

Agricultural Transformation

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Introduction

The global agricultural sector is facing challenges from a growing population, trade wars, climate change, and outbreaks of plant and animal diseases, which are leading to food insecurity and economic inequality. In response, many governments are pushing for “Agricultural Transformation” with the goals of increasing the quantity and quality of output, adding value across the supply chain, diversifying products, and mitigating risks from both natural and man-made disasters. The key technologies driving this agricultural transformation can be grouped into three categories: 1) technologies that change the overall production process, 2) technologies that improve specific parts of the process, and 3) technologies that create new products.

In Thailand, most farmers are small-scale, with limited capital and skills. Krungsri Research therefore believes that appropriate technologies should be ‘accessible, simple, low-cost, and deliver clear results.’ The proposed approaches are as follows: 1) Knowledge and Skill Enhancement: Focus on using group applications, learning platforms, providing online tools, and creating databases for decision-making; 2) Value Addition and Market Access: Implement basic processing technologies, traceability systems, and online marketplaces; 3) Transition to Smart Farming: Focus on cost reduction, promoting the use of applications for precise farm management, and utilizing small-scale agricultural machinery. With government support enabling farmers to access appropriate technologies, these measures can sustainably elevate the livelihoods of Thai farmers.

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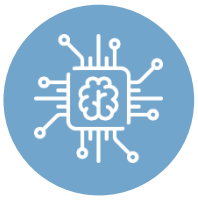


Introduction: The Agricultural Sector and the Path to Transformation

The agricultural sector has long been the backbone of the economy, playing a crucial role as the primary source of food-one of the four fundamental human needs-and providing shelter as well as economic security. However, increasing external risks such as trade wars, global warming, epidemics, and environmental degradation have led to agricultural output in certain areas and periods being insufficient for consumption. This has resulted in a lack of food security, which could ultimately lead to economic and social inequality. Therefore, to ensure food security and improve people's livelihoods, many countries worldwide are prioritizing the transformation of the agricultural sector.

Agricultural transformation is the process of changing production methods and supply chain management within the agricultural sector to enhance efficiency. This is achieved by applying technologies, innovations, and new concepts to meet the evolving demands of consumers, society, and the global market. Key drivers of this transformation include:

1. **Innovation and Technology:** This is the core of agricultural transformation, as seen in the evolution of the agricultural sector from Era 1.0 to Era 5.0 (Figure 1), each driven by new innovations and technologies. The current era, Agriculture 5.0, integrates various technologies and innovations to boost production potential. Examples include the use of digital data combined with engineering tools, the application of biotechnology to enhance the traits of plants and animals, and the use of agricultural data to analyze production and sales strategies.



2. **Population:** The United Nations projects that the global population will increase to 9.7 billion by 2050[1/], leading to a more than 25% rise in food demand. Furthermore, the diverse global population-in terms of society, culture, religion, health, age, and income-has a variety of food needs. An increase in per capita consumption may also lead to competition for agricultural products to ensure food security. Therefore, many countries must transform their production models or develop new ways to increase agricultural output to meet their domestic needs.



3. **Nature and Environment:** Constraints from natural resources and environmental changes-such as natural disasters, invasive pests and diseases, rising global temperatures, desertification or increasing aridity, and water pollution-require people in frequently affected areas to accelerate development in order to cope with these challenges and overcome the limitations of existing resources.



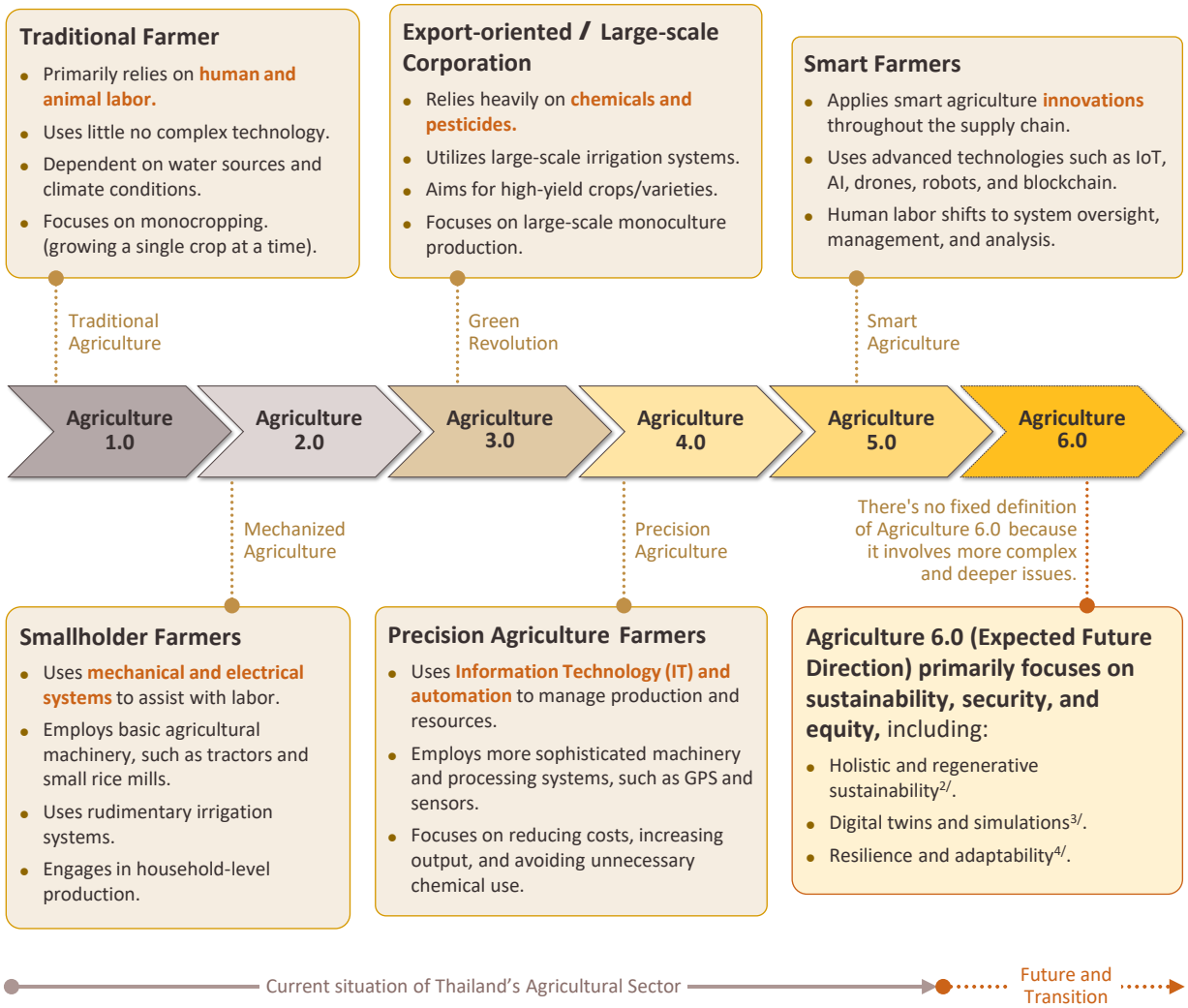
4. **Policies and Regulations:** The interconnectedness of the global economy and trade means that policies and regulations in one country can impact the supply chain in another. For instance, increased tariffs can raise the cost of imported goods, while policies supporting environmental sustainability-such as avoiding agricultural products from deforested areas, reducing carbon footprints, and verifying sustainable production-encourage many countries to rapidly develop their agricultural sector to comply with the standards and regulations of their global trading partners.



1/ Source : United Nations Population Division, 2025

Figure 1

Agricultural Eras and Their Key Characteristics



Source : Asian International Journal of Social Sciences, Krungsri Research

2/ Holistic and Regenerative Sustainability: This approach to farming takes a holistic view of the entire ecosystem. It includes practices such as Zero Waste production, converting agricultural byproducts into value-added resources, and farming that actively regenerates natural resources, with objectives to reduce reliance on new resources, create a natural balance, and ensure long-term sustainability.

3/ Digital Twins and Simulation: This involves creating a virtual replica of an entire farm or a specific part of it. This digital twin is linked to real-time data, allowing for experimentation, improvements, and the prediction of outcomes for various changes within the farm before implementing them physically. This process helps to reduce risk and increase crop efficiency.

4/ Resilience and Adaptability: This is the process of designing the agricultural sector to be highly flexible, capable of adapting to and coping with climate change, disasters, and shifts in production plans. It also involves securing a reserve of agricultural products to ensure food security.

Box 1

The future of agriculture can be further extended towards the concept of "sustainable development" or "nature-centric" agriculture, or Agriculture 6.0. This involves using modern innovation while sustainably managing agricultural resources. In other words, it focuses on conserving natural resources alongside farming. Developed countries, particularly within the European Union, are starting to adopt policies that prioritize natural resource conservation in their trade, investment, and production, and are even making these a prerequisite for international trade.

Although all four drivers are important and interconnected, **to effectively promote agricultural transformation, the development of innovation and technology should be the primary focus. Technology serves as a crucial "enabler"** that helps the agricultural sector tackle the challenges posed by the other three drivers. This approach provides a root-cause solution and enhances the sector's capability to overcome various limitations and challenges, leading to a genuine transformation.



Concrete examples of agricultural transformations

The primary goals of agricultural transformation-increasing the quantity and quality of output, adding value across the supply chain[5/], and reducing risks-all depend on **innovation and technology as the key drivers of change in the agricultural sector. The technologies[6/] used in agriculture can be divided into three main groups:**

1

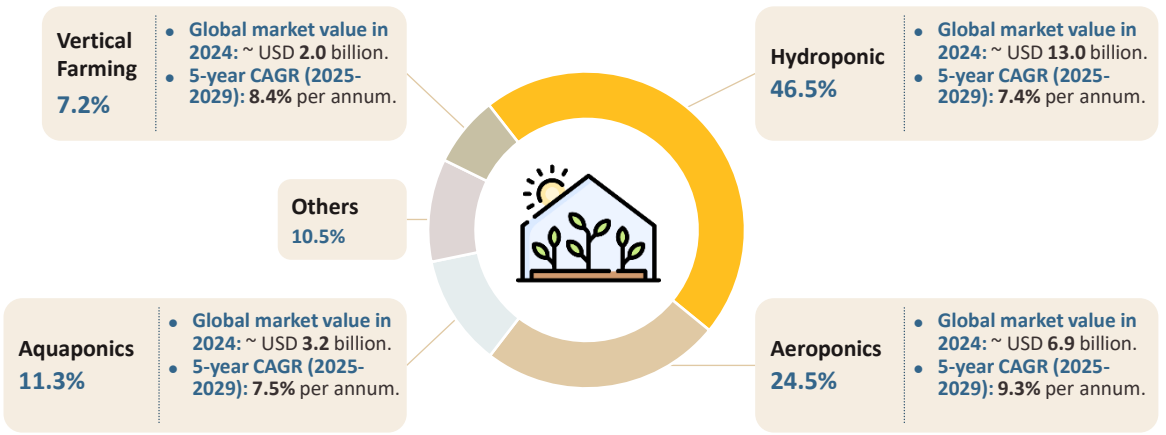
Technologies that Increase the Quantity and Quality of Agricultural Output throughout the Production Process. This group of technologies helps expand farming methods and overcome production limitations, such as cultivating crops in deserts or farming in the sea. The most popular method is greenhouse cultivation using various techniques, including hydroponics, aquaponics, aeroponics, and vertical farming.

These techniques use technology to mitigate constraints related to space, insects, and pests, allowing for the control of nutrients and a reduction in risk from natural disasters. As a result, crops can be cultivated year-round, which meets the needs of consumers or importing countries that demand high-quality produce or have limited space. However, the limitation of this technology is the high initial investment. There is also a risk from economic uncertainty, as the high cost of the produce may not be suitable during an economic downturn.

- **Greenhouse Market Value:** Technavio estimates that the global greenhouse market was valued at USD 28.0 billion in 2024 and is projected to reach USD 40.9 billion by 2029, with a Compound Annual Growth Rate (CAGR) of 7.9% per year (Figure 2). Key players in the global greenhouse industry include Europrogress, Industries Harnois, Top Greenhouses, Dalsem Greenhouse Projects, Ceres Greenhouse Solutions, and Asian Perlite Industries.

Figure 2

Greenhouse Market Share by Farming Technology in 2024



Source : Technavio, EMIS, Krungsri Research

5/ The Agriculture Value Chain begins with the preparation of raw materials, which are then fed into the production process. After cultivation, the produce is harvested, processed, or packaged. It is then stored for future use or transported for distribution to various locations to ultimately be sold to consumers.

6/ For definitions and applications of specific technologies, please refer to the appendix.

Box 2

Greenhouse farming is a method of cultivation within a controlled environment to ensure optimal conditions for plant growth, including light, temperature, humidity, water, nutrients, and disease management. There are two main types:

- **Closed Systems (Indoor / Plant Factory):** This involves cultivating plants in a fully enclosed structure with complete environmental control. It uses technologies such as artificial lighting, temperature control systems, and air circulation. The advantages are high and consistent outputs, along with year-round production. The main disadvantage is the high cost.
- **Open Systems (Outdoor / Conventional Greenhouse):** This involves creating a structure to cover plants outdoors, primarily using natural sunlight and ambient weather. While providing less environmental control, it requires a lower initial investment and less complex technology.

2

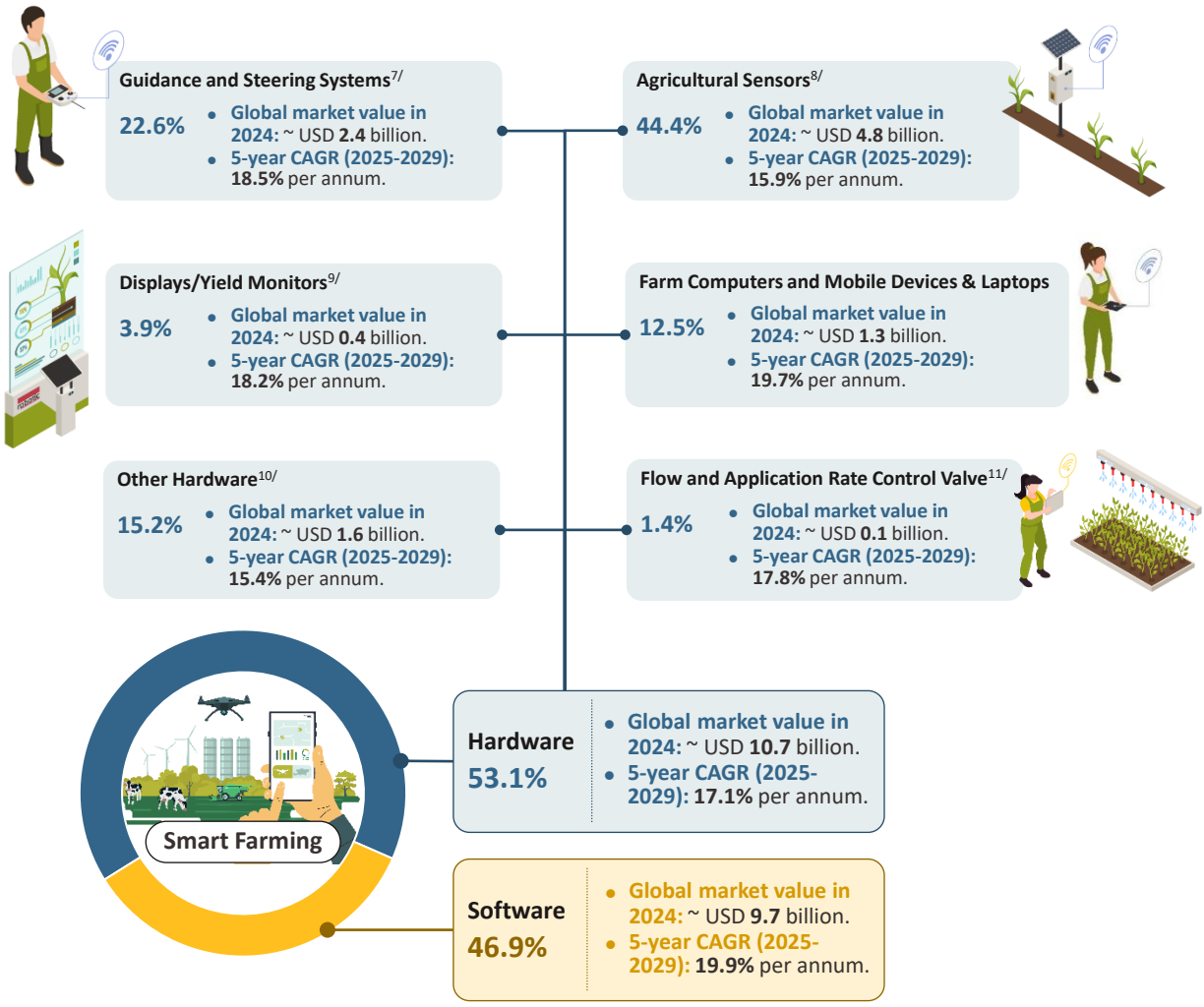
Technologies that Improve Efficiency, Output, and Quality in Agriculture, or Transform Specific Steps of the Agricultural Production Process: These technologies are particularly suitable for farmers with limited capital, as they are flexible and can be adopted incrementally based on needs and available funds. Widely known innovations include Precision Agriculture, Sensor Systems (for measuring moisture, light, and nutrients), GIS & GPS mapping and navigation systems, Drones, Robotics, the Internet of Things (IoT), Artificial Intelligence (AI), Blockchain, Applications and Platforms, Augmented Reality (AR) and Virtual Reality (VR), and 3D and 4D-Printing.

When used in combination, these technologies enable Smart Farming (Figures 3 and 4), which enhances efficiency and output, conserves resources, reduces damage, is environmentally friendly, and helps farmers make better, data-driven decisions. However, there are also some drawbacks, which include high initial costs, a reliance on advanced knowledge and infrastructure (such as electricity and the internet), the need for continuous software updates, and a long and uncertain payback period due to fluctuating produce prices.

- **Smart Farming Market Value:** BIS Research estimates that the global smart farming market was valued at USD 20.4 billion in 2024 and is projected to grow to USD 47.6 billion by 2029, with a Compound Annual Growth Rate (CAGR) of 18.5% per year. Prominent global players in this market include Deere & Company, CNH Industrial, Kubota Corporation, AGCO Corporation, Climate, BASF, Hexagon, Ag Leader Technology, CropX, and Cargill.

Figure 3

Smart Farming Market Share by Product in 2024 (Part 1)



Source : BIS Research, EMIS, Krungsri Research

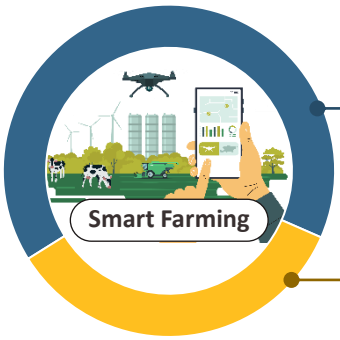
Box 3

Hardware: The hardware component of smart farming includes advanced technologies that boost efficiency and output, as well as solutions like automation and farm machinery control, sensor technology for data collection and analysis, and climate control mechanisms for greenhouse farming. This hardware utilizes key innovations such as IoT, Blockchain, and AI to precisely monitor crops and livestock and improve operational efficiency.

7/ Guidance and Steering Systems: Using navigation and positioning technology, these systems allow for the automated control of machinery, increasing the precision and efficiency of planting, fertilizing, and harvesting.
8/ Agricultural Sensors: These sensors are used to collect and transmit data on soil conditions, weather, pest activity, and plant health. The critical environmental and biological data they provide offers real-time insights, which are essential for making data-driven decisions to optimize crop management and yield.
9/ Displays/Yield Monitors: These devices display various physical properties such as temperature, humidity, pressure, pH levels, and soil moisture. They collect and analyze large datasets and then present this information to the farmer, thereby enhancing agricultural efficiency through precise data management and real-time monitoring.
10/ Include automated harvesters and planters, drones and aerial imaging systems, and feed management systems.
11/ Flow and Application Rate Control Valves: These valves are equipped with control mechanisms to accurately regulate and monitor the flow of liquids. This helps to optimize the use of water and nutrients for plants and animals.

Figure 4

Smart Farming Market Share by Product in 2024 (Part 2)



Hardware 53.1%

- Global market value in 2024: ~ USD **10.7** billion.
- 5-year CAGR (2025-2029): **17.1%** per annum.

Software 46.9%

- Global market value in 2024: ~ USD **9.7** billion.
- 5-year CAGR (2025-2029): **19.9%** per annum.

Farm Operation Management[12/] 53.4%

- Global market value in 2024: ~ USD **5.2** billion.
- 5-year CAGR (2025-2029): **19.9%** per annum.



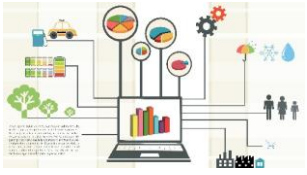
Hardware Control Application[13/] 15.8%

- Global market value in 2024: ~ USD **1.5** billion.
- 5-year CAGR (2025-2029): **18.1%** per annum.



Data and Predictive Analytics[14/] 30.8%

- Global market value in 2024: ~ USD **3.0** billion.
- 5-year CAGR (2025-2029): **19.6%** per annum.



Source : BIS Research, EMIS, Krungsri Research

Box 4

Software: The software component of the smart agriculture market consists of applications and platforms used for farm management, mapping, livestock/feed management, and monitoring crop and animal health, as well as weather conditions. These solutions are accessible via desktop computers, smartphones, and mobile devices, providing farmers with real-time and actionable data.

12/ Farm Operation Management Software: This software has a wide range of functions, including automated farm data logging and storage, monitoring and analysis of farm activities, tracking expenses and revenue, financial management through accounting programs, farm planning support systems, purchasing functions, and marketing tools. Farm management software helps farmers efficiently plan production, farm operations, and daily tasks.

13/ Hardware Control Application: This is a program that manages and coordinates computer devices and other hardware to ensure efficient operation. Examples include software used with hardware that controls fluid systems, or farming robots/drones used for automated tasks like sowing seeds, watering plants, fertilizing, and pest control.

14/ Data and Predictive Analytics Software: This software focuses on analyzing farm data from sensors or farmer-input data, covering variables such as humidity, weather, and water flow. Integrated with Artificial Intelligence (AI) and Machine Learning, this software enables farmers to make informed decisions, conduct predictive analysis, and optimize crop or livestock management processes to mitigate production risks.

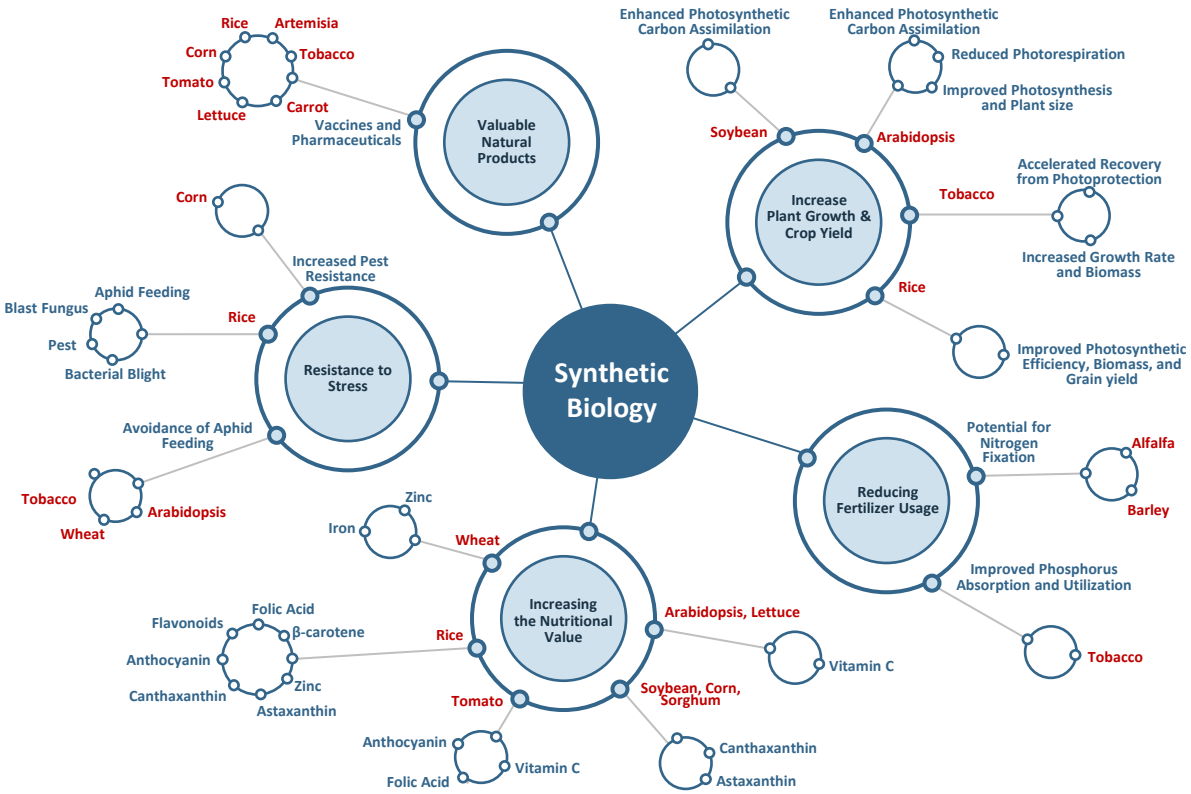
3 **Technologies that Increase Output and Improve Quality Through the Development of New Products:** This involves enhancing quality or creating new products in a lab or through scientific processes to replace traditional, time-consuming production methods. Examples include Synthetic Biology, Cellular Agriculture, and Genetic Modification.

Synthetic Biology Technology: This technology offers several key advantages: 1) it produces higher yields from plants resistant to diseases, pests, and adverse weather; 2) it is resource-efficient and environmentally friendly by reducing the use of fertilizers and pesticides; 3) it expands the market with new products that have increased nutritional value; and 4) it provides raw materials for high-value industries such as the pharmaceutical and vaccine industries (e.g., corn, tobacco, artemisia, and lettuce), the energy industry (e.g., soybeans, switchgrass, sunn hemp, and sugarcane), and the nutritional supplement industry (e.g., rice, wheat, tomatoes, and soybeans) (Figure 5). However, this technology has limitations, including high costs, particularly for research and development, making it difficult for small-scale farmers to access. There are also concerns regarding safety and ethics, as well as the need for appropriate laws and regulations. It also requires highly skilled personnel.

- **Market Value of Synthetic Biology:** Arizton Advisory & Intelligence estimates that the synthetic biology market in the food and agriculture industries was valued at approximately USD 3.7 billion in 2024 and is projected to grow to USD 11.6 billion by 2029, representing a Compound Annual Growth Rate (CAGR) of 26.0% per year. Major players in the synthetic biology industry include Ginkgo Bioworks, Inari, Pivot Bio, Calyxt, AgBiome, Conteva Agriscience, Cibus, Evogene, Demeetra AgBio, and Avalo.

Figure 5

Application of Synthetic Biology in Agriculture



Source : Arizton Advisory & Intelligence, EMIS, Krungsri Research



Current Overview of Thailand's Agricultural Sector

To determine the most suitable approach for the agricultural transformation in Thailand, Krungsri Research utilized a combined SWOT and PESTEL analysis framework. This involved integrating the analysis of 1) Internal Factors, which include Strengths and Weaknesses, and 2) External Factors, including Opportunities and Threats from the SWOT framework. These were then integrated with the environmental factors from the PESTEL framework: P - Political and government policies, E - Economic, S - Social, T - Technological, E - Environmental, and L - Legal. The analysis is presented as follows (Table 1):

Table 1

SWOT and PESTEL Analysis of Thailand's Agricultural Sector

		Positive Factors	Negative Factors
		Strengths	**Weaknesses**
Internal Factors	**Seller (Farmer/ Entrepreneur)**	• Thailand's climate and geographical location are conducive to agriculture, allowing for the cultivation of a wide variety of crops and year-round production. • Thai farmers possess traditional wisdom, local knowledge, and inherited skills, giving certain agricultural products a unique identity.	• Most farmers are smallholders, lacking capital and burdened with high household debt due to high production costs and unstable income/selling prices. • Most farmers lack business and marketing management skills. • Farmer groups and agricultural institutions are not yet strong, and they lack bargaining power or access to markets, leaving them vulnerable to price suppression by middlemen. • The farming population is aging, leading to potential labor shortages. Furthermore, the predominantly elderly workforce has limited access to modern knowledge and technology.
	Buyer (Consumer/ Importer)	• Thai agricultural produce is available year-round and offers a wide variety, providing buyers with extensive choices. • Thai agricultural products have a global reputation for quality and accepted standards. • Thailand is a major producer and exporter of agricultural goods, establishing its image as a reliable source of food security. This builds confidence among buyers and importers in purchasing from the country.	• Concerns over toxic residue from the excessive use of agricultural chemicals. • The quality of produce from smallholder farmers may be inconsistent and lack standardization, leading to varying product quality for buyers. • Selling prices are highly volatile and seasonal, as cultivation is primarily dependent on nature, causing consumers to face frequent price fluctuations.

Table 1

SWOT and PESTEL Analysis of Thailand's Agricultural Sector (Part 2)

		Positive Factors	Negative Factors
		Opportunities	**Threats**
External Factors	**P – Political factors**	• The government, personnel, civil society, and various organizations in the country are highly cooperative and supportive of agriculture, which is favorable for farming and agro-industries. • The government has clear policies and strategic plans that prioritize the development of the agricultural sector, such as policies supporting R&D in smart agricultural technology and policies to enhance production for food security. • There is international cooperation in the exchange of knowledge and technology, which provides opportunities for accessing technology and increasing the capacity of Thailand's agricultural sector. • Many countries worldwide are prioritizing food and energy security, which presents an opportunity for Thailand to increase its agricultural exports.	• Political instability is frequent, impacting the confidence of both domestic and foreign investors and causing a lack of continuity in agricultural-related plans and projects. • Past government policies have focused on a piecemeal approach, failing to be comprehensive and lacking integration across the entire supply chain. • Trade wars and protectionist policies, especially non-tariff trade barriers like cultivation and livestock standards, may increase the costs for Thailand's agricultural sector. This, in turn, impacts the competitiveness and export capabilities of its products.
	E – Economic factors	• The interconnectedness of global markets is causing a corresponding expansion in the demand for agricultural products as a basic consumer good. • Supply chains are becoming more complex and diverse, offering opportunities for agribusiness and agricultural service sectors to expand. Examples include agricultural drone services, soil and water sensors, and online trading platforms.	• Global economic volatility leads to uncertain purchasing power for consumers and importers, which impacts Thailand's agricultural production and exports. • Global agricultural commodity prices are highly volatile, influenced by production costs and factors such as oil, chemical fertilizers, pesticides, transportation, and exchange rates. • Most neighboring countries have lower agricultural production costs and labor wages than Thailand. This has led to an increasing number of foreign investors relocating their production bases to these countries.
	S – Social factors	• Consumers are increasingly mindful of health and wellness trends, leading to higher demand for organic and healthy food products. • Thai cuisine and food culture are gaining global recognition and popularity, increasing the demand for Thai agricultural ingredients and products.	• The growing preference among some segments of the Thai population for foreign cultures and processed foods may decrease the demand for domestic, staple agricultural products. • The number of working-age people in the agricultural sector is declining as workers migrate to the industrial and service sectors. This, coupled with an aging population, contributes to a labor shortage. Additionally, some parts of society hold a negative perception of farming as a profession.
	T – Technological factors	• The global development of new technologies and innovations is improving agricultural efficiency, reducing costs, and increasing yields. Examples include plant varieties that are resilient to adverse weather, automated irrigation systems, soil condition sensors, and agricultural product preservation technologies. • The growth of online trading and e-commerce platforms is expanding, which will help farmers reach consumers directly and easily broaden their customer base.	• Farmers lack access to capital and the knowledge to apply modern technology, which has limited the widespread use of new technologies in the agricultural sector. • Some research and development (R&D) efforts do not address the specific needs or limitations of farmers, most of whom are small-scale operators.
	E – Environmental factors	• Thailand possesses a favorable climate, biodiversity, and environment that are conducive to agriculture. • Thailand has a geographic advantage in terms of transportation and logistics.	• The threat of climate change is leading to more frequent natural disasters, such as severe droughts, flash floods, and erratic seasons. These pose a significant obstacle to agricultural development and directly result in crop damage. • The emergence of new diseases in humans, plants, and animals, such as rubber tree leaf fall disease, cassava mosaic disease, and African swine fever, causes a decline in agricultural output and income while increasing the costs of care and prevention. This significantly limits investment in new technologies. • The overutilization of natural resources is leading to environmental degradation.
	L – Legal factors	• Favorable laws and measures for the agricultural sector, such as GAP (Good Agricultural Practices) standards, Organic certification, GI (Geographical Indication) registration, and carbon credit markets, help producers add value or highlight their agricultural products' unique selling points.	• A lack of legal clarity can halt connections with international markets. • The increasingly strict environmental regulations from trading partners are becoming a significant trade barrier.

Source : OAE, Krungsri Research

Based on the analysis, a multi-stakeholder approach is necessary to accelerate the transformation of Thai agriculture. Key stakeholders, in particular, should focus on the following:

Farmers: From “Traditional Producers” to “Smart Agri-preneurs”. Thai agriculture has several strengths that can be leveraged.

1) **Production:** The focus should be on precision agriculture to reduce dependence on weather, leverage technology to ensure consistent product quality, and elevate products to high-value goods like organic and Geographical Indication (GI) items. This also requires developing products that comply with Good Agricultural Practices (GAP) standards to build consumer confidence.

2) **Business and Marketing:** Farmers must evolve from being mere "producers" into "entrepreneurs" with business acumen in farm management, cost-benefit analysis, online marketing, production planning, and branding. They should also form groups through cooperatives, community enterprises, or associations to strengthen their bargaining power for both purchasing inputs and selling outputs.

Entrepreneurs or Exporters: From “Middlemen” to “Thai Agri-brand Builders”. Thai agriculture has numerous strengths that can be built upon.

1) **Storytelling and Branding:** Thai entrepreneurs can use the strengths of local wisdom and product uniqueness for storytelling. They should highlight organic and GI products that meet GAP and environmental standards and build a recognizable brand instead of just selling undifferentiated commodities.

2) **Platform-based Market Access:** Leverage Social Commerce (e-commerce and social media) to expand sales channels, promote products, and present compelling stories about their products.

The Ecosystem: Achieving Stability and Continuity. This involves creating a stable and continuous environment through: i) Government Policies, formulating policies that promote sustainable development throughout the entire supply chain; ii) Integrated Cooperation, fostering collaboration among government agencies, financial institutions, and the private sector to ensure support is coordinated and moves in a unified direction; iii) Modern and Clear Legislation, updating laws and regulations, especially those related to trade, investment, and import-export; and iv) Accessible Agricultural Technology, providing clear and accessible agricultural technologies to help farmers compete in the global market.

However, the key structural problem that the agricultural sector must urgently address is the lack of business and marketing skills among smallholder farmers. Their limited access to capital and technology is a “critical bottleneck”, preventing most farmers from capitalizing on existing strengths and opportunities. This keeps them trapped in a cycle of debt, high costs, and unstable income. Even with government support, excellent technology, or high-quality products, if farmers remain merely "producers" who wait for middlemen to purchase their goods, they will be unable to fully exploit these opportunities.



Krungsri Research View: How Will Thai Agriculture Embrace Technology?

Given that most Thai farmers are smallholders with limited land and liquidity constraints, they face high production costs, low and uncertain returns, and significant debt. The agricultural workforce is also shrinking due to demographic changes, with the average age of farmers being higher than in other sectors. Therefore, the adoption of highly advanced technologies may not be suitable in the Thai context. Instead, technologies should be "accessible, simple, low-cost, and deliver clear results." Krungsri Research has analyzed the following approaches for guiding the Thai agricultural sector in its transition to modern technology:

1) **Knowledge and Skill Empowerment Technologies:** With Thailand's extensive communication networks and widespread smartphone access, these technologies provide a simple, low-cost channel that supports and facilitates other tasks.

   - **Link > Forming Groups with Communication Technology:** Farmers can use applications such as Line and Facebook to form groups, communicate, share experiences, solve problems collaboratively, strengthen networks, and enhance their bargaining power. For those without access to digital technology, traditional methods–such as cooperatives and village farming groups–remain effective for knowledge sharing and development.

   - **Learn > Learning via Online Platforms:** Platforms can serve as a bridge between farmers and experts or service providers. There are two types: 1) learning platforms (e.g., DOAE e-Learning[15/], TARR[16/], Kaset One Farmer[17/]) which offer video tutorials, modern farming techniques, and channels for expert consultation; and 2) business platforms (e.g., Agri Service Provider[18/], Icon Kaset[19/], ALLRENT[20/]) which provide services like drone spraying, harvesting machinery rentals, and other agricultural services.

   - **Log > Collecting Data for Decision-Making:** The government and other stakeholders can collaborate to develop a database system that supports farmers in cultivation planning. This system should encompass three main types of data: **production factors** (weather[21/], soil and water conditions[22/], pests[23/]), **market information** (agricultural product prices[24/], market demand[25/]), **and knowledge** (cultivation techniques, fertilizer and water management, modern agricultural technology, production standards). This data, gathered from reliable sources, should be analyzed and simplified into easy-to-understand graphs and infographics. This information can then be disseminated through familiar applications like Line[26/] and Facebook[27/]. This approach will help farmers reduce risks in production planning, improve marketing strategies, and make rational decisions based on real data, leading to sustainable farming and stable income.

15/ This platform is managed by the Department of Agricultural Extension, Ministry of Agriculture and Cooperatives. It offers online courses aimed at developing the knowledge and skills of agricultural extension officers and the general public.
16/ This platform is managed by the Agricultural Research Development Agency (Public Organization) or ARDA. It serves as a repository for agricultural research, connecting data from both public and private sector organizations to provide easy access to research and knowledge for interested parties.
17/ This platform is managed by the Ministry of Agriculture and Cooperatives. It is advised and supervised by academics from the Land Development Department who provide guidance to farmers on all aspects, including crop planning, farm plot management, production activity logging, and cost/profit/loss calculation. Agricultural academics or extension specialists provide plot-specific advice.
18/ This platform is managed by the Department of Agricultural Extension, Ministry of Agriculture and Cooperatives. It serves as a database of agricultural machinery service providers and other related service providers nationwide, with the goal of promoting the use of machinery to replace human labor.
19/ This application was developed by Icon Kaset Co., Ltd., a subsidiary of ICP Group, a manufacturer and distributor of fertilizers and agricultural drones.
20/ This platform is managed by CPAC, a subsidiary of SCG (Siam Cement Group). While not directly focused on the agricultural sector, its function as a nationwide hub for renting all types of machinery, including large-scale agricultural machinery like tractors or construction equipment for farming areas, makes it relevant.
21/ This includes daily, weekly, and seasonal weather forecasts, as well as data on rainfall, temperature, humidity, and wind speed, to assist in making decisions about irrigation, fertilization, and preventing damage from natural disasters.
22/ This includes data on soil quality, water sources, and available water volume, enabling farmers to efficiently select suitable crops to cultivate given their available resources.
23/ This involves a notification system for outbreaks in nearby areas, along with information on proper and safe prevention and eradication methods.
24/ This includes current and future price trends for agricultural products at both local and national levels.
25/ This provides data on the overall volume of produce expected to enter the market this year, which helps in forecasting supply and planning production to align with demand.
26/ These can be used to send direct and consistent notifications of important information, such as daily weather forecasts, alerts for disease outbreaks, or weekly summaries of crop prices.
27/ This can serve as a space for knowledge exchange, Q&A sessions between farmers and experts, and for posting educational content in video or image formats.

2) **Value Addition and Market Access Technologies:** Farmers who can utilize communication tools or have sufficient capital for simple processing machinery can leverage technology to add value to their agricultural products and thereby increase their income.

- **Technology for Processing > Basic Processing Technology:** Farmers can apply simple technologies to develop and process their agricultural products. Examples include solar drying, chilling/freezing, pelletizing, and compressing. These processes not only add value but also reduce spoilage, extend shelf life, and facilitate storage and transportation (Figure 6).

Figure 6

Examples of Processed Agricultural Products



Solar Drying

Dried fruit products have a higher selling price than fresh fruit, even though their volume decreases due to water loss. For example, fresh pineapples sell for about 12-13 Baht per kilogram. However, after drying, it takes approximately 10-15 kilograms of fresh pineapple[28/] to produce 1 kilogram of dried pineapple, which can be sold for 250-350 Baht per kilogram. Consequently, drying enables farmers to earn profits 1.5-2 times[29/] higher than selling fresh pineapples.

This is because drying can add value by:

- **Extending Product Shelf Life:** Fresh fruit lasts no more than 1-2 weeks, while dried fruit can be stored for up to a year.
- **Creating New Products:** Fresh fruit is transformed into a healthy snack, which can target the health-conscious market or be sold as a souvenir.
- **Reducing Transportation Costs:** The significant weight reduction makes it easier and more cost-effective to transport the product to distant areas or for international export.



Frozen

Freezing seasonal fruits, vegetables, or meat not only allows them to be sold year-round but also enables export to international markets at a higher price.

Freezing adds value because it:

- **Enables Year-Round Sales:** Products can be processed and stored during peak season to be sold during the off-season, when prices are significantly higher.
- **Opens Up Export Markets:** Freezing preserves quality and flavor, making it possible to transport products by sea or air to foreign markets where demand is high and prices are more lucrative than in the domestic market.
- **Reduces Spoilage:** For produce that is not visually appealing enough to sell whole, operators can cut and freeze only the usable parts thereby supporting a Zero Waste approach.
- **Increases Consumer Convenience:** Some frozen agricultural products undergo preliminary processing, providing consumers with ready-to-eat goods that save them time on preparation or peeling.

28/ In 2025, the price for pineapples for processing was 12-13 Baht/kg, with cultivation costs at 4.5-4.8 Baht/kg. Source: Office of Agricultural Economics.
29/ Based on revenue minus costs, for both fresh and dried pineapples, at a fresh-to-dried processing ratio of 15:1.

- **Traceability > Track and Trace Technology:** Farmers acting as entrepreneurs can implement simple data recording systems, such as QR Codes or Barcodes on their products. This allows consumers to access information on the origin of raw materials, production methods, and product standards, which builds consumer trust, elevates product standards, and increases opportunities to enter new consumer markets.
- **Trade Platform > Online Trading Platforms:** The growing number of online trading platforms provides farmers with easier market access, reducing their reliance on middlemen, offering transparent access to market prices, and enabling them to quickly and widely expand their customer base. In Thailand, several online agricultural marketplaces exist, including DGT Farm[30/], Ortorkor Delivery[31/], Taladkasetronline.com[32/], Thailandpostmart.com[33/], Farmto[34/], DurianTradeX[35/], and Thai Rubber Trade[36/]. Farmers can also utilize social media and popular e-commerce platforms such as Line, Facebook, TikTok, Shopee, and Lazada to promote and sell their products.

  In addition to these marketplaces, the government has developed platforms to facilitate new agricultural entrepreneurs, such as OAE Ag-Info[37/], Farmbook Application[38/], Kaset One Farmer, Biz Portal[39/], and SME One ID[40/]. These platforms enhance transaction efficiency and business matching within Thailand's agricultural ecosystem.

30/ This platform is managed by the National Bureau of Agricultural Commodity and Food Standards (ACFS), an agency under the Ministry of Agriculture and Cooperatives. Its purpose is to serve as a channel for farmers to sell agricultural products that meet established standards.
31/ This platform is managed by the Marketing Organization for Farmers (MOF), a state enterprise under the Ministry of Agriculture and Cooperatives. It focuses on selling high-quality agricultural products from the MOF market.
32/ This platform is managed by the Department of Agricultural Extension, Ministry of Agriculture and Cooperatives, with the goal of helping Thai farmers sell their produce directly to consumers, by passing middlemen.
33/ This platform is managed by Thailand Post Co., Ltd., a state enterprise under the Ministry of Digital Economy and Society. Its key feature is leveraging the postal network for nationwide transportation of agricultural products.
34/ This platform is a startup founded by a group of young farmers who aim to use technology to directly connect producers with consumers.
35/ This platform is a collaboration between Global Multimodal Logistics Co., Ltd. (GML), the Marketing Organization for Farmers (MOF), and DurianTradeX Co., Ltd., to enhance the export of agricultural products, especially durian.
36/ This platform is managed by the Rubber Authority of Thailand (RAOT), a state enterprise under the Ministry of Agriculture and Cooperatives. It serves as a digital channel for rubber trading, enabling fast and convenient transactions while also providing traceability of the rubber's origin to comply with international standards, such as the European Union's EUDR regulation.
37/ This platform is managed by the Office of Agricultural Economics (OAE), an agency under the Ministry of Agriculture and Cooperatives. The platform's objective is to serve as a central source of agricultural economic information and news, and to be used for agricultural planning and decision-making. This includes information on agricultural product prices, agricultural calendars, production and market situation monitoring, warnings, public relations news, and government policies.
38/ This platform is managed by the Department of Agricultural Extension, Ministry of Agriculture and Cooperatives. It is a tool for farmers to register and update their agricultural activities.
39/ This platform is managed by the Digital Government Development Agency (Public Organization) (DGA) in collaboration with relevant agencies. Its purpose is to allow for the online submission of applications for licenses and necessary documents to start or operate a business.
40/ This platform is a collaboration between the Office of Small and Medium Enterprises Promotion (OSMEP) and the DGA. It serves as an identity verification system for entrepreneurs, linking them to various government services.

3) **Smart Farming Technologies for Cost Reduction and Efficiency Improvement:** If farmers can use basic digital technology, as well as small-scale machinery or equipment, or have sufficient investment capital for modern technology, they can apply the following:

- **Manage > Precision Management:** Farmers can utilize basic technologies such as: 1) smartphone applications combined with simple soil testing kits to analyze crop nutrient needs and optimal water levels, providing quick information for immediate problem-solving; and 2) applications or platforms with accurate weather forecasts or information on regional plant disease outbreaks, enabling farmers to prepare and prevent damage in a timely manner, reducing losses and the cost of rehabilitating their plots.
- **Machine > Small-Scale Machinery:** The market now offers an increasing number of small agricultural machinery products tailored for small farm plots, such as walking tractors, tillers, and drones for small-area spraying. These machines are becoming more affordable and offer multiple functions, making them more convenient to use than larger machinery.

The aforementioned approaches demonstrate that a sustainable transformation of Thailand's agricultural sector does not depend solely on expensive technologies. Rather, it must be adapted to the realities of the country's smallholder farmers. The government should serve as a central hub for building a digital agricultural ecosystem that effectively connects farmers to knowledge, information, and markets. The priority is to promote access to technologies that are easy to use, low-cost, and deliver tangible results, whether for learning, data-driven decision-making, or market access. Such measures will help reduce production risks, increase returns, and strengthen long-term livelihood security. Ultimately, the transition to a new agricultural era will only be successful when every farmer can truly utilize technology as a tool to improve their quality of life.

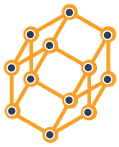


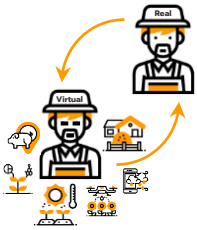
Appendix

Modern Agricultural Technologies

	Definition, Function, and Properties	Strengths and Limitations for Agricultural Use
3D Printing 	3D printing is a process for creating three-dimensional objects based on a digital blueprint. It builds objects layer by layer according to a designed shape. The materials used are fine powders, such as a mix of fruits and vegetables, plastics, or cement.	+ Convenient and Cost-Effective: It allows for the self-fabrication of parts or repairs of agricultural machinery. Materials can also be recycled and reused for new prints. + Product Diversity: It enables the creation of a wide range of agricultural products, such as food for people who cannot eat solid foods, calorie-controlled or vitamin-enhanced foods, agricultural spare parts, and even small-scale tissue printing. – Job Security: A significant concern is the potential for this technology to replace human labor and occupations.
4D Printing 	4D printing is an extension of 3D printing that incorporates the dimension of time. The resulting objects can change their shape under specific conditions, such as vibration, pressure, light, water, temperature, or magnetic fields. This is achieved by designing and programming the material's composition at a nanomolecular level.	+ Self-Adapting and Self-Repairing Devices: This technology allows for the design of devices that can return to their original shape. Examples include water pipes that can expand, contract, and twist, or tires that can change shape to suit different road conditions, whether wet or dry. + Use in High-Risk Areas: It is highly applicable in areas prone to natural disasters or damage, such as regions with high seismic activity, flooding, storms, or conflict zones.
Artificial Intelligent 	Artificial Intelligence (AI) is computer systems designed and developed to demonstrate intelligence in thinking, analyzing, planning, and decision-making. It does this by processing large datasets and can adapt its operations and applications to various situations.	+ Reduces Costs, Increases Production Efficiency, and Minimizes Losses: AI is used in conjunction with other innovations. For instance, it can be installed in drones to survey and collect agricultural environmental data, or used with robots to plant, harvest, and eliminate weeds. – High-level scientific expertise, knowledge, care, and maintenance are required. It also relies on continuous development, high costs, ethical concerns, and potential job displacement.
Big Data 	Big Data refers to massive volumes of data that lack a clear structure, grow rapidly, come in a variety of types, and have not yet been fully processed. In Thailand, this type of data is increasingly used in the agricultural sector-for example, to create a database of Thai farmers that compiles information on the number of households, planted areas, crop types, production volumes, and product prices.	+ Informed Production and Planning: Big data allows farmers to select and plan their production to align with current market situations. + Risk Management: It helps in managing risks related to production, sourcing raw materials, and finding buyers that are suitable for their specific area. It can also be used for analyzing crop insurance premiums. + Empowered Decision-Making: Farmers can access real-time information on true market prices and monitor various situations, such as natural disasters and disease outbreaks. – Long-Term Investment: The initial investment is high, so this is primarily a role for the government to take on. – Data Security: There are concerns regarding the security and proper use of the data.
Blockchain 	Blockchain is a decentralized ledger that allows all relevant parties to access every transaction record. It creates a network in which transactions are recorded in cryptographically secured blocks linked in a chronological chain. This structure makes fraudulent transactions extremely difficult, ensuring a high degree of data reliability.	+ Supply Chain Transparency: It provides transparency in transactions and product traceability, such as managing payments to farmers and tracking the production and transportation paths. + Streamlined Verification: It reduces the time and steps needed for product verification while enhancing food safety standards. + Information Symmetry: It creates information symmetry within the supply chain, particularly concerning product pricing. This reduces the role of middlemen and lowers the overall cost of agricultural goods. – Data Integrity: A key concern is the transparency and origin of the initial data, as this directly impacts food safety and, consequently, consumers and the environment.

	Definition, Function, and Properties	Strengths and Limitations for Agricultural Use
Cultured Meat/ Plant-Based Meat 	Cultured Meat involves culturing stem cells from a model animal in a bioreactor at a suitable temperature, using a culture medium that contains the essential nutrients for cell growth. Different types of meat require specific cultivation conditions. Cultured meat can be produced as beef, chicken, pork, and tuna, but only the muscle tissue portion. Plant-Based Meat, on the other hand, is made from plants, engineered to mimic the appearance, texture, and taste of real meat.	+ Meets Diverse Consumer Demands: Because these products are manufactured in a laboratory setting, they have high and consistent quality and are clean and sterile. They are free from antibiotics and residual animal hormones, and their nutritional value can be enhanced. This makes them ideal for health-conscious consumers and the elderly. + Environmentally Friendly: Production requires minimal land and generates low greenhouse gas emissions. It also reduces animal cruelty, the risk of disease outbreaks, and food shortages caused by natural disasters. – Access to Production: Access is limited by intellectual property rights and the high cost of technology. – Consumer Concerns: There are consumer anxieties regarding the safety and nutritional content of these products.
Drone 	A drone, or Unmanned Aerial Vehicle (UAV), is controlled remotely from the ground or by a pre-programmed flight path. Drones come in various shapes, sizes, and designs depending on their function, such as analyzing soil and farm plots, seeding crops, monitoring irrigation, or assessing plant health by examining leaf color.	+ Versatile Benefits: Their utility depends on their application. They can reduce the need for manual labor in tasks such as seeding or harvesting, cut down on the time required to survey or inspect farm damage, and lower health risks associated with spraying herbicides. + Technological Synergy: Drones can be integrated with other technologies, such as sensors, satellite systems, IoT, and AI. – Adoption Barriers: The factors that currently limit their application in the agricultural sector are the complexity of their use, the cost of the equipment and maintenance, and their overall cost-effectiveness.
Genetic Modification 	Genetic technology, or genetic engineering, involves modifying the DNA or genetic makeup of plants and animals through various processes, such as DNA sequencing, cloning, cisgenesis, transgenesis, and gene inactivation.	+ Increased Resilience: Farmers can cultivate crops that are resistant to natural disasters and environmental limitations, such as floods, droughts, cold weather, and threats from weeds and herbicides. This significantly enhances food security. + Enhanced Traits: It allows for the specific addition of desirable traits, such as increased yield, nutritional value, taste, aroma, color, the ability to be converted into biofuel upon decomposition, protein content, or altered harvest seasons. – Environmental and Ethical Concerns: There are significant concerns regarding the impact on nature, animal welfare, the quality and stability of the products, the effects of consumption, and social acceptance.
Internet of Things - IoT 	IoT refers to the network of electronic devices and objects that can connect and exchange data with one another via the internet. Users can issue commands or link these devices through an internet network to other equipment.	+ Efficiency and Cost Reduction: IoT provides precise, up-to-date data, which reduces costs and the workload of monitoring for anomalies, thereby increasing production efficiency. In agriculture, it is used with tractors, greenhouse temperature sensors, and robots or drones for field work. – Data Security: A key concern is the security and storage of data, which could impact food safety and, consequently, affect consumers and the environment.
Robotics 	Robots are machines that can operate autonomously without human control, running on pre-set programs and integrated with sensors or microprocessors. Their capabilities can be enhanced by integrating them with other IT systems such as AI or satellite technology.	+ Full Production Cycle Integration: Robots can be used at every stage of the agricultural production structure, including planting, spraying herbicides, automated harvesting, packaging, and food transportation. + Key Benefits: Their primary advantages are mitigating labor shortages, reducing production costs, ensuring high safety during production, providing consistent and standardized production efficiency, and saving time. – Job Displacement: A significant concern is their potential to displace human labor. – Legal and Safety Issues: Other concerns include safety and legal liability.

	Definition, Function, and Properties	Strengths and Limitations for Agricultural Use
Nano technology 	Nanotechnology involves creating or analyzing products at a very small scale or adding special properties. For example, it can be used to produce slow-release nano-pellet fertilizers, create improved animal feed that helps reduce diseases, or develop tools for monitoring environmental conditions such as plant growth and chemical residue levels.	+ Innovation and Precision: Nanotechnology offers opportunities for new innovations and enhances the precision of agricultural production. This includes innovations that improve product quality, prevent plant diseases, or detect chemical residues. – High Cost: The initial investment is expensive. – Bio-safety & Bio-security Risks: There are significant safety and security risks, particularly concerning the impact on consumers and the environment due to residue in soil, plants, and animals.
Smart Farming 	Smart farming involves using various technologies to transform traditional farming and livestock raising into a more commercialized operation. It is based on four key components: detection, decision-making, action, and evaluation. These principles are applied in conjunction with technologies such as sensors, GPS, and robotics.	+ Increased Efficiency and Quality: Smart farming reduces time and risk while enhancing production quality and standards. It enables precise, unit-level management, not just for the entire area. For example, if a specific spot lacks water or fertilizer, a farmer can address the issue immediately before the crop is damaged. – Structural Issues: The main limitations are structural, especially concerning education and access to fundamental technologies. This includes a lack of essential infrastructure for communication, satellite systems, robotics, and sensor technology.
Synthetic Biology 	Synthetic biology is a scientific and technological development that uses technical design principles at the molecular level to create new biological systems, such as synthetic bacteria that shorten the production time for certain foods and beverages (e.g., cheese, alcoholic drinks) or improve the disease resistance of agricultural crops.	+ Resource and Cost Efficiency: It reduces the use of resources such as land for livestock, herbicides, and energy, making it more environmentally friendly and affordable. Production becomes simpler while maintaining the same sensory characteristics. – Disrupted Production Chains: The production chain can change as consumers gain the ability to use this technology to produce things themselves. – Bio-safety & Bio-security Concerns: The main limitations are concerns about safety and bio-security, particularly the challenge of managing organisms, as errors could lead to new epidemics. There are also concerns about the impact on the environment, consumers, product quality, stability, and ethical considerations.
Smart Materials 	Smart materials are substances that can change their properties in response to environmental conditions such as pressure, temperature, moisture, pH, electricity, and magnetic fields. While similar to 4D printing, they have broader applications. In agriculture, they can be used for packaging fruits and vegetables to improve preservation and make it easier to monitor food conditions.	+ Enhanced Quality and Standards: They help improve the quality and standards of both production and product sales. + Reduced Food Waste: They reduce food spoilage and waste by allowing both consumers and producers to know the exact condition of the food, ensuring it is suitable for delivery or consumption. When combined with sensor systems, smart packaging can transmit real-time data on product status, including quantity, shelf life, transportation, and market information. – High Cost: They are expensive for products that have a low per-unit value.
Hydroponic  **Aquaponic**  **Aeroponic/ Fogponic** 	Hydroponics is a method of growing plants without soil, where the roots are submerged in a nutrient-rich water solution. This technique can be expanded into Aquaponics, which combines growing plants with raising fish. Fish waste provides fertilizer for the plants, creating a symbiotic relationship. Aeroponics involves growing plants in an air or mist environment without soil. Nutrients are delivered to the roots through a fine mist from nozzles measuring 20 micrometers. Fogponics is a similar technique that uses nozzles producing a mist of 5-30 micrometers. This system enhances the foliar feeding mechanism of plants, as their leaves can absorb particles in the 1–25-micron range.	+ Overcomes Geographical Limitations: These methods allow for precise control of the plant's environment, overcoming limitations posed by geography, such as deserts or areas with unsuitable soil (e.g., highly acidic or saline soil). + Superior Production Efficiency: They yield a greater quantity and higher quality of produce compared to conventional cultivation. + Reduces Resource Use: They significantly decrease the consumption of water, fertilizer, and labor, as well as the time required for land preparation and harvesting. – Requires High Investments: These methods require a much higher initial investment than traditional farming, including sophisticated technology, clean water, controlled greenhouses, and increased electricity consumption. – Demands High-Level Expertise: They require more knowledge, experience, and careful monitoring than conventional farming. This is due to risks that need close tracking, such as waterborne diseases and nutrient levels.

	Definition, Function, and Properties	Strengths and Limitations for Agricultural Use
Augmented Reality 	Augmented Reality (AR) is a technology that overlays 3D objects onto the real world. It operates by using sensors to detect images, sounds, touch, or even smells, then generating a 3D image based on the input. This image is processed by software and viewed by the user through display devices such as mobile phone screens, glasses, televisions, or smart contact lenses.	+ Training and Promotion: AR can be used for training, showcasing, inspecting, or demonstrating products. + Real-World Simulation: It can simulate realities in real-time. For example, it can identify a pest and suggest ways to manage it, or pinpoint defects in plants, animals, or farming plots, such as symptoms of illness or disease. It can also be used to monitor the growth and changes in plants and animals. ■ R&D focus: Its primary application is currently in education, research, and development. – Trust and Adoption: Challenges lie in building trust and gaining acceptance for the innovation's practical application.
Virtual Reality 	Virtual Reality (VR) technology simulates a virtual world separate from the real one, allowing users to interact with these simulated environments through various devices. Examples include flight simulators for pilots, tractor-driving simulators, livestock farm simulations, ecosystem simulations for farm plots or livestock farms, and agricultural training using virtual models.	+ Virtual Prototyping: It enables the creation of virtual prototypes, which reduces the time, cost, labor, space, and resources that would be required to build a physical prototype. + Simulated Field Trials: It allows farmers and researchers to simulate agricultural ecosystems or environments, conducting virtual field trials. This helps them understand the true variables for cultivation without the risk of real-world environmental factors affecting the results. ■ R&D focus: Primarily used for education, research, and development. – Trust and Adoption: Challenges lie in building trust and gaining acceptance for the innovation's practical application.

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