circular economy. We will then explain to them the definition of the circular economy as provided by the Ellen MacArthur Foundation and determine if they have engaged in any activities that can be considered part of the circular economy.

Face-to-face, drop-off, and phone-calling methods were employed to distribute the questionnaire. Among 500 distributed questionnaires to agricultural households in the Red River Delta, Vietnam, there are 473 valid questionnaires returned. Instead of clearly defining which factors are drivers or barriers to CE adoption in our survey, we use a Likert 5-point scale ranging from 'strongly disagree' to 'strongly agree' to let respondents evaluate the degree of each factor. Specifically, in our questionnaire, for each potential determinant of circular economy practices adoption, we use at least three Likert questions (see Appendix). We also collect information about households' income as net profit per employee. The level of CE adoption is divided into 4 levels including "having no plan to adopt CE", "having a plan but not sure when will adopt the CE", "in the process of adopting CE", and "already adopted the CE". We also use the number of working labors, household age, and total assets as control variables for households' income. Table 3 illustrates the details of these variables. These factors are analyzed using partial least squares structural equation modeling (PLS-SEM) to figure out which ones are enablers or obstacles. PLS-SEM represents a technique in structural equation modeling that enables the assessment of intricate cause-and-effect associations within path models featuring latent variables. PLS-SEM adheres to SEM notations and symbols, incorporating a path diagram to illustrate connections among latent variables and between each measurement variable and its corresponding latent variables. However, in contrast to the traditional covariance-based structural equation modeling (CB-SEM), PLS-SEM is recognized as a flexible modeling approach that does not necessitate stringent assumptions regarding distributions, sample size, and measurement scale.

Table 2. Data description and summary statistics.

Variable	Definition	Mean	Std	Min	Max
Households' income	Logarithm of net profit per working member.	0.549	0.457	0.006	1.984
CE adoption level	The level of CE adoption of households. If a corporation embraced at least one sort of CE-related practice, the CE adoption level is 4. It has a value of 3 if a company is in the process of implementing at least one of the CE-related practices. If a company hasn't adopted any of the CE-related practices yet, but plans to do so, it gets a value of 2. Furthermore, it has a value of 1 if a business has not implemented and does not intend to adopt any of the CE-related practices.	0.137	0.345	1	4
Labor	Number of employees (Unit: person)	6.288	2.192	3	12
Household age	The number of years of agricultural producing of the household (Unit: year)	7.867	4.283	1	15
Total assets	the total amount of assets owned by the household (Unit: Billion VND)	11.037	6.719	0.207	270.620

4. Results and Discussion

Common Method Variance (CMV) gives rise to a form of bias known as common method bias, which can artificially inflate the perceived relationship between two constructs. In simpler terms, CMV leads to a systematic overestimation of the association among the scale items. To address this potential bias in our data analysis, we employed Harman's single-factor test [30] to examine the presence of CMV. The results of the principal component factor analysis revealed that the largest factor accounted for only 25.99% of the total variance, which falls below the 50% threshold [31]. Consequently, our data does not exhibit CMV bias, and thus, we can proceed with our data analysis without concerns regarding this issue.

Before delving into the analysis of causal relationships between variables, we prioritized ensuring the validity and reliability of our study model. To achieve this, we assessed various indicators including factor loadings, Cronbach's alpha (CA), factor loadings from exploratory factor analysis (EFA), composite reliability (CR), and average variance extracted (AVE). The reliability and validity of the constructs are presented in Table 3. The Cronbach's alpha values ranged from 0.910 to 0.982, surpassing the recommended threshold of 0.70, indicating satisfactory internal consistency [32]. Similarly, the composite reliability values, ranging from 0.950 to 0.983, exceeded the minimum criterion of 0.70 [32]. The average variance extracted values for the four variables fell within the range of 0.856 to 0.882, meeting the recommended threshold of 0.50. Additionally, the factor loadings exceeded the recommended value of 0.4 [32]. Overall, the examination of the measurement properties confirms the unidimensionality and conceptual consistency of the scale.

Table 3. Construct reliability and validity.

Constructs	Questions	Factor loading	Cronbach's alpha	Composite reliabilities	AVE
TECH	TECH1	0.840	0.935	0.958	0.882
	TECH2	0.908			
	TECH3	0.902			
	TECH4	0.828			
PR	PR1	0.790	0.916	0.961	0.860
	PR2	0.899			
	PR3	0.868			
	PR4	0.853			
FI	FI1	0.868	0.909	0.950	0.826
	FI2	0.917			
	FI3	0.793			
	FI4	0.892			
MAN	MAN1	0.895	0.922	0.983	0.859
	MAN2	0.906			
	MAN3	0.794			
	MAN4	0.965			
CUS	CUS1	0.869	0.910	0.960	0.859
	CUS2	0.903			
	CUS3	0.919			
	CUS4	0.791			
SOC	SOC1	0.922	0.929	0.980	0.857
	SOC2	0.861			
	SOC3	0.855			
	SOC4	0.788			
OI	OI1	0.912	0.929	0.978	0.856
	OI2	0.955			
	OI3	0.966			
	OI4	0.868			

Table 4 illustrates the path coefficients from the PLS-SEM analysis. Among 6 factors that are potentially affecting the level of CE adoption in agricultural households in the Red River Delta, Vietnam, we find evidence for the negative influence of technology and the positive influence of policy and regulation, management, customers, and society. Only financial issues have no impact on the CE adoption.

Lacking proven technologies is one of the main obstacles that hinder CE adoption [33]. The estimated coefficient of technology in our model ($\beta = -0.128$, p-value = 0.000) provides evidence for the above conclusion. Kandasamy et al. [34] state that from a technological perspective, renovation operations, especially recycling, can be costly and inefficient, leading to material losses and additional expenses. Moreover, the advancement of the agricultural circular economy faces obstacles such as limited agricultural informatization and a lack of flexibility in technology adoption [35]. These factors contribute to the hesitancy of households in less developed countries to embrace the circular economy, as the inefficiency of technology hinders its implementation.

The drivers that promote the level of CE adoption in agricultural households in Red River Delta, Vietnam are policy and regulation ($\beta = 0.245$, p-value = 0.000), management ($\beta = 0.210$, p-value = 0.000), customers ($\beta = 0.254$, p-value = 0.000), and society ($\beta = 0.222$, p-value = 0.000). The estimated coefficient of policy and regulation proves that governments in Vietnam are trying to create a favourable environment for the development of the circular economy in agriculture. In the revised Vietnamese Environmental Protection Law that took effect on January 1st, 2022, the government tries to improve extended producer responsibility (EPR), which means companies' re-

Table 4. The estimations of path coefficients.

	Path coefficients	p-value
Direct effects		
Technology -> Level of CE adoption	–0.128***	0.000
Policy and regulations -> Level of CE adoption	0.245***	0.000
Financial issues -> Level of CE adoption	–0.014	0.637
Management -> Level of CE adoption	0.210***	0.000
Customers -> Level of CE adoption	0.254***	0.000
Society -> Level of CE adoption	0.222***	0.000
Level of CE adoption -> Organizational innovations	0.610***	0.000
Level of CE adoption -> Households' income	0.448***	0.000
Organizational innovations -> Households' income	0.107***	0.000
Indirect effects		
Level of CE adoption -> Organizational innovations -> Households' income	0.065	0.000
Adjusted R^2		
Level of CE adoption	0.569	
Organizational innovations	0.671	
Households' income	0.672	

Note: *** indicates significant at 1% significance level.

sponsibility no longer ends at the point of sale but extends to disposal and recycling. Vietnam's new law gives companies two choices: recycle or pay up. Companies must have systems to collect their goods once customers are done with them, extract materials with value and dispose of the rest. If not, they pay into an environmental fund or face a big fine. Besides, in the revised law, the Vietnamese government also supports circular economy transition via policies and standards that enable the three Rs (3Rs): reduce, reuse, and recycle [7]. Besides, the Vietnamese government's circular economy propaganda seems to have worked well as business managers, consumers, and society all have perceptions and requirements for businesses to promote the adoption of the circular economy.

Regarding the impact of CE adoption on households' income and the mediator role of organizational innovation, this study used bootstrapping statistics while performing the SEM, as recommended by Zhao et al. [36], to test for the hypotheses related to the mediating effects among the constructs. We find a significantly positive relationship among these three variables. Specifically, level of CE adoption -> organizational innovations ($\beta = 0.610$, p-value = 0.000); level of CE adoption -> households' income ($\beta = 0.448$, p-value = 0.000); and organizational innovations -> households' income ($\beta = 0.107$, p-value = 0.000). These results suggest that besides directly enhancing households' income, the level of CE adoption also increases organizational innovation, which in turn also boosts the households' income. Therefore, our result suggests that organizational innovation fully mediates the relationships between the level of CE adoption and households' income.

From the above findings, several managerial implications can be drawn. Although technology is the main tool that must be used to achieve circular economy, low technology is a weakness that hinders the ability of agricultural households to adopt the CE. Therefore, the Vietnamese government should pay attention to supporting businesses to access new technologies that help to accelerate the implementation of the circular economy in agricultural households. Besides, the government should continue to improve policy and regulation in supporting the CE adoption, and encourage customers and society in the use of products from the circular business. Lastly, businesses need to focus on improving management and organizational innovation to stimulate the impact of CE on households' income.

5. Conclusions and Policy Implications

Our results shed light on what factors are drivers or barriers to the CE adoption of agricultural households in Red River Delta, Vietnam. Besides, we examine the impact of the level of CE adoption on households' income with the mediating role of organizational innovations. From a survey of 473 agricultural households in the Red River Delta, Vietnam, the PLS-SEM results show the negative influence of technology and the positive influence of policy and regulation, management, customers, and society on the level of circular economy adoption of agricultural households. Besides, there is significant evidence of the positive impacts of circular economy adoption on households' income in the sample. Furthermore, organizational innovation played a full mediating role between circular economy adoption and households' income.

Although this study has made valuable contributions to the literature on the circular economy (CE), there are some limitations that should be noted. Firstly, the temporal aspect poses a constraint in this study as the adoption of CE, organizational innovation, and households' income require time to develop or acquire, potentially mitigating their positive impacts. Therefore, a longitudinal design would be beneficial for further investigation. Additionally, the research sample size is relatively small. Future research could expand upon this idea by including larger samples and examining other industries and regions to enhance the generalizability of the findings.

To enhance the implementation of a circular economy in agriculture in Vietnam, thereby increasing the income of farmers, it is necessary to address the following issues:

i. Enhance the credit policy system in agriculture by providing preferential interest rates, encouraging the establishment and effective implementation of agricultural insurance funds, and support funds for farmers, and enterprises investing in high-tech and circular agriculture. Conduct research on incentive policies for credit institutions regarding loan capital and interest rate compensation due to the implementation of agricultural interest rate reduction policies;

ii. Research and implement incentive policies for corporate income tax, fees, and charges in sectors such as research activities, pilot projects, and scaling up in circular agriculture. Study and supplement value-added tax incentive policies for pilot agricultural products in high-tech and circular agriculture models, as well as for products that serve as tools, equipment, and techniques for implementing circular agriculture models;

iii. Support research activities and the transfer of technology and innovative solutions in the field of circular economy. There is a need for determination in effectively transferring and timely implementing scientific advancements into practical production activities of farmers and businesses in the field of circular agriculture;

iv. Develop and implement preferential land policies such as policies that support land consolidation, exemption or reduction of land rent, and water surface rent fees imposed by the State. Additionally, provide exemptions or reductions in land use fees to assist households and agricultural businesses in accumulating land, expanding scale, and successfully applying circular economy models in agriculture;

v. Pay attention to attracting and training human resources for the agricultural sector to enhance the awareness and capacity of farmers, enabling them to proactively and confidently apply effective circular economy models in agriculture that are suitable for the rural conditions of Vietnam;

vi. Enhance the role of local government agencies in agricultural management to provide guidance and support to farmers in implementing production activities in accordance with the goals and regulations set by the State, while aligning with market trends and requirements;

vii. Expand the market for circular agriculture products by leveraging the role of industry associations and leading enterprises in connecting, sharing, and linking production along the value chain.

Author Contributions

Study conception and design: Quang Phu Tran, The Kien Nguyen; data collection: Quang Phu Tran, The Kien Nguyen; analysis and interpretation of results: Quang Phu Tran, The Kien Nguyen, Manh Cuong Dong; draft manuscript preparation: Quang Phu Tran, The Kien Nguyen, Manh Cuong Dong; manuscript revision: Quang Phu Tran, The Kien Nguyen, Manh Cuong Dong. All authors reviewed the results and approved the final version of the manuscript.

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Data Availability

All data used in the study are available from the author upon request.

Conflicts of Interest

The authors declare no conflict of interest.

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Appendix A

Constructs		Questions
TECH	TECH1	The company's current technological machines are suitable for circular economy
	TECH2	The company cares about technical development related to the CE adoption
	TECH3	The company is improving technology for the CE adoption
	TECH4	The company is willing to cut-off profit in order to improve technology for the CE adoption
PR	PR1	The current policies and regulations of government encourage households to adopt the CE
	PR2	The current policies and regulations of government force households to adopt the CE
	PR3	The government supports households in adopting the CE
	PR4	The government have subsidies for the CE adoption
FI	FI1	The financial situation of your company is suitable for the CE adoption
	FI2	Your company have no financial difficulties in adopting the CE

Table Appendix continued

Constructs		Questions
	FI3	You have no concern about financial issues when considering the CE adoption
	FI4	Finance is a strength of your company if it adopts the CE
MAN	MAN1	Do you (as a manager) think that the CE adoption is important for your company?
	MAN2	Your company's current management system is suitable for the CE adoption
	MAN3	The manager board of your company is interested in adopting the CE
	MAN4	Your company is willing to revise the management system to adopt the CE
CUS	CUS1	Customers care about the products from circular economy
	CUS2	Customers requires the products from circular economy
	CUS3	Customers are increasingly interested in circular economy products
	CUS4	Customers have certain criteria regarding circular economy when choosing products
SOC	SOC1	Society care about the products from circular economy
	SOC2	Society requires the products from circular economy
	SOC3	Society is increasingly interested in circular economy products
	SOC4	Society has pressure on your company in adopting the CE
OI	OI1	Innovation in technology
	OI2	Innovation in business practices
	OI3	Innovation in workplace organization
	OI4	Innovation in external relations

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RESEARCH ARTICLE

Impact of Participation in Young Smart Farmer Program on Smallholder Farmers' Income: A Propensity Score Matching Analysis

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Abstract: The increase of elderly workers in the agricultural sector will decrease productivity using traditional agriculture production which causes the reduction of income. The Young Smart Farmer program is one of the solutions to solve the problem by developing new generation farmers' agricultural abilities replacing elderly farmers and creating incentives for the new generation to turn to agricultural occupation. Thus, this paper principally assessed the impact of the participation of young farmers in the YSF program on farm income and the determinants of the YSF program factor of young farmer's participation in the YSF program. The total number of samplings is 340 comprising 210 participants and 130 non-participants in the YSF program of the northeast area of Thailand. The data were analyzed using descriptive statistics and the propensity score matching approach to estimate the treatment effect of YSF participation on farm income among smallholder farmers. The results presented that the participants were younger with higher education, more experience and technology support, and had higher farm income compared to non-participants. The propensity scores matching results revealed a significant effect between farmer participation and farm income. The increase in farmers' income from the participation of young smart farmers was estimated to be approximately 6758.59 $/year compared to non-participants of 3066.63 $/year. To encourage young people to participate more in the YSM program the government should provide more support that can stimulate the young farmers' farming economic activities to improve their quality of living and be fully satisfied with their livelihood. Also, the government should encourage a strong network within the group which consequently increases knowledge sharing, technology, and agricultural activities from the production process to marketing.

Keywords: Young smart farmer; Participation; Farm income; New generation; Aging farmer

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1. Introduction

Changes in the population structure of Thailand moving towards an aging society (over 60 years of age) with a tendency to increase from 11.6 million people or 17.57 percent in 2020 to 20.5 million people or 32.1 percent in 2040 [1,2] have affected the rate of economic growth, labor efficiency and food security of Thailand in the future. Moving toward an aging society of workers in the Thai agricultural sector is more severe than the overall image of the country. It was found that the proportion of agricultural workers aged over 60 years increased from 2003 to 2013 with a percentage of 13% to 19% and in 2021 it reached 62.8% while the proportion of younger workers (15-40 years) dropped significantly from 48% to 32% during the same period. The proportion of elderly workers has increased in every area and all production activities [3,4]. This tendency consequently affected the labor quality of the agricultural sector with an emphasis on high labor intensive and productivity of the agricultural sector with the use of new technology in modern agriculture, which has decreased too. The reason for this phenomenon is that elderly workers in the agricultural sector are still unable to adapt to the changing situation and learn or use low technology [5]. With this context, future agriculture will obviously use less labor, but may be more productive by applying new technology to increase productivity of production for moving toward agricultural development 4.0. From the abovementioned problems, the government has provided guidelines in the National Economic and Social Development Plan No. 11 (2012-2016) and No. 12 (2017-2021) as well as the 20-year National Strategy (2018-2037) to address the problem. Emphases have been placed on developing youth farmers' capacity through increased per capita income as well as improving livelihood [6,7]. As a result, the Department of Agricultural Extension implemented a project on the development of young farmers aged 17-45 years to become Young Smart Farmers (YSF) by focusing on the process of exchanging knowledge and networking, letting farmers be the "center for self -learning and learning design" and having agricultural extension staff for "learning management". Therefore, the main goals of this project are to develop new generation farmers' agricultural abilities to replace elderly farmers and create incentives for the new generation to turn to agricultural occupation by applying knowledge, experiences of ancestors, wisdom and modern technology to increase production and marketing efficiency in preparation for becoming Smart Farmers [8]. Being Young Smart Farmer (YSF), they must pass the criteria of potential assessment which consists of (1) having a total agricultural income (2) having knowledge of what they are doing (3) having information for decision-making (4) having production and marketing management (5) being aware of product quality and consumer safety (6) being responsible for the environment/social aspect and (7) being proud to be a farmer. In 2014-2017, a total of 7,598 youth farmers participated in the Young Smart Farmer project. The youth farmers were diverse in terms of agricultural land size. Some youth farmers worked in agriculture as a supplementary occupation in agricultural production areas of less than 0.15 hectares or 1 rai. Besides, other youth farmers inherited agricultural production from their parents in large agricultural areas [1,9]. Furthermore, it was found that such new youth farmers had a variety of agricultural production. For example, some of them had business-oriented agricultural production. At the same time, some farmers' production attached importance to sustainable agricultural production and was related to community development. At present, young farmers have participated in the Young Smart Farmer project, many of whom completed higher education with master's and doctoral degrees and came from various professions such as engineers, architects, civil servants, factory owners, etc. The development of young farmers has appeared in some countries as visible in the project on lending money to young farmers so as to start farming in the European Union, the United States, and Japan [10]. Moreover, Korea provided funds for training and knowledge, the areas for farming and housing, and funds and technology in farming for the youth interested in agriculture [11]. The above points have demonstrated the importance of joining the Young Smart Farmer project for production development in the agricultural sector.

Farmers' engagement in agriculture activities is a significant factor in rural development because they play a vital role in alleviating poverty, polishing decision-making capacity, sustaining self-reliance and a better standard of living, improving farming products, and increasing the acquisition of new knowledge for farming activity [12]. There is a need to determine factors that delimitate farmers' participation in the Young Smart Farmer program in order to enhance the performance of such a program. The major determinants of farmers' choice to participate in the agricultural program comprise social economic elements of the households such as demographic variables (for example, age, occupation, farm size, education level, knowledge, skills, and finance), institutional (for example, cooperative's membership, credit accessibility, social support, and land holdings), technology, (for example, access to machines and equipment) [13-15]. The conclusion of how factors affecting the farmers' decision to engage in an agriculture scheme are context-specific and changeable from one region to another. Specifically, the objectives of the study are to analyze the socioeconomic and institutional factors that affect the farmer's participation in young smart farmers in order for policymakers to enhance this program planning and execution mechanism for crop productivity. Furthermore, the literature emphasizes studies associated with participation in agriculture scheme is focused specifically on knowledge transmission and subsidy program for crop production [10,16]. As the aforementioned reviews, the literature further perceives that the participation of youth in the agriculture sector is not completely investigated including scarce studies on socioeconomic factors of young farmer's participation in agriculture. In addition to this limitation, it is apparent that there are no previous studies reviewing the impact of young farmers' participation on farmer's income in Thailand and this program is typically voluntary. However, an individual farmer engages only when the benefit outweighs the cost of participation. The current methodical approach of determining the differences between young smart farmer participants and non-participants requires the segregation of the 'true' effect of the program (causal effect) from the effect of initial differences in characteristics of the two groups ('selection effect'). The motivation of the study is based on the insufficiency of research on the effect of young smarter participation on farm income. Additionally, the study aims to analyze the impact of young smart farmer participation by using the Propensity Score Matching (PSM) method. Consequently, the study findings will be invaluable for policy-makers to formulate strategies that contribute to the effectiveness of the existing young smart farmers in agricultural development.

2. Methodology

2.1 Study Area

The study consists of a household sample survey and data collection in Northeastern Thailand study areas comprising 5 provinces; namely, KhonKaen, Chaiyaphum, Kalasin, Maha, Sarakham and Nakhon Ratchasima provinces (Figure 1). The Northeast is located between latitudes 14°7' and 18°27' north and longitudes 100°54' to 105°37' E [17]. The Northeast's total area is 105.53 million rai as plateau, which slopes towards the east and resembles a pan, divided into 2 large zones, namely the Korat plain basin in the Mun and Chi River basins characterized by plateaus interspersed with hills and the Sakon Nakhon basin to the north of the region from the Phu Phan Mountain range to the Mekong River. The mountain range of separation between the Korat basin and the Sakon Nakhon basin is the Phu Phan Mountain range. The Northeast's total area of 106.03 million rai is classified into a forest area of 56.38 million rai or 53.17 percent, an agricultural area of 32.50 million rai or 30.65 percent and other usable areas of 17.15 million rai or 16.18 percent of the region. Most agricultural products in the area are major plant products, viz. rice, animal feed corn and industrial sugarcane. This location produces the main economic crops of the country. Nevertheless, the production model still relies heavily on rainwater which results in low productivity. The Northeast's main crops include rice, industrial sugarcane and cassava with the largest rice-growing area in the country. Jasmine rice 105 is mostly grown in the central and lower areas of the region. Thung Kula Ronghai particularly covers the areas of Yasothon, Sisaket, Surin, Maha Sarakham, and Roi Et Provinces while Thung Samrit covers the areas of Nakhon Ratchasima and Buriram Provinces. The overall average yield per rai is lower than the national level due to traditional agriculture. Also, it has the most sugarcane and cassava growing areas in the country. Most sugarcane is cultivated in the areas of Nakhon Ratchasima, Chaiyaphum, Khon Kaen, Kalasin and Udon Thani Provinces and cassava is obtained mostly in the areas of Nakhon Ratchasima, Chaiyaphum and Udon Thani Provinces [18,19]. In 2018, the Department of Agricultural Extension assigned the Offices of Agricultural Extension and Development No.1-9 of the Northeast to conduct a training project on Young Smart Farmer's empowerment for youth farmers who passed the development process of the Department of Agricultural Extension at the provincial level since 2014-2017. The purpose of training is to promote and develop the capacity of young farmers to apply modern technology for increasing production efficiency, agricultural product management and marketing like pro-

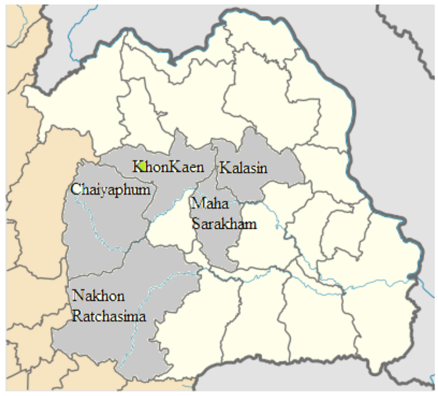

Figure 1. Northeast map.

Source: Northeastern Thailand—Isaan [17].

fessional farmers and 1,500 youth farmers participated in the project [8].

2.2 Data and Sampling Procedure

Primary data were mainly used for the study and the data were collected from 2022 to 2023 through a questionnaire distributed to smallholding farmers. Information on socio-economic variables and production activities was obtained through the use of a structured questionnaire. A multiple-stage random sampling technique was employed to conduct this research. First, it purposively selected 5 provinces, namely, KhonKaen, Chaiyaphum, Kalasin, Maha, Sarakham and Nakhon Ratchasima provinces and focused on young farmers aged less than 45 years who participated in the young smart farmer program (YSF). Second, it selected a district of each province totaling 5 districts to engage for consultation with the Office of Agricultural Extension and Development No 4, namely, Mueang Khon Kaen district, Mueang Chaiyaphum district, Mueang Kalasin district, Mueang Maha Sarakham district and Mueang Nakhon Ratchasima district. Two communities were selected in each district based on a simple random technique and this included 10 communities respectively. In this study, the number of households selected from each district is quite the same without considering the ratio of the number of total farm households in each district. On average, 21 young farmers participated in the YSF program while on the other hand, 13 young farmers without participation in the YSF program from each community totaled 340 young farmers.

2.3 Data Analysis

Impact evaluation attempts to estimate the mean effect of participating in a young smart farmer program (treatment group) by comparing the outcomes of non-participants. This evaluation of the treatment effect may be biased due to the existence of confounding factors [18]. The impact evaluation studies typically rely on propensity score matching (PSM) techniques that refer to creating a comparison group by matching each observation on the treatment group with a control group by similar characteristics which provides an accurate estimate of the average treatment effects [20-22] and appropriately weighted by the propensity score distribution of treated participants [23,24], The propensity score is a prominent method to calculate the balancing score based on the estimated equation of a logistic regression. Upon estimation of the propensity scores, the actual matching may be consistent with numerous algorithms such as nearest neighbor matching, caliper matching, radius matching, and kernel matching [25]. Having estimated the propensity scores, the actual matching can follow various algorithms [25-29] such as nearest neighbor matching, caliper matching, radius matching, and kernel matching. The matching algorithm is a compromise choice between bias and variance and is crucial for small samples because the distinct algorithms produce the same result in an asymptotic way.

Moreover, the purpose of the study is to evaluate the average treatment effect on treated (ATT) for explicating participants in the YSF program (treatment) affecting farm household income [30,31]. The outcome would have been observed for the treatment group if they had not been treated (control group). The treatment effect can be calculated as the difference in mean outcome. The average treatment effect on the treated (ATT) is defined as Caliendo and Kopeinig [25]. The assumptions are to be fulfilled for the matching; the first is the conditional independence assumption required in the absence of treatment of both groups that produces the same outcome variable value given no differences to the relevant characteristics [24]. These pertinent characteristics are dedicated to those who are not themselves affected by the treatment but are involved in influencing the treatment status and the outcome variable. The stable unit treatment assumption is the situation in which the condition of the individual's decision does not rely on the behavior of others [25,32,33]. It is achievable to assess the mean effect of professional preparation of the entire population rather than the individual itself. In this regard, estimating the effect of participants is the assignment of treatment of selection participants that are not randomly selected but instead, these participants voluntarily elect to participate in YSF program [25,26,32]. A propensity score model is applied in this research which is calculated based on the estimated equation of a logistic or probit regression [22,25] to overcome the problem of self-selection bias. The function of these characteristics expresses matching multiple characteristics is identical to matching on a single balancing score as Rosenbaum and Rubin's [22] views.

The outcome variables of average income and YSF participation of participants and non-participants were in comparison with the nearest neighborhood matching method of ATT estimation without any significant biases. ATT is the average treatment on treated (the impact of participant), D = 1 is the group of participated farmers and D = 0 is the group of non-participants and X_i is the set of controlled Covariates [34]. Upon the evaluation match successful, the ATT can be calculated as the difference between the groups' mean values:

$$\mathrm{ATT} = \mathrm{E}\{\mathrm{E}[\mathrm{Y_i}|\mathrm{p}(\mathrm{X_i}); \mathrm{D}=1] - \mathrm{E}[\mathrm{Y_i}\ |\mathrm{p}(\mathrm{X_i}); \mathrm{D}=10]|\mathrm{D}=1\} \quad (1)$$

In this context, the linear regression with treatment effects model is an appropriate procedure to estimate the impact of a treatment on an outcome variable [22,35] by comparing farm production and income between participants and non-participants in the young smart farmer program in Stata software, version 18.0 [36]. The Logit model was used to estimate propensity scores (p scores) of whether the young participants were in the program or not in which yes (for participant) = 1 and if not (non-participant) = 0, thus binary response variable. As mentioned, the study emphasized the factors influencing young farmer participation in the YSF program. The variables commonly used in many previous studies to investigate the effect of young farmer participation on farm income were gender, age of farmer, cultivated area, education level, membership of group farmer, farming experience, farm income, technology support such as agricultural machinery, drip irrigation and solar cells for farm use, agricultural training and agricultural input subsidy [18,26,28,37-41] (Table 1). The impact of treatment with a comparison of YSF participation and income between participants and non-participants was written with the following equation [15].

$$Y_i = \mathrm{Ln}\frac{P_i}{1-P_i} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 ++ \beta_7 X_7 ++ \beta_8 X_8 + \beta_9 X_9 + \beta_{10} X_{10} + \varepsilon \quad (2)$$

where P_i is the probability of adopting the use of rice straw compost, $P_i = 0$ indicates no adoption and $P_i = 1$ indicates adoption.

Y = The probability of participating in young smart farmer program
β_0 = The intercept
β_1-β_{10} = The regression coefficients of the dependent variables
X_1 = Gender of farmer
X_2 = Farmer's age
X_3 = Farmer's education
X_4 = Cultivated area
X_5 = Membership of group farmer
X_6 = Farming experience
X_7 = Farm income
X_8 = Technology support
X_9 = Training
X_{10} = Agricultural input subsidy
ε = The disturbance term

3. Results and Discussion

3.1 Description and Summary of the Explanatory Variables

A total of 340 respondents includes participants with a proportion of 61.76 percent and non-participants of 38.24 percent. Participants can be divided into 2 groups:

Table 1. Definition and measurement of variables.

Variable	Definition and measurement
Gender of farmer (X_1)	0 = Female 1 = Male
Farmer's age (X_2)	Years
Farmer's education (X_3)	0 = Otherwise 1 = Bachelor degree or above
Cultivated area (X_4)	ha
Membership of group farmer (X_5)	0 = No 1 = Yes
Farming experience (X_6)	Number of year spent in farming
Farm household income (X_7)	Gross farm earnings ($/Year)
Technology support (bio-fertilizer, solar cell energy, machinery) (X_8)	0 = No 1 = Yes
Training (X_9)	0 = No 1 = Yes
Agricultural input subsidy (X_{10})	0 = No 1 = Yes

(1) 49.92% of participants are those who have inherited the farm and farm successor, which can be divided into 3 groups as follows: Participants who graduated with bachelor's degrees from other fields accounted for 29.95%, participants who graduated with bachelor's degrees from agricultural-related fields accounted for 15.48%, and 4.49% were participants who graduated from high school level with grade 12. Also, (2) participants who were not descendants of farmers and graduated from other fields that were not related to agriculture accounted for 11.84%. The reason why participants decide to join the YSF is that most participants need new knowledge to develop their agriculture or upgrade their own agriculture because farmers have little experience in farming. It is different from non-participants in that most of them were descendants of farmers and graduated less than secondary school level, representing 35.18%, and 3.06% graduated with a bachelor's degree (Table 2).

About 57.6 percent are male participants while 66.2% percent are male non-participants interviewed females of 41.9% and 33.8% of participants and non-participants respectively. The difference between the two groups when disaggregated by gender was not statistically significant. The majority of participants just started family activities after stopping working in the non-agricultural sector while the most of non-participants had been involved in farming activities since childhood aged over 13. Participants have a higher year of formal education than non-participants indicating that most participants had graduated from uni-

Table 2. Type of young farmer who participates in YSF program.

Item	Percentage
Participants	**61.76**
Farm successor	49.92
Participant who graduated with bachelor's degrees from other fields and quitted a non-farm job before entering agriculture	29.95
Participant who graduated with bachelor's degrees from agricultural-related field and quitted a non-farm job before entering agriculture	15.48
Participant who was graduated with high school level and worked farming job aged over 13	4.49
Non-farm successor	11.84
Non-participants	**38.24**
Non-participant who was successor involved farm activity aged over 13 and graduated less than secondary school level	35.18
Non-participant who was successor involved farm activity after quitting non-farm job and graduated with bachelor's degrees fromother fields	3.06
Total	**100**

versity with a bachelor's degree and also engaged in non-farm jobs. In contrast, most non-participants have not continued their education after having inherited the farm. The participation in YSF program has increased with increased education [42]. The difference between the two groups with education was statistically significant at 1%. The mean age of participants was 39.10 years while non-participants had a mean of 37.46 years and the difference is statistically significant (p = 0.01) showing that most of the participants were below 40 years of age in line with Muhammad-Lawal [43]. This implies farmers have a capacity and experience with an average of 6.80 years of participants and 16.99 years for non-participants. The mean difference in farmer's experience between participants and non-participants is 10.18 and statistically significant at 1 percent. Most participants ever worked in non-agricultural sector and the YSF program has encouraged young people to become new entrants in agriculture [44,45] to learn practical knowledge in agricultural production either in organic vegetable farming or value-added farming activity [46,47]. In addition, about 47.10 percent of the participants were formally involved in membership of community enterprise groups whereas 61.5 percent of the non-participants were. Most participants are likely to identify as entrepreneurs with self-investment [48,49]. Most of participants with the proportion of 84.3% have more technology support than non-participants (27.0%) with a statistically significant (p = 0.01). Participants had a mean income of 6758.59 $/year while non-participants obtained a mean of 3066.63 $/year which was mostly derived from rice, cassava and sugarcane. The difference between the mean incomes for the two groups was significant at 1 percent (Table 3) and the participant's income has the potential to improve their livelihood [16,50].

3.3 Propensity Scores and Matching

From the estimates of parameters by the Logit model, the propensity score is calculated for all farms with the matching analysis. In this study, PSM analysis is carried out using psmatch2 module [51]. The parameter testing was carried out simultaneously and partially. Simultaneous testing used the likelihood ratio test. The test results obtained by the LR chi^2 value of 287.68 with Prob > chi^2 of 0.000 indicate that the independent variables in the model simultaneously influenced the participation of and explained the farmer's propensity of participation in the young smart farmer program [52,53]. The estimated log likelihood value is highly significant indicating that the model with predictors is to be preferred over a model without predictors. Farmer's gender (X_1), farmer's age (X_2), farmer's education (X_3), membership of farmers (X_5), farming experience (X_6), farm income (X_7) and technology support (X_8) were statistically significant at the confidence level of 99 percent. Also, agricultural input subsidy (X_9) was statistically significant at 95 percent, as well as cultivated area (X_4) and training (X_9) had a relationship in the same direction except is not significant. It was found that if the gender, farmer's age, education level, farm income, agricultural input support and technology support were increased by 1 year, the probability that farmers decided to participate in young smart farmers increased by 1.374, 0.1367, 2.483, 0.001, 0.626 and 2.455 percent, respectively (Table 4). According to the results, farmer participation in YSF was higher among farmers who were older nearly

Table 3. Summary of statistics for participants and non-participants.

Variable	Participant (N = 210, 61.76%)			Non-participant (N = 130, 38.24%)			Mean difference	*t*-value
	Mean	SD	%	Mean	SD	%		
Gender	0.819	0.341		0.338	0.475		–0.481	–1.549^{ns}
0 = female			41.90			33.80		
1 = male			57.60			66.20		
Farmer's age (years)	39.10	5.267		37.461	5.946		–1.638	–2.652***
Farmer's education	0.771	0.420		0.154	0.362		–0.618	–13.851***
0 = Otherwise			22.9			84.6		
1 = Bachelor degree			77.1			15.4		
Cultivated area	3.571	2.995		3.278	2.653		–0.293	–0.914^{ns}
Membership	0.471	0.500		0.616	0.488		0.144	2.602***
0 = No			52.90			38.50		
1 = Yes			47.10			61.50		
Farming experience (years)	6.805	5.180		16.992	8.783		10.188	12.525***
Income ($/year)	6758.595	8593.056		3066.631	7206.823		–3691.965	–4.698***
Technology support	0.843	0.365		0.277	0.449		–0.566	–12.706***
0 = No			15.70			72.30		
1 = Yes			84.30			27.00		
Training	0.719	0.451		0.739	0.442		0.019	0.389^{ns}
0 = No			28.10			47.70		
1 = Yes			71.90			52.30		
Agricultural input subsidy	0.200	0.401		0.184	0.389		–0.154	0.348^{ns}
0 = No			80.00			81.20		
1 = Yes			20.00			18.50		

Note: ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

40 years because they had more experience from non-farm jobs before entering the YSF program and applied to improve toward modern farms as well as try new concepts to increase the yield of product similar to the studies [54,55]. Male farmers are more likely to participate in the YSF program because they must manage and control a limited resource efficiency and farm activity requires more physical work consistent with the studies [10,55,56]. The participants are educated the more they decide to participate in the YSF program to acquire more knowledge on advanced technology and the modern farming practices and apply it in production and marketing to increase the yield and marketing channel along with increasing the value added of agricultural products through the product processing. This result is in line with the findings affirming that participants with farming experience are less likely to participate YSF program [10,57-60]. This is probably due to the fact that experienced farmers were conservative in traditional farming with monocropping such as rice, cassava etc. and did not adopt modern farming with technology and innovation [61-63].

However, the farmers in the YSF program still have limitations in many aspects and that is farmers still lack knowledge and skills in production, marketing, innovation and technology that can be applied with local wisdom due to a lack of experience and expertise in farming (around 7 years) especially for farming management and addressing the issue of soil nutrient deficiency problems, drought, flooding in some areas and irrigation. The higher the farm income, the higher the probability level of YSF participation or the more likely to participate in the YSF program. This result is in agreement with the findings of the research [64]. The participant will change the farming practices from the traditional way to modern farming and high-precision agriculture that emphasizes the production of agricultural products by adopting innovation and modern technology management thus resulting in raising the income and quality of life of farmers through self-reliance. With increasing incomes, participants are able to raise capital to develop their products potentially. Participants are more likely to obtain technology support with modern farming and will manage to bring innovation and modern technology into production to increase efficiency, reduce labor use and production costs by managing the factors of production and existing businesses cost-effectively as well as increasing the value added of agricultural products and method is similar to previous studies [65-67]. Also, the development of production processes and products contributes to the certification of agricultural standards both domestically and internationally and helps to raise the level of export as well as to increase the income and quality of life of farmers for a better living.

3.4 Impact of Participating in Young Smart Farmer Program on Farmer's Income

The comparison between the characteristics of households and the matching algorithm explores the equal distribution of each value of the propensity score with both the treatment and control groups. It uses three matching methods namely; nearest-neighbor matching (NN) with either replacement or no replacement, kernel matching (Kernel), and Caliper with radius matching (0.05), to compare the results. It presents the p-values of the characteristics with insignificant differences between variables after matching after matching or most t-tests accept the null hypothesis that there was no systematic difference between the treatment group and the control group. These outcomes indicate no significant difference between the two groups matching [28,68,69]. The balancing hypothesis was satisfied because there were no significant differences between variables after matching (Table 5).

According to the estimates, the mean bias before matching was 67.9%. After matching, the mean bias reduced to 53.01%, 52.90%, 66.72% and 66.42% for nearest neighbor matching with its replacement, nearest neighbor matching with no replacement, kernel and caliper matching methods, respectively. It is obvious that the percentage reduction in bias for all four matching methods was greater than 50%. Kernel has the highest Bias Reduction at 66.72% and the matching substantially reduced the selection bias [23] (Table 6).

In this study, PSM analysis is carried out using psmatch2 [8] module. The ATT estimation based on their propensity scores using nearest neighbor matching, kernel matching and caliper matching methods of propensity scores [25,28,29,39] is shown in Table 7. The results show that the participation in YSF program had a significant impact on farm income and productivity at a significant level of 1% across all matching techniques. The farm income was positive and significant at $p < 0.010$, meaning that the increases in farmers' income were derived from the participation of young smart farmers. For this study, it can be inferred that any difference between the average incomes of participants and the matched group of non-participants, ATT on farm income is 3806.369 to 4450.172 $/year of participation in the YSF program (Table 7). In other words, the increase in farmers' income from the participation in the YSF program is higher than non-participants. This is based on the fact that the two groups are matched on the equality of their propensity scores. The increased farmers' income is also found in studies [58,70-75]. The fact that participants in the YSF program have the ability to be self-reliant and have creative ideas as well as use modern

Table 4. Propensity score estimation results by using the Logit model.

Variable	Coefficient	Standard error	Z	P > |Z|
Gender	1.374	0.489	2.80	0.005***
Farmers' age	0.137	0.040	3.39	0.001**
Farmers' education	2.483	0.439	5.65	0.000***
Cultivated area	0.501	0.082	0.62	0.536ns
Membership	–2.067	0.533	–3.88	0.000***
Farmers' experience	–1.446	0.029	–4.90	0.000***
Income	0.001	0.005	3.27	0.001***
Technology support	2.455	0.437	5.62	0.000***
Training	–0.289	0.476	–0.61	0.545ns
Farm input subsidy	0.626	0.531	1.74	0.082*
LR chi^2 287.68 Prob > chi^2 0.0000 Pseudo R^2 0.6360				

Note: ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 5. Testing of covariates balance for treated and untreated.

Variables	Unmatched matched		Mean		%bias	%Reduction in bias	*t*-value	*p*-value
			Treated	Control				
Gender	Unmatched		0.819	0.339	19.2		1.55	0.122
	Matched	NN replacement	0.819	0.339	20.0	–9.0	2.14	0.033
		NN no replacement	0.492	0.339	6.1	68.0	2.54	0.012
		Kernel	0.819	0.262	22.2	–16.0	2.28	0.023
		Caliper	0.819	0.255	22.5	–17.3	2.31	0.022
Farmers' age	Unmatched		39.1	37.462	29.2		2.65	0.108
	Matched	NN replacement	39.1	36.929	38.7	–32.5	4.33	0.000
		NN no replacement	37.7	37.462	41.7	84.5	0.37	0.712
		Kernel	39.1	37.106	35.5	–21.7	4.03	0.000
		Caliper	39.1	37.08	36.0	–23.3	4.10	0.000
Farmers' education	Unmatched		0.771	0.154	157.3		13.85	0.000
	Matched	NN replacement	0.771	0.681	23.0	85.3	2.08	0.038
		NN no replacement	0.646	0.154	12.4	20.3	9.33	0.041
		Kernel	0.771	0.661	28.2	82.1	2.53	0.012
		Caliper	0.771	0.664	27.4	82.6	2.46	0.014
Cultivated area	Unmatched		3.571	3.278	10.3		0.91	0.361
	Matched	NN replacement	3.571	3.703	–4.7	54.6	0.91	0.542
		NN no replacement	3.447	3.278	6.0	42.4	0.49	0.626
		Kernel	3.571	3.733	–5.7	44.7	–0.71	0.475
		Caliper	3.571	3.545	0.9	91.3	0.11	0.912
Membership	Unmatched		0.471	0.615	–29.1		–2.60	0.010
	Matched	NN replacement	0.471	0.376	19.3	33.8	1.98	0.048
		NN no replacement	0.523	0.615	–18.7	35.9	–1.50	0.134
		Kernel	0.471	0.364	21.7	25.4	2.24	0.026
		Caliper	0.471	0.358	22.9	21.2	2.37	0.018
Farming experience	Unmatched		6.805	16.992	–130.1		–12.52	0.050
	Matched	NN replacement	6.805	4.638	27.4	78.9	4.52	0.215
		NN no replacement	8.139	16.992	–113.1	13.1	–8.00	0.012
		Kernel	6.805	4.651	29.2	77.5	4.88	0.081
		Caliper	6.805	4.538	29.0	77.8	4.80	0.000
Technology support	Unmatched		0.843	0.277	138.3		12.71	0.000
	Matched	NN replacement	0.843	0.885	–3.5	97.5	–0.41	0.683
		NN no replacement	0.753	0.277	111.6	15.7	8.72	0.010
		Kernel	0.843	0.876	–8.2	94.1	–0.99	0.325
		Caliper	0.842	0.875	–7.7	94.4	–0.93	0.353
Training	Unmatched		0.719	0.738	–4.4		–0.39	0.697
	Matched	NN replacement	0.719	0.709	2.1	50.9	0.22	0.829
		NN no replacement	0.761	0.739	5.2	18.9	0.43	0.669
		Kernel	0.761	0.754	–7.9	–81.4	–0.82	0.414
		Caliper	0.719	0.759	–9.2	–11.7	–0.95	0.341
Farm input subsidy	Unmatched		0.200	0.185	3.9		0.35	0.728
	Matched	NN replacement	0.200	0.633	–10.6	–27.2	–10.0	0.010
		NN no replacement	0.200	0.185	3.9	30.0	0.31	0.754
		Kernel	0.116	0.629	–10.8	–26.9	–9.91	0.004
		Caliper	0.101	0.638	–12.7	–27.4	–10.12	0.000

Table 6. Test of selection bias after matching.

Mean algorithm	Unmatched/Matched	Pseudo R^2	Likelihood ratio x^2	Mean bias	% Bias reduction
NN replacement	Unmatched	0.639	288.98	67.9	53.01
	Matched	0.423	256.53	31.9	
NN no replacement	Unmatched	0.639	288.98	67.9	52.90
	Matched	0.423	246.53	32.0	
Kernel	Unmatched	0.639	288.98	67.9	66.72
	Matched	0.396	230.81	22.6	
Caliper	Unmatched	0.639	288.98	67.9	66.42
	Matched	0.549	197.97	22.8	

Table 7. Estimated treatment effects of participation on household income.

Mean algorithm	Unmatched matched	Treated	Controls	ATT	S.E.	*t*-value
NN replacement						
	Unmatched	6758.595	3066.631	3691.965***	785.828	4.70
	Matched	6758.595	2261.890	4496.705***	1277.896	5.52
NN no replacement						
	Unmatched	6758.595	3066.631	3691.965***	685.828	4.70
	Matched	6873.000	3066.631	3806.369***	722.285	5.27
Kernel						
	Unmatched	6758.595	3066.631	3691.965***	161.980	5.11
	Matched	6758.595	2308.423	4450.172***	158.715	3.31
Caliper						
	Unmatched	6758.595	3066.631	3691.965***	785.828	4.70
	Matched	3077.188	2194.939	4440.922***	1857.363	4.39

technology to manage agriculture is because they play an important role as a leader in local agriculture to transfer knowledge to youth and farmers in rural areas. As a result, the agricultural sector progress is improved by extending the results of development to other farmers as well as being the creator of a network and cooperation to encourage agricultural extension work and farmer organizations efficiently, resulting in community economic growth. The YSF group is useful for farmers as a network for learning in which friends can exchange information with each other and expand the market network to reduce production costs. The YSF network organizes two-month events called home visits at the provincial and district levels. However, the network is weak to help each other in terms of production and processing to reduce costs and expand the market.

4. Conclusions

The study evaluated the effect of participation in the YSF program for young farmers on farm income in Northeast Thailand. The study used regression with an endogenous treatment effect model to evaluate the effect of participation in the YSF program on farm income. The findings exhibited that gender, age, education, technology adoption, and income significantly increase participation. However, the farmers' participation was significantly reduced by their farming experience. The findings further imply that on average, participation in the YSF program could able to more earn an income of around 6758.59 $/year as compared to non-participants of 3066.63 $/year. The results showed significant positive impacts of participation in the YSF program. The participants prefer to quit their full-time jobs to do agriculture thus causing a feeling of being taken advantage of by the product marketing system. In terms of farm management, farmers are unable to solve the problems because of a lack of management skills towards modern farming. Therefore, the government should be more supportive of those who need to start farming to make it an economically satisfactory livelihood. Also, the government should encourage a strong network within the group which consequently increases knowledge sharing, technology, and agricultural activities from the production process to marketing. This will help motivate Young Smart Farmer to become a good leader in agriculture in the future and build the strength of learning groups and networks. The government should support participant to raise a network level in the form of a company, cooperative or enterprise that has an auditable and transparent accounting system which result in an increase of job opportunities, income, and good relationship with various agencies.

Author Contributions

Supaporn Poungchompu wrote the manuscript with input from all authors and analyzed the data. Porntip Phuttachat prepared a data survey and cooperated in the field survey. All authors discussed the results and commented on the manuscript.

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Data Availability

The findings of this study are available from the corresponding author upon reasonable request.

Conflict of Interest

The authors declare that there is no conflict of interest.

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RESEARCH ARTICLE

Determining Economic Optimum Soil Sampling Density for Potassium Fertilizer Management in Soybean: A Case Study in the U.S. Mid-South

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Abstract: Determining the number of samples to collect in a field to develop soil-test K (STK) maps that are sufficiently accurate for profit-maximizing fertilizer rate prescription maps is complex. The decision also hinges on the application method—variable rate or uniform rate (VRT vs. URT). Using a 400 m^2 fishnet grid on a 26.3-ha irrigated soybean field, the authors compared sampling densities ranging from 5 to 60 samples or 5.3 ha/sample to 0.40 ha/sample. Subsequently, the authors simulated yields based on STK maps generated with that range of samples taken to generate i) associated profit-maximizing fertilizer-K rates (K*) that varied by grid with VRT, or ii) a single fertilizer rate based on field-average STK with URT, to compare revenue less fertilizer cost (NR) across VRT, URT, and sampling strategy. With more information, NR increased at a diminishing rate as crop needs could be better matched to fertilizer needs with greater detail in STK maps with VRT. Also, fertilizer use with URT was higher than VRT given the field-specific distribution of STK. Regardless of the sampling strategy, NR was higher for VRT than URT, however, that benefit was smaller than the upcharges for VRT equipment. Marginal benefits from added soil sampling were smaller than their marginal cost leading to an optimal least-cost, 5-sample strategy and URT. Changing one of the 5 sampling locations, however, revealed unreliable field average STK estimates. Since soil samples inform about several macronutrients, splitting soil sampling charges across K and P profitably justified sampling near every 1.5 ha with URT.

Keywords: Soil sampling density; Potassium; Soybean; URT; VRT

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1. Introduction

The profit-maximizing number of soil samples to collect in a field depends on the value gained from collecting that extra information. As such, optimal spatial soil sampling density or economic optimum sampling density (EOSD) translates to an economic and environmental benefit-cost tradeoff analysis. In essence, this research analyzes the benefit of greater spatial knowledge of soil-test potassium (STK) to inform K fertilizer rate and application technology selection at the onset of the growing season. Variable-rate technology (VRT) may be used to tailor in-season fertilizer-K application rates to grid portions of the field to avoid excess/insufficient nutrient application for profit maximization and/or minimization of nutrient runoff. To maximize each field's productivity, VRT equipment precision plays an important role in matching crop nutrient needs to spatial soil nutrient availability that usually needs to be supplemented with fertilizer. Fertilizer rate changes, both along the path and across the operating width—for equipment with section control—are not instantaneous, and may only occur in lumpy increments (i.e. in 5 kg K h^{-1} increments). Thus, with VRT, spatial fertilizer placement may suffer from timing and rate change capability errors. Nonetheless, compared to less complex and lower-cost uniform rate technology (URT), where the field receives the same fertilizer rate across the entire field, field profitability improvement with VRT due to nutrient matching is expected but is also costly. Changes in yield, fertilizer use, and application costs differ between URT and VRT and are impacted by the spatial precision of information available as well as the equipment's ability to match application rate to different crop needs in subsections of a field with varying STK. Quantifying yield and fertilizer use changes leads to a potential benefit estimate that, in turn, needs to be greater than the added cost for soil sampling and an upcharge for VRT compared to URT application equipment, for producers to benefit financially. At the same time, environmental benefits are possible as excess nutrient application in regions of the field where fertilizer may not be needed or could be applied at lesser than URT rates is expected to lead to less nutrient loss (e.g., runoff).

A large body of literature discusses the economic and environmental benefits of VRT adoption [1-5] and the effect of different spatial soil sampling densities and interpolation methods on mapping accuracy [6-8]. The optimum grid size of VRT fertilizer prescription maps has also been evaluated [9]. However, the economic benefit of sampling density or EOSD in site-specific or whole-field management under both design and model-based sampling in a precision agricultural setting has not been evaluated [10].

Soil sampling for nutrient management commenced in the mid-1940s with rapid adoption in North America. Murell et al. [11] documented continued growth in the number of soil samples collected annually between the early 2000s and 2015. Reasons for this growth are both an increase in acreage being sampled and finer spatial soil sampling densities. In Arkansas, the number of client soil samples submitted to the University of Arkansas System Division of Agriculture Marianna Soil Test Laboratory increased by almost 17.8% from 2011 to 2021 [12,13]. In 2011, 60% of the samples were collected using grid sampling. The remainder was collected as field- or area-average. In 2021, 77%, 7.5%, and 1.7% of the samples were collected using 1 ha, 0.8 ha, and 0.4 ha grid sampling, respectively. Farmers use soil test results to inform management practices, and the collected data must be reliably interpreted for spatial fertilizer rate recommendations either at the field scale using URT or the sub-field grid scale using VRT.

Temporal variation in soil-test nutrient holdings is a function of crop rotation, fertilizer application rate, and the farmer's approach to nutrient management. For instance, fertilizer rates can be selected to build sub-optimal soil nutrient levels to the optimum range using a 'build and maintain' approach. Fertilizer rates can also be selected to maximize profitability in the given year of application using a 'sufficiency' approach. Along those lines, Oliver et al. [14] suggested that for the case of K-fertilizer in fields with rice (*Oryza sativa* L.) and soybean (*Glycine max* L.) in rotation, annual profit-maximizing K-fertilizer rates led to similar input use whether or not the value of soil-test K was taken into consideration (long-run) or not (short-run). Further, short-run, profit-maximizing 'sufficiency' rates were lower compared to 'build and maintain' fertilizer rate extension recommendations that are based mainly on yield removal and soil-test K information in the application year. Given minor profitability and yield implications between 'build and maintain' vs. 'sufficiency' approaches, Oliver et al. [14] recommend the use of a short-run profit-maximizing modeling tool for soybean [15] and rice [16] to estimate yields and input use subject to soil-test K information, yield potential, input cost, and output price information.

Lawrence et al. [10] stated that at least 7.4 soil samples ha^{-1} are needed to adequately inform about soil-test phosphorus (P) at a five percent precision level. The cost of collecting soil samples and analyzing the soil ranges widely, but for average farmers, meeting the precision level as mentioned above would likely be a burden when valued at \$5.50 per sample or \$40.77 ha^{-1} using the representative mid-southern cost of production information from 2023 as reported by Mississippi State University [17]. However, this cost may need to be adjusted based on multiple end uses of soil sampling information. For example, the cost of soil sampling across multiple macro-nutrients (Nitrogen (N)-P-K) should be allocated to benefits created by individual nutrient applications (N, P, or K) for a proper cost-benefit analysis. Furthermore, soil sampling information may also inform about pH, organic matter, variable rate seeding and/or pest control. Hence, addressing the economic benefit of increasing spatial soil sampling density in the context of farm field net returns is a complex endeavor.

Given this background, we surmise that producers lack information about costs and benefits related to the number of soil samples collected at the field level with attendant implications about how much fertilizer to apply and whether or not to invest in more expensive variable- rather than uniform-rate application. The hypothesis is that soil sampling density and application method lead to different field profitability estimates and are obtained by: i) simulating soybean yield based on STK maps of varying accuracy using decision support software [15]; ii) calculating profit-maximizing K-fertilizer rates by grid; iii) comparing partial field returns across sampling strategy and application method to determine the economically optimal sampling density (EOSD); iv) conduct sensitivity analysis on soil sampling cost, application technology cost differences, fertilizer rate change equipment capability, and impact of sampling location.

2. Conceptual Framework

To quantify the benefits of different spatial soil sampling densities, the law of diminishing marginal returns [18] suggests that producer profit at the field level will increase with more intensive soil sampling because the greater accuracy from site-specific information will more closely match the plant's nutrition needs with the applied fertilizer rate. The expectation is that those benefits will diminish as the number of samples increases. The EOSD is thus reached where the marginal benefit of additional samples is equal to their marginal cost.

3. Materials and Methods

This research collected STK data from a 26.3-ha farm field near Lonoke, Arkansas in the spring of 2021. Historically, various crops, including rice, soybean, and corn (*Zea mays* L) have been grown in this field, with soybean grown in the year prior to sampling. A total of 65 soil samples at a sampling depth of 15.24 cm generated the most 'informed' soil map for the field (Figure 1) at a spatial soil sampling density of approximately 2.5 samples ha^{-1}. Soil sample information was successively removed to create soil maps of less and less accuracy as information was withheld with fewer sampling locations (black dots) in Figure 1 from left to right.

Using inverse distance weighting (IDW), soil maps with a fishnet grid size of 20 m × 20 m (400 m^2) were created to match equipment technology capable of changing application rate every 20 m given field application speeds of up to 4.5 m s^{-1} and anticipatory rate change time requirements of 2 seconds. Using a spin spreader or granular pneumatic application equipment, an operating width of 20 m without section control is relatively standard.

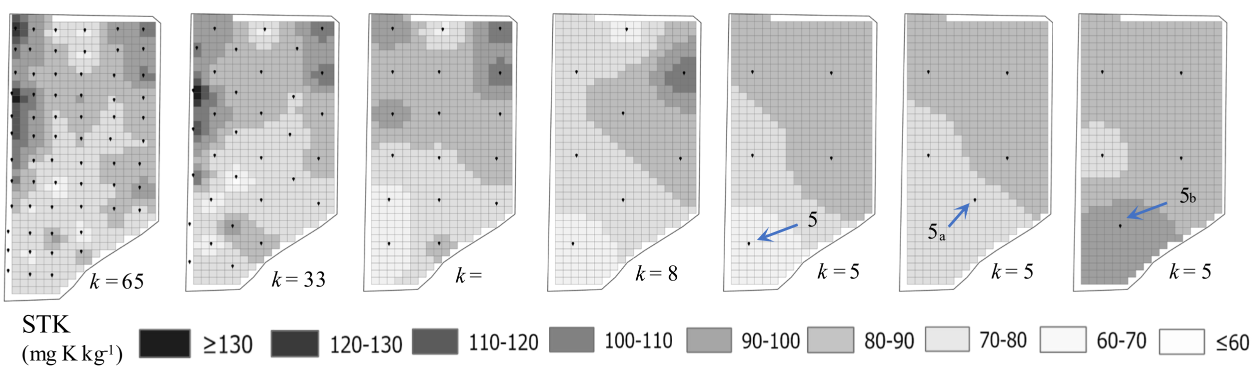

Figure 1. Field STK maps were created using ArcGIS Pro's (ESRI, Redlands, CA, USA) inverse distance weighting interpolation method (radius variable 12, power 2) with 602 – 20 m × 20 m grids at decreasing spatial soil sampling densities from left to right. STK are Mehlich-3 extractable soil K values in the top 0-15.24 cm soil layer in the spring of 2021, Lonoke, AR. Soil sampling strategies vary by the number (*k*) of soil samples taken. Sampling locations are shown with black dots. For the lowest soil sampling density strategy, the selection of the 5th sampling location was labeled for sensitivity analysis.

As such, variable rate application employs profit-maximizing-fertilizer-K application rates (K*) per grid that are based on i) calculated yield response to added K-fertilizer using prior research [15]; ii) estimated soil-test K maps that vary by soil sampling density (Figure 1); iii) 10-year average crop price; iv) fertilizer cost; and v) a user-specified field yield potential as explained in greater detail below. In comparison, the profit-maximizing uniform field rate is calculated using the same information, except that the average soil-test K value for the field rests on values per grid that change with the number of soil samples and every grid receives the same fertilizer rate.

To assess profitability changes across soil sampling strategy and application method (URT vs. VRT), field partial returns are calculated from estimated field yield times crop price minus the sum of i) fertilizer cost driven by application rate(s); ii) technology-dependent fertilizer application cost; and iii) soil sampling charges impacted by number of soil samples used. Comparison of field partial returns across sampling strategy, VRT and URT, will allow identification of the EOSD and application method as the one with the highest field partial returns.

Using the leftmost soil map in Figure 1 as the baseline, successive removal of information, as shown in Figure 1 had 33, 17, 8, and 5 soil samples remaining. This led to spatial soil sampling densities ranging from 2.47 samples ha^{-1} to 1.25, 0.65, 0.30, and 0.19 samples ha^{-1} or taking a soil sample roughly every 0.4, 0.8, 1.5, 3.3, and 5.3 ha from left to right, respectively. The latter three sampling densities are most common in Arkansas and the highest sampling density of 1 sample per 0.4 ha is considered by industry experts to be the highest sampling density a commercial crop producer or custom applicator would entertain to gain accurate field information.

The most used sampling design for many field studies is systematic sampling using transects or grids [19]. While statisticians often criticize systematic sampling designs, they are considered the most economically efficient way of collecting or analyzing information in commercial agricultural settings [20]. The STK data from each sampling density were interpolated to a fishnet grid of 20 m × 20 m using IDW with a power parameter of 2. To simplify the analysis, grids not fully included in the field boundary were excluded from the analysis as was a detailed field path analysis. As such, the field size was reduced from 26.3-ha to 24.08-ha with 602 grids comprising the field unit analyzed.

Inverse distance weighting and Kriging methods were considered as possible options for interpolation. However, semivariogram analysis (Kriging) could prove site-specific, and, as such, IDW would be more comparable across sampling density scenarios. Also, with the successive elimination of soil sampling locations, we strived to maintain more or less equal distances between sampling locations so as not to require knowledge of semivariogram parameters [6]. Finally, numerous agronomic software tools (e.g., Agstudio, Ag Leader, and Trimble Inc.) use the IDW method as their primary interpolation method to create prescription maps for seeding and fertilizer inputs [21]. In that sense, IDW conforms to what might happen when performing actual field applications.

3.1 Field Profit Estimation

Calculating soybean field partial returns as a function of yield-driven soybean revenue less operating expenses for soil sampling, fertilizer, and fertilizer application charges will vary with soil sampling density, resultant soil map information, and whether or not fertilizer is applied using VRT or URT. To obtain grid-based yield estimates, a recently published decision aid that simulates yield based on STK and K-fertilizer application was used [15]. Their tool was developed using field trial information from 2004 to 2019 involving 374 individual treatment means from 86 site-years of fertilizer-K response trials with 4 to 5 K-rate treatment comparisons to zero-K control treatments per site year. To make the tool usable across fields, yield response to K-fertilizer was estimated using relative yield by indexing K rate treatment yields relative to the yield-maximizing K rate treatment (RY = 100) for each trial. Using that relative yield response to fertilizer rate, the decision aid requires entry of a field's yield potential (*YP*) to estimate soybean yields that are achieved with varying K-fertilizer rates. The profit-maximizing K-fertilizer rate thus is a function of yield response, STK, crop price, and fertilizer cost. Hence, grid-level yield estimates ($\widehat{Y}_{ij}$) in response to STK and fertilizer application (K) were possible using Popp et al.'s [15] coefficient estimates by grid (i) when using soil maps that varied by soil sampling strategy (j) based on the number of soil samples collected (k) as follows:

$$\begin{aligned}\widehat{Y}_{ij} = (&60.013 + 0.354 \cdot STK_{i65} - 7.615 \cdot 10^{-4} \cdot STK_{i65}^{2} \\ &+ 0.558 \cdot K_{ij} - 1.896 \cdot 10^{-3} \cdot {K_{ij}}^{2} \\ &- 5.150 \cdot 10^{-3} \cdot STK_{i65} \cdot K_{ij} \\ &+ 1.673 \cdot 10^{-5} \cdot STK_{i65} \cdot {K_{ij}}^{2} \\ &+ 1.114 \cdot 10^{-5} \cdot {STK_{i65}}^{2} \cdot K_{ij} \\ &- 3.614 \cdot 10^{-8} \cdot {STK_{i65}}^{2} \cdot {K_{ij}}^{2})/100 \cdot YP/25\end{aligned} \tag{1}$$

where the part of the equation in parentheses represents the relative yield index estimate based on the field trials and division by 25 accounts for the number of 400 m^2 grids ha^{-1} for a yield estimate per grid. Note that while

K_{ij} will vary by grid and sampling density, the 'most informed' STK_{i65} (left-most field map in Figure 1) is used regardless of sampling density to develop yield estimates.

As in Popp et al. [15], the profit-maximizing fertilizer application rate K* (in kg K ha^{-1}) is obtained by setting the marginal cost of added fertilizer-K equal to the marginal revenue the added fertilizer delivers as follows:

$$K_{ij}{}^* = \frac{\left[\frac{c_K}{\frac{YP}{100} \cdot P_S} - (0.558 - 5.150 \cdot 10^{-3} \cdot STK_{ij} + 1.114 \cdot 10^{-5} \cdot STK_{ij}^2)\right]}{[2 \cdot (-1.896 \cdot 10^{-3} + 1.673 \cdot 10^{-5} \cdot STK_{ij} - 3.614 \cdot 10^{-8} \cdot STK_{ij}^2)]} \quad (2)$$

Ten-year average Arkansas soybean price (P_S = \$0.398 kg^{-1}) and fertilizer-K cost (c_K = \$1.094 kg^{-1}) were used to avoid unusually high or low values [22,17]. Fertilizer cost was transformed from muriate of potash fertilizer (500 g K kg^{-1}) cost information as reported by Mississippi State University to \$ kg^{-1} K and is deemed representative of mid-Southern US prices a producer would pay. Importantly, $K_{ij}{}^*$ are developed using STK_{ij} that varies from STK_{i65} as less information is available to make progressively less accurate field STK maps (Figure 1 moving from left to right) for VRT fertilizer rate recommendations that vary by grid.

Uniform fertilizer rate recommendations by sampling strategy were calculated similarly,

$$UK_j{}^* = \frac{\left[\frac{c_K}{\frac{YP}{100} \cdot P_S} - (0.558 - 5.150 \cdot 10^{-3} \cdot \overline{STK}_j + 1.114 \cdot 10^{-5} \cdot \overline{STK}_j^2)\right]}{[2 \cdot (-1.896 \cdot 10^{-3} + 1.673 \cdot 10^{-5} \cdot \overline{STK}_j - 3.614 \cdot 10^{-8} \cdot \overline{STK}_j^2)]} \quad (3)$$

except $\overline{STK}_j$ are the simple averages of the field STK map derived STK_{ij} that, in turn, are a function of the number of soil samples used and lead to one fertilizer rate for the entire field.

Plugging $K_{ij}{}^*$ from Equation (2) into Equation (1) as K_{ij}, field level partial returns using VRT are:

$$FPR_{j,VRT} = \sum_{i=1}^{n} (Y_{ij,VRT}^* \cdot P_S - K_{ij}{}^*/25 \cdot c_K - C_{VRT}/25) - FSSC_j \quad (4)$$

where n = 602 is the number of grids in the field, C_{VRT} = \$5 ha^{-1} are added VRT application charges in comparison to uniform rate application, and $FSSC_j$ are field soil sampling charges that depend on the number of samples taken at different sampling densities (k = 65, 33, 17, 8 and 5 samples in the field) at the cost of \$5.50 per sample (SSC) as reported by Mississippi State University [17]. Dividing fertilizer cost and C_{VRT} by 25 again adjusts for the number of grids ha^{-1}.

By the same token, field-level partial returns using URT were calculated with Y_{ij}^* estimates from Equation (1) using UK_j^* from Equation (3):

$$FPR_{j,URT} = \sum_{i=1}^{n} (Y_{ij,URT}^* \cdot P_S - UK_j{}^*/25 \cdot c_K) - FSSC_j \quad (5)$$

3.2 Sensitivity Analyses on Technology Soil Sampling Density-Related Charges

Since the cost difference between application charges for VRT vs. URT fertilizer application can vary substantially, a breakeven C_{VRT} upcharge for VRT compared to URT fertilizer application was calculated by subtracting revenue less fertilizer cost per field across the two application technologies as that net revenue difference is the maximum C_{VRT} a producer would pay to be as profitable with VRT compared to URT:

$$BEC_{j,VRT} = \sum_{i=1}^{n} \left(Y_{ij,VRT}^* \cdot P_S - \frac{K_{ij}{}^*}{25} \cdot c_K\right) - \sum_{i=1}^{n} \left(Y_{ij,URT}^* \cdot P_S - \frac{UK_j{}^*}{25} \cdot c_K\right) \quad (6)$$

In addition, as soil sampling charges (SSC) may vary not only by the charge of individual soil samplers but also by different factors: field size, crop, and number of nutrient content analyses in the report, breakeven SSC was calculated for different sampling densities. Breakeven represents the maximum a producer could pay per soil sample to adopt a particular soil sampling strategy j to achieve the same level of profitability regardless of the number of soil samples collected. It was calculated by solving for the SSC per soil sample that makes each FPR_j across sampling strategy equal and is different when more expensive VRT compared to URT is employed as follows:

$$BESSC_{j,VRT} = \frac{FSSC_j - \left(\max_j FPR_{j,VRT} - FPR_{j,VRT}\right)}{k} \quad (7)$$

$$BESSC_{j,URT} = \frac{FSSC_j - \left(\max_j FPR_{j,URT} - FPR_{j,URT}\right)}{k} \quad (8)$$

The numerator represents the maximum to pay for soil sampling to be indifferent between the most profitable sampling strategy (max FPR) and their alternative. As such, it is the strategy-relevant field soil sampling charges less the amount of profit lost by choosing a sub-optimal sampling strategy, a disadvantage that can only be justified if paying less per sample. Recall that $FSSC = SSC \cdot k$.

3.3 Sensitivity Analyses on Sampling Location and Application Rate by Grid

As the importance of a particular soil sample taken in a field influences a more significant portion of the soil map with fewer samples taken per field, the location of individual sample points also increases in importance. As shown in Figure 1, the effect of a location change for one of the sample points is used to exemplify this issue in an irregularly shaped field where this issue may be more prominent than in a square or rectangular field.

Finally, the assumption to this point was that the application equipment could change the grid application rate to match K* recommendations exactly. What if the equipment could only change K* in 5.6 kg K ha^{-1} or 11.2 kg KCl ha^{-1} muriate of potash fertilizer increments as the equipment moves from grid to grid? How would this technology limitation impact economic performance and recommendations?

3.4 Statistical Analysis

To assess differences in estimated STK, fertilizer application rate, and field partial returns, fishnet grid-based estimates were randomly assigned to four replicates. Analysis of variance was used to investigate differences in the average, standard deviation, minimum and maximum STK and K* values between sampling strategies. The sampling strategy was the explanatory variable, or treatment effect, and separate linear models were fitted for each descriptive statistic. For each model, the number of degrees of freedom for the treatment effect and residual error were 6 and 21, respectively. Analysis of variance was also used to investigate differences in field-level returns for URT and VRT at the different sampling densities. The main effects of sampling strategy and K fertilizer application method and their two-way interaction were considered as explanatory variables. The number of degrees of freedom was 6 for the main effect of the sampling distribution, 1 for the main effect of K fertilizer application method, 6 for the two-way interaction, and 42 for the residual error. The null hypothesis was that there were no significant differences in field partial return between sampling strategy and application method combinations. The null hypothesis was evaluated at P = 0.05, and post-hoc analysis was computed when appropriate using multiple pairwise comparisons. Statistical differences between treatment pairs were summarized using the compact letter display and the method established by Gramm et al. [23].

4. Results and Discussion

To benefit from VRT, the yield and fertilizer use benefits from minimizing under- and over-fertilization at the grid level in comparison to URT, must outweigh the added cost. Table 1 and Figure 1 highlight this issue by indicating changes in the fishnet grid estimates of STK and their field average, minima, and maxima across sampling densities. With more information comes more significant variability in STK, as shown in the standard deviation estimates. Hence the potential for fertilizer rate mismatch, given spatially varying STK, decreases as more information is obtained.

Also, the choice of soil sampling location can significantly impact the average STK, as shown in the last three columns of the rows with STK information. Pending the choice of one sample location 5, 5_a, or 5_b (Figure 1), field soil map information changed, leading to average field STK that successively increased for 5, 5_a, and 5_b.

Recall that profit-maximizing K* (K_{ij}^* for VRT and UK_j^* for URT) varies indirectly with STK or the more STK available in the soil, the less fertilizer K* is needed to maximize profit as evident in Table 1. In addition, K_{ij}^*, using Equation (2), varies by grid and by soil sampling strategy under VRT, and hence variance in grid STK_{ij} translated to larger variance in K_{ij}^* as sampling density increased. Additionally, it is interesting with URT that the profit-maximizing fertilizer rates, UK_j^*, were all larger than the average K_{ij}^*, a result that is likely due to the non-normal spatial distribution of STK_{ij}, as shown in the field STK maps (Figure 1).

Regarding sample point selection with the least-cost soil sampling strategy with 5 soil samples, K* successively decreased with greater STK when moving from sample points 5 to 5_a and 5_b. While the change in STK is small, it does impact the profit-maximizing K* more so than across all the other soil sampling strategies. Hence, the selection of location leads to random outcomes, a finding that relates to Lawrence et al.'s [10] findings in terms of soil map precision.

Using the field STK map information from Figure 1, the profit-maximizing K_{ij}^* were mapped in Figure 2, with the expected yield, input use, and financial implications highlighted in Table 2. As expected, yield variability increased with greater sampling density, given that K* and STK were more variable with the greater number of soil samples collected. At the same time, using the URT-based UK_j^*, led to more uniform yields than experienced with VRT. Since both yield estimates were calculated using the same, highest-information STK field map, spatial yield variability was mainly a function of VRT fertilizer use. The impact is small and would likely not be observable visually in the field by the producer. While yield variance was different, average yields were more or less the same and increased with lesser sampling density as average STK decreased and thereby fertilizer use increased, driving yields higher with lesser sampling density.

At the same time, the direct relationship between sampling density and average STK in the field is likely random and field-specific (Table 1). Note, for example, that this direct relationship between STK and sampling density changed numerically when reducing the number of samples from 8 to 5 and more or less significantly so when choosing different sampling points for the fifth soil sample with the least-cost sampling strategy occurring where $k = 5$.

Table 1. Estimated marginal means for the average, standard deviation, minimum, and maximum Mehlich-3 extractable soil-test K (STK) values in the top 15.24 cm soil layer and their resultant profit-maximizing K fertilizer rates (K*) using 10-yr average soybean price (P_S = \$0.40 kg^{-1}), fertilizer K cost (c_K = \$1.09 kg^{-1} K), and 5,044 kg ha^{-1} yield potential (YP) at decreasing soil sampling density from left to right in a 24.08-ha field near Lonoke, AR, 2021.

	Soil sampling strategy (j)[1]						
# of samples (k)	65	33	17	8	5	5_a	5_b
Statistic	*STK* in mg K kg^{-1}						
Average STK_{ij}	$83.5^{b,2}$	82.8^{b}	81.2^{c}	78.5^{d}	79.2^{d}	81.0^{c}	85.9^{a}
Standard Deviation	10.2^{a}	9.7^{ab}	8.8^{bc}	8.2^{cd}	7.2^{d}	3.6^{e}	4.4^{e}
Minimum	62.4^{b}	61.7^{b}	61.4^{b}	60.5^{b}	60.3^{b}	74.4^{a}	76.4^{a}
Maximum	125.3^{a}	122.6^{a}	104.2^{b}	104.7^{b}	87.5^{c}	87.4^{c}	95.7^{bc}
	K* in kg K ha^{-1}						
Average K_{ij}^{*3}	100.0^{c}	100.6^{c}	102.1^{b}	104^{a}	103.7^{a}	102.7^{b}	98.9^{d}
Standard Deviation	9.5^{a}	8.9^{a}	6.7^{b}	6.0^{bc}	4.6^{cd}	2.6^{d}	3.6^{d}
Minimum	44.2^{b}	46.8^{b}	81.1^{a}	80.4^{a}	97.8^{a}	97.9^{a}	90.4^{a}
Maximum	125.3^{a}	122.6^{a}	104.7^{b}	104.2^{b}	95.7^{bc}	87.5^{c}	87.4^{c}
UK_j^{*4}	101.0^{c}	101.5^{c}	102.7^{b}	104.6^{a}	104.1^{a}	102.8^{b}	99.2^{d}

Notes:

[1] See Figure 1 for soil sampling locations with varying soil sampling strategies j leading to STK_{ij} per grid i, and resultant profit-maximizing K_{ij}^{*} or uniform rate UK_j^{*}.

[2] Same letter(s) across sampling strategy j for a particular statistic (within a row) indicate no statistically significant differences at P = 0.05 for all models.

[3] See Equation (2) for the calculation of K_{ij}^{*} that vary by strategy and grid.

[4] See Equation (3) for the calculation of UK_j^{*} that vary by strategy only and is uniform across grids.

While yield results (Table 2) were somewhat random and more or less numerically invariant between VRT and URT, fertilizer use (Table 1) within a sampling strategy was always numerically less with VRT than URT and a direct result of a better match between spatial STK changes that dictated changes in K*. The fertilizer use difference between VRT and URT got smaller with less accurate soil mapping. Combining yield and fertilizer use effects, we measured the benefits from added soil sampling. A noticeable trend shows more or less stable field net revenue (revenue less fertilizer cost varied ≤ \$4 across sampling strategy, k = 65 at \$44,391 and k = 5 at \$44,387) for URT and a greater range of \$39 (k = 65 at \$44,415 and k = 5_b at \$44,376) with VRT across sampling strategy. Again, this is likely field-specific. Nonetheless, added information impacts VRT more than URT as URT applies only a slightly different UK* across sampling strategies whereas VRT results in a multitude of K* changes across grids based on the prescription maps (Figure 2). Hence, added soil map accuracy mainly benefited VRT profitability as expected.

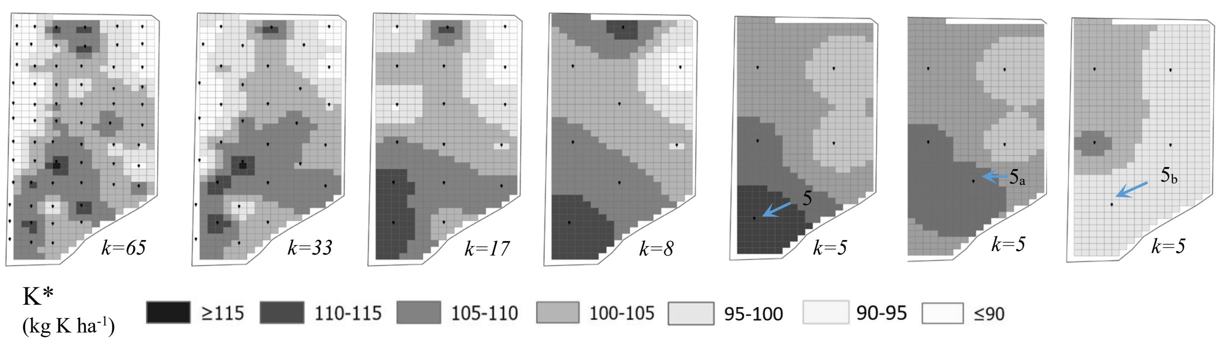

Figure 2. Grid-level profit-maximizing fertilizer-K rates (K*) for each of 602-400 m^2 grids with decreasing sampling density from left to right, Lonoke, AR, 2021. Soil sampling strategies vary by the number (k) of soil samples taken. Sampling locations are shown with black dots. For the lowest soil sampling density strategy, the selection of the 5th sampling location is labeled for sensitivity analysis.

Table 2. Estimated soybean yields (Y), field revenue ($Y \cdot P_S$), a \$5 ha^{-1} upcharge for variable rate technology (VRT) vs. uniform rate technology (URT), and soil sampling cost (SSC) of \$5.50 per sample for comparison of field partial returns (FPR) by application technology using 10-yr average soybean price (P_S = \$0.40 kg^{-1}), fertilizer K cost (c_K = \$1.09 kg^{-1} K), and 5,044 kg ha^{-1} yield potential (YP) and soil sampling strategyin a 24.08-ha field near Lonoke, AR, 2021.

	Soil sampling strategy (*j*)[1]						
# of samples (*k*)	65	33	17	8	5	5_a	5_b
Description	*Soybean average yield (standard deviation) in kg ha⁻¹*						
Y_{VRT}	4,913 (20)	4,914 (20)	4,917 (16)	4,921 (16)	4,920 (12)	4,918 (7)	4,906 (12)
Y_{URT}	4,913 (1.8)	4,914 (1.5)	4,917 (0.9)	4,922 (0.2)	4,921 (0.1)	4,918 (0.8)	4,908 (2.8)
	Field revenue in \$						
$REV_{VRT} = Y_{VRT} \cdot P_S$	\$47,048	\$47,059	\$47,086	\$47,128	\$47,120	\$47,095	\$46,981
$REV_{URT} = Y_{URT} \cdot P_S$	\$47,050	\$47,064	\$47,094	\$47,140	\$47,129	\$47,097	\$47,000
	Field fertilizer-K expense in \$						
$FC_{VRT} = K^*_{ij} \cdot c_K$	\$2,632	\$2,649	\$2,687	\$2,740	\$2,732	\$2,704	\$2,606
$FC_{URT} = UK^*_j \cdot c_K$	\$2,659	\$2,673	\$2,703	\$2,753	\$2,741	\$2,706	\$2,610
	Field revenue less fertilizer cost in \$						
$REV_{VRT} - FC_{VRT}$	\$44,415	\$44,410	\$44,399	\$44,388	\$44,388	\$44,391	\$44,376
$REV_{URT} - FC_{URT}$	\$44,391	\$44,391	\$44,390	\$44,387	\$44,388	\$44,390	\$44,389
	Field VRT upcharge & soil sampling cost in \$						
C_{VRT}	\$120	\$120	\$120	\$120	\$120	\$120	\$120
FSSC	\$358	\$182	\$94	\$44	\$28	\$28	\$28
	Partial field return in \$						
FPR_{VRT}[2,3]	\$43,938[j]	\$44,108[h]	\$44,186[g]	\$44,224[e]	\$44,240[d]	**\$44,243[d]**	\$44,228[d]
FPR_{URT}	\$44,033[i]	\$44,209[f]	\$44,297[c]	\$44,343[b]	\$44,361[a]	**\$44,363[a]**	\$44,362[a]
	Breakeven upcharge for VRT in \$ for field						
BEC_{VRT}[3]	\$24	\$19	\$9	\$1	\$0	\$1	-\$14
	Breakeven soil sampling charge in \$ per sample						
$BESSC_{VRT}$[3]	\$0.80	\$1.39	\$2.08	\$3.08	\$4.81	\$5.50	\$2.39
$BESSC_{URT}$	\$0.44	\$0.86	\$1.63	\$3.04	\$5.08	\$5.50	\$5.35

Notes:

[1] See Figure 1 for soil sampling locations with varying soil sampling strategies *j* leading to STK_{ij} per grid *i*, and resultant profit-maximizing K^*_{ij} or uniform rate UK^*_j.

[2] Same letter(s) across sampling strategy *j* and application technology indicate no statistically significant differences at P = 0.05 for all models.

[3] See Equations (4) and (5) for calculating partial field returns (FPR). See Equation (6) for the maximum field cost for variable rate technology application of fertilizer, or its breakeven cost, and see Equations (7) and (8) for the maximum soil sample charge per sample allowable before switching to the profit-maximizing sampling strategy.

On the cost side of added information, field soil sampling charge differences across sampling strategies varied considerably more (*k* = 65 at \$358 and *k* = 5 at \$28 or a range of \$330) than the benefits or field revenue less fertilizer cost numbers (\$4 URT and \$39 VRT). As such, cost savings with lesser sampling led to the most profitable field partial returns as highlighted with bold lettering in the FPR rows per application technology in Table 2. For both VRT and URT, the economic optimum sampling density (EOSD) was to collect 5 samples.

The breakeven C_{VRT} (Equation 6) increased with greater information as expected and was highest at \$24 with most information used. However, none of the sampling strategies led to greater field partial returns with VRT than URT. Hence the variation of STK in this field would not justify the use of VRT as the added upcharge for VRT application of \$120 for the field is greater than the maximum benefit attained by more precisely matching field nutrient availability with crop needs at the grid level.

Similar to the breakeven VRT upcharge results, the breakeven price for soil sampling showcased that soil sampling charges needed to decrease to justify increased accuracy in STK values. Given soybean production, the cost of soil sampling may be allocated across 2 macronutrients: P and K. The cost per nutrient per soil sample for K would thus drop to \$5.50/2 samples or \$2.75 per sample collected. At this cost, the EOSD is somewhere between 17 and 8 samples or sampling every 1.5 to 3.3 ha, as the most one could afford for sampling to not be worse off, or the $BESSC_{URT}$ with 17 samples was \$1.63 per sample, and the $BESSC_{URT}$ with 8 samples was \$3.04 per sample.

Repeating this analysis with lesser equipment accuracy (assuming fertilizer rate changes in increments of 5.6 kg K ha^{-1} by grid), results are summarized in Table 3 and show remarkably similar findings when compared to Table 2. Again, VRT is not profitable; however, with the aforementioned breakeven cost for SSC at \$2.75 per sample, the EOSD is now much closer to 8 samples than 17 samples at higher equipment accuracy. Also, as profit-maximizing UK_j^* reacted to changes in average field map STK in a much more lumpy manner, given the 5.6 kg K ha^{-1} increment, field fertilizer expenses of either \$2,633 or \$2,765 were observed.

Now URT fertilizer expense was no longer always higher with URT than with VRT as in Table 2. With that loss in equipment accuracy, the justification for more precise STK maps thus expectedly is slightly lower.

Table 3. Estimated soybean yields (Y), field revenue ($Y \cdot P_S$), a \$5 ha^{-1} upcharge for variable rate technology (VRT) vs. uniform rate technology (URT), and soil sampling cost (SSC) of \$5.50 per sample for comparison of field partial returns (FPR) by application technology using 10-year average soybean price (P_S = \$0.40 kg^{-1}), fertilizer K cost (c_K = \$1.09 kg^{-1} K), and 5,044 kg ha^{-1} yield potential (YP) and soil sampling strategy in a 24.08-ha field near Lonoke, AR, 2021, using grid-based K* rate at nearest 5.6 kg K ha^{-1}.

	Soil sampling strategy (*j*)[1]						
# of samples (*k*)	65	33	17	8	5	5_a	5_b
Description	*Soybean average yield (standard deviation) in kg ha^{-1}*						
Y_{VRT}	4,913 (21)	4,914 (20)	4,917 (17)	4,921 (16)	4,921 (12)	4,918 (7)	4,907 (13)
Y_{URT}	4,910 (2.3)	4,910 (2.3)	4,923 (0.4)	4,923 (0.4)	4,923 (0.4)	4,923 (0.4)	4,910 (2.3)
	Field revenue in \$						
$REV_{VRT} = Y_{VRT} \cdot P_S$	\$47,049	\$47,056	\$47,080	\$47,125	\$47,124	\$47,095	\$46,994
$REV_{URT} = Y_{URT} \cdot P_S$	\$47,024	\$47,024	\$47,151	\$47,151	\$47,151	\$47,151	\$47,024
	Field fertilizer-K expense in \$						
$FC_{VRT} = K_{ij}^* \cdot c_K$	\$2,634	\$2,647	\$2,681	\$2,737	\$2,739	\$2,706	\$2,619
$FC_{URT} = UK_j^* \cdot c_K$	\$2,633	\$2,633	\$2,765	\$2,765	\$2,765	\$2,765	\$2,633
	Field revenue less fertilizer cost in \$						
REV_{VRT} - FC_{VRT}	\$44,415	\$44,409	\$44,399	\$44,387	\$44,385	\$44,389	\$44,374
REV_{URT} - FC_{URT}	\$44,390	\$44,390	\$44,386	\$44,386	\$44,386	\$44,386	\$44,390
	Field VRT upcharge & soil sampling cost in \$						
C_{VRT}	\$120	\$120	\$120	\$120	\$120	\$120	\$120
FSSC	\$358	\$182	\$94	\$44	\$28	\$28	\$28
	Partial field return in \$						
FPR_{VRT}[2,3]	\$43,937[j]	\$44,107[h]	\$44,185[g]	\$44,223[e]	\$44,237[d]	**\$44,241[d]**	\$44,226[e]
FPR_{URT}	\$44,033[i]	\$44,209[f]	\$44,292[c]	\$44,342[b]	\$44,358[a]	\$44,358[a]	**\$44,363[a]**
	Breakeven upcharge for VRT in \$ for field						
BEC_{VRT}[3]	\$24	\$19	\$13	\$1	-\$1	\$3	-\$16
	Breakeven soil sampling charge in \$ per sample						
$BESSC_{VRT}$[3]	\$0.82	\$1.45	\$2.19	\$3.26	\$4.78	\$5.50	\$2.63
$BESSC_{URT}$	\$0.42	\$0.83	\$1.35	\$2.86	\$4.58	\$4.58	\$5.50

Notes:

[1] See Figure 1 for soil sampling locations with varying soil sampling strategies *j* leading to STK_{ij} per grid *i*, and resultant profit-maximizing K_{ij}^* or uniform rate UK_j^*.

[2] Same letter(s) across sampling strategy *j* and application technology indicate no statistically significant differences at P = 0.05 for all models.

[3] See Equations (4) and (5) for calculating partial field returns (FPR). See Equation (6) for the maximum field cost for variable rate technology application of fertilizer, or its breakeven cost, and see Equations (7) and (8) for the maximum soil sample charge per sample allowable before switching to the profit-maximizing sampling strategy.

5. Conclusions

The goal of this research was to find an economically optimal sampling density and make a recommendation about whether or not VRT fertilizer application is profitable in comparison to applying fertilizer using URT. Using 65 soil samples collected in a 26.3-ha field dedicated to irrigated soybean production near Lonoke, AR, field STK maps were developed. By successively withholding collected soil sample information, soil map accuracy declined.

Using simulated yields that vary as a function of yield potential, STK and profit-maximizing K-fertilizer rates, field profitability implications of alternative soil map accuracy could be evaluated. This is innovative as profit-maximizing rates involving soybean price and fertilizer cost in addition to STK and yield potential alone have not been evaluated in this context to date. The proposed methods are deemed more informative and representative of what producers may do. Also, conducting this kind of analysis with actual field trials would be cost prohibitive and marred with difficulties as no two fields are the same and the same field can't be used over time given changes in STK.

Findings supported that more information led to superior net revenue (revenue less fertilizer cost) results at diminishing rates as expected with VRT. In comparison, URT used more fertilizer than VRT, given the spatial mismatch that was a function of the field-specific distribution of STK present in the soil before planting. Changes in fertilizer expense and yield implications across sampling strategy or benefits of added soil sampling were much less pronounced than concomitant changes in soil sampling charges. This was especially so at the initial cost of \$5.50 per sample to collect P and K information needed for fertilizer rate prescriptions in soybean. Allocating this charge to each macronutrient equally resulted in an optimal economic sampling density between 17 and 8 samples for this field with the assumption that profit-maximizing fertilizer rates could be adjusted from grid to grid to exact needs based on IDW grid estimates of STK. Relaxing equipment accuracy to adjust the fertilizer rate in increments of 5.6 kg K ha^{-1} lowered the economically optimal number of samples to just above 8 samples.

These results supported the use of URT in comparison to VRT, which is similar to Lowenberg-DeBoer and Erickson's [3] findings. The upcharge for reducing spatial mismatch in fertilizer application was considerably larger than the economic benefit derived. Nonetheless, a difference of approximately \$100 profit in a field (comparing FPR_{VRT} to FPR_{URT} in Tables 2 or 3 by sampling strategy) may well not be large enough of an economic deterrent for producers not to employ VRT. Further, greater sampling densities are economically justified with VRT than URT regardless of equipment accuracy ($BESSC_{VRT} > BESSC_{URT}$ in Tables 2 or 3 by sampling strategy).

With higher sampling density justified with VRT, the impact of potentially picking a poor soil sampling location at least sampling density (5 vs. 5a vs. 5b in the figures), becomes a moot point. Further work is needed to generalize findings to more fields in hopes of finding a rule of thumb that may help producers decide whether or not to adopt VRT in comparison to URT. At the same time, yield response to K-fertilizer is different by crop. As such, this research ought to be replicated across more crops. Finally, profit-maximizing K-fertilizer rates depend on crop price and fertilizer cost. Additional sensitivity analysis in that vein could be insightful.

Author Contributions

Bayarbat Badarch: initial writing; modeling. Michael Popp: conceptualization; modeling assistance; writing and editing; funding acquisition. Aurelie Poncet: conceptualization; statistical analysis; soil sample data acquisition. Shelby Rider: map generation. Nathan Slaton: conceptualization; editing.

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Data Availability

Data can be obtained from the authors upon request.

Conflict of Interest

The authors declare that they have no known competing interests or personal relationships that could have appeared to influence the work reported in this paper.

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