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The Promotion and Industrial Benefits of Smart Agriculture in Taiwan

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ABSTRACT

Facing the dramatic shortages in manpower and the global agricultural issues which impacted on agricultural productivity, the Council of Agriculture (COA) has been promoting the "Smart Agriculture Program" since 2017 to 2022 for developing agriculture by researching and introducing innovative technologies and equipment. The promotion of the Smart Agriculture Program integrated interdisciplinary professional talents of information and communication technology (ICT) industry for agricultural transformation and selected 10 primary industries as main targets for promotion: orchids, seedlings, mushrooms, rice, agricultural facilities, major export crops, marine fishery, aquaculture, poultry and livestock industries. The program aims to draw up R&D course according to each industry's needs through the two principal frameworks of "smart production" and "digital service." It is divided into four dimensions: (1) facility design; (2) field management; (3) production and marketing deployment; and (4) consumer services, forming a loop system of sensing, monitoring, decision-making and automatic feedback. Farmers will be able to select suitable tools that can help them manage with smart tech according to their particular needs. The Smart Agriculture Program has accumulated substantial research results, and the promotion of smart agriculture in one industry from each of the three sectors of crops, fishery, and animal industry is introduced. With the help of smart technologies, digitized production is practiced, and various technologies of monitoring, management and analysis are available to apply precise fertilization and pesticides, so as to achieve efficiency in the use of materials and the quality of agricultural products and environmental friendliness. In terms of production value of the industry, the promotion of smart agriculture has encouraged the farmers to accept the new technologies and to engage in industrial transformation and upgrading to realize the vision of efficiency, safety, and low risk. Moving towards the next phase of smart agriculture, in the pursuit of intelligent production and digitized production and marketing, the focus needs to be on the accurate and effective integration, the use of labor-saving technological products, and the promotion of popular application of achievement results through the ecosystem and agricultural service mechanism.

Keywords: smart agriculture, smart production, digital service, artificial intelligence, human-machine collaborative device, common information platform, Internet of Things(IoT), big data, expert system

INTRODUCTION

In recent years, Taiwan's agricultural employment population (Statistical data by Statistics Office, 2022) has decreased from 730,000 in 2000 to 550,000 in 2016, indicating a reduction of 25%. The population of agricultural workers over the age of 65 has also risen from 10% to 17% and the average age risen from 61.2 to 63.5. Agricultural manpower is in a large shortage and there is a gap of passing down of experience and knowledge, so that the agricultural productivity is seriously affected. Taiwan also has faced the global agricultural issues such as climate change, arable land scarcity, water shortage and food security, *etc.* One of the ways to mitigate the impact on agricultural productivity is by developing and

introducing innovative technologies and equipment. Precision farming technology roadmap 2010-2030 mentioned that automation and robotics, imagery and sensors, big data and digitalization, and bioengineering will be crucial to agriculture in the years ahead (Islamic Development Bank, 2020).

Taiwan's information and communication technology (ICT) industry is technologically mature and has global advantage. To integrate interdisciplinary professional talents for agriculture transformation, the "Smart Agriculture Program" has been implemented by the Council of Agriculture (COA) since 2017 to 2022, which is now a part of the "New Agriculture" in the "Industrial Innovation 5+2 Policy." There are 10 primary industries selected as main targets to be implemented based on the market scale, higher demand, willingness and acceptance for industrial upgrading, higher competitive advantages, and opportunities for turn-key transfer. These industries include orchids, seedlings, mushrooms, rice, agricultural facilities, marine fishery, aquaculture, poultry and livestock and industries of the major export crops, which could be divided into 2 major categories: protected cultivation and open field cultivation.

The program aims to draw up R&D course according to each industry's needs through "smart production" and "digital service", the two principal frameworks. Three major strategies are implemented: (1) promotion by the Smart Agriculture Alliance of the development and application of key technologies for smart agricultural production to establish an agricultural productivity knowledge and service support system; (2) development of diversified models of digital agricultural convenient service and value chain integration by integrating information technologies; and (3) enabling a new communication mode between producers and consumers with humanized interactive technologies.

Through the research and development of smart production and management, small farms are saved from low efficiency in separated operation and assisted to pursue high efficiency and productivity, and through the use of Internet of Things (IoT) and big data technologies, an active all-round agricultural consumption/service platform can be built to meet the needs of all agricultural stakeholders and increase consumers' trust and confidence in the safety of agricultural products. At the same time, a common information platform is built to serve as the platform for the storage, analysis and application of huge amounts of information for the pioneering industries, with the hope that key technologies of smart agriculture can be independent and localized to help develop startups on agricultural services. The use of smart technologies is also hoped to help develop a high-quality agricultural environment of an operation model that saves labor, reduces costs, and achieves higher efficiency, to develop high international competitiveness in the pursuit of efficiency, safety and low risk.

Promotion of agricultural transformation and upgrading in key industries

The Smart Agriculture Program is promoted to construct systems of the smart production and marketing and the digital service. It is divided into four dimensions: (1) facility design; (2) field management; (3) production and marketing deployment; and (4) consumer services (Figure 1), forming a loop system of sensing, monitoring, decision-making and automatic feedback. With the application of big data analysis technologies on the common information platform, big data information is accumulated from the sensing systems of the environment and crops, and through integrated IoT control modules, combined with two-way man-machine collaboration with smart tools such as robotic arms, drones, etc. and then analyzed and compared by the expert system of agricultural technical parameter management module. The results are used as the basis for decision-making such as crop quality control, pest control, external risk warning, greenhouse environmental control, cultivation and nutrition management, and yield estimation. Furthermore, complete systems of traceability and notification services are built between the two ends of production and marketing and consumption, so that the information of the agricultural products (production, transportation and marketing, nutrition, etc.) is effectively released through a humanized interface. The producers also receive feedbacks of the analysis of consumer habits and trends of consumption. Producers will be able to select suitable tools that can help them manage with smart tech according to their particular needs.

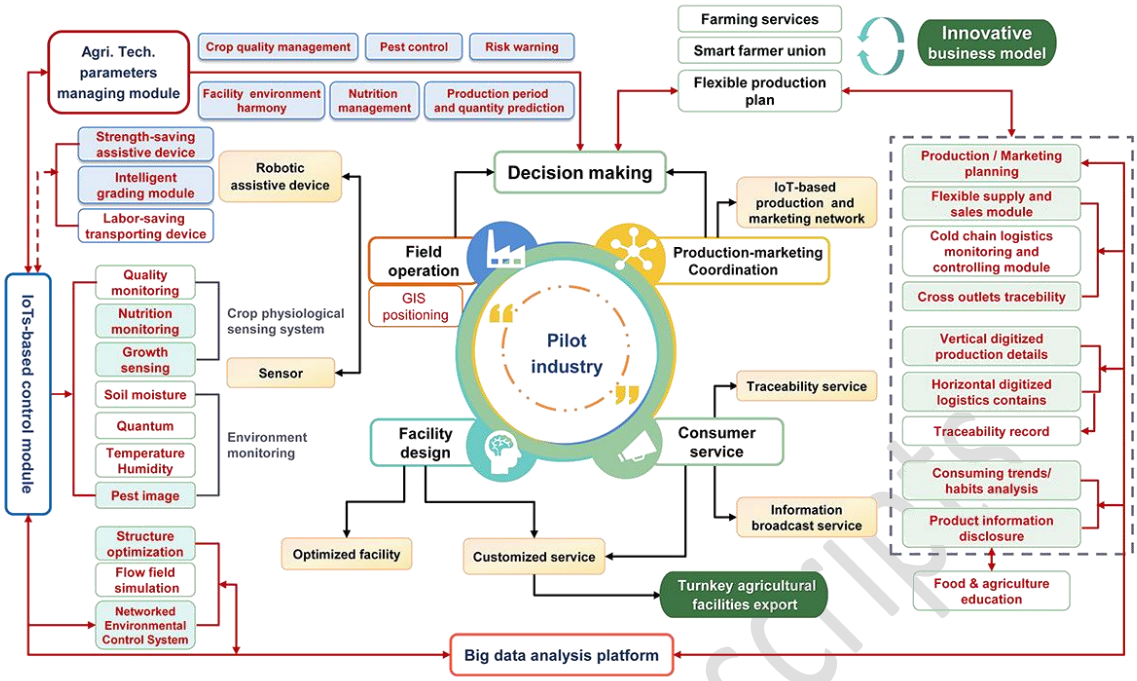

Figure 1. Construction of cross-domain key technologies—a framework of smart production and digital service industries

Among the 10 industries selected as leading industries in the Smart Agriculture Program based on conditions of demand of the industries, opportunities of technology introduction, and competitive advantages, industry needs, introduction opportunities and competitive advantages, each has its special attributes, problems, and therefore, various focuses of development. In the next section of the paper, the promotion of smart agriculture in one industry from each of the three sectors of crops, fishery, and animal industries is introduced.

(1) Crops: The mushroom industry serves as an example here. Faced with problems such as labor shortage, low production efficiency, and lack of integration of production systems, which result in uneven quality, this is an industry that urgently needs transformation to form a new smart mushroom supply chain that improves the production model in terms of field management and facility design. Through the promotion of the Smart Agriculture Program, on the dimension of production, the liquid inoculation technologies are applied in conjunction with the energy-saving equipment and smart environmental control to reduce costs and improve efficiency, and on the dimension of management, the full environmental control cultivation system is integrated with IoT sensing technologies and connected to the Enterprise Resource Planning (ERP) system to make production scheduling and decisions on order management, so that production and sales can be more flexible. Digital management helps enhance product specifications and quality. The future plan is to further explore and enhance the big data system to build an intelligent expert system for precision cultivation and stable production.

(2) Fishery: Take the aquaculture industry for example. The industry now faces the high reliance on labor power and experience, rapid weather changes and high risks. The focus of development is the sensing application of field management to reduce labor cost and reduce risks of operation. At present, image recognition technologies have been used in field management to monitor the feed intake of the fish, to determine their energy, and to apply adequate amount of feed to minimize wasted feeds. Sensory monitoring equipment connected to the Internet of Things is used to monitor water quality and pathogens. A smart handheld pathogen detector can detect the quality of aquaculture water to provide real-time warnings to minimize losses. A digitized expert system of production experience is developed to provide reference in decision making. And, in order to open up diversified channels for export and to link production and sales, a certification system is being developed to assist aquatic products with international certification.

(3) Animal industry: The example used here is the dairy industry. Dairy farms in Taiwan also face problems such as the heavy reliance on labor. The production management is mostly done with records on paper, which make it difficult to analyze and interpret. The focus of development now

is the application of smart machines for field management. Intelligent robots are now introduced into the five major daily workflow lines of cattle (milking, feeding, cleaning, health care and delivery). Take the smart milking robot as an example. Before milking, it can judge the health status of the breasts and the milk quality and yield. This controls the quality of the milk collected, increases the number of times of milking and milk volume, and enhances production efficiency and reduces the time of manual milking. Further applications will be developed for assistive devices for health care and delivery care of the cattle.

Through the promotion of smart production and digital services and with the integration and application of information and communication technologies, agriculture is systematized from production, marketing to consumer markets. With digitized knowledge, automated production, optimized production, convenient operation, and the cloud-based traceability system, the upgrading and transformation of industries is enabled and new industries related to smart agriculture can be developed such as agricultural knowledge service industry and intelligent agricultural machinery, creating a new agricultural context.

Realization of the social and economic value of agriculture

As the first phase of the Smart Agriculture Program will be completed in 2022, there is great interest in observing the contribution of the scientific and technological achievements of smart production and digital services to the overall social agricultural economy. The effort of promotion in the first three to four years has been focused on research and development related to smart production, such as labor-saving and energy-saving automation and smart machinery or technologies. The technology readiness levels (TRL) (Government of Canada, Innovation, Science and Economic Development Canada, 2018) of the 10 leading industries indicate that most of those industries have reached TRL 4 or higher with the technical levels they developed (Table 1). That is, they have gone out of the laboratory for actual testing in the field and have laid the foundation for subsequent materialization and commercialization of the products.

Table 1. TRL of related achievements of Smart Agriculture Program

Technology Readiness Levels TRL			Technical achievements
Research	**TRL 1**	Basic principles of concept are observed and reported	• Intelligent orchard management technology for pineapple
	TRL 2	Technology concept and/or application formulated	• Prediction model of pineapple fruit storage and transportation period • Improvement and application of passenger type crawler self-propelled tea picking machine
	TRL 3	Analytical and experimental critical function and/or proof of concept	• Expert system of environmental control agriculture.
Development	**TRL 4**	Component and/or validation in a laboratory environment	• Basic breeding environment parameter database and intelligent expert knowledge base for aquaculture • Chicken voiceprint recognition and marking system
	TRL 5	Component and/or validation in a simulated environment	• Automatic monitoring trap for *Spodoptera litura* • Intelligent LED squid fishing light and cloud expert system • Surface unmanned vehicle monitoring technology

Technology Readiness Levels TRL			Technical achievements
	TRL 6	System/subsystem model or prototype demonstration in a simulated environment	• IoT system for pineapple orchard • Pineapple fruit washing and selecting system • Insects monitoring system for paddy field • Robot loading/unloading system for rice seedling tray • *Pomacea* clear machine • Intelligent monitoring and cloud management platform for rice • Ride-on picking machine for tea • Expert decision-making system for tea trade • Development of automatic fish sorting, arranging and transporting system • Image identification technology in cage culture • Intelligent Mobile Working Robots for Poultry Farms • Chicken thermal imaging and visual recognition system • Poultry farming big data system
Deployment	**TRL 7**	Prototype ready for demonstration in an appropriate operational environment	• Light supplement and labor-saving equipment for orchids • Automatic loading and unloading of mushroom bags • Intelligent irrigation system for rice • Rice seedling allocation trading platform • Intelligent management system for greenhouse production • Automated insect pest monitoring and analysis • Harvesting date, yield prediction and fertilization recommendation system in Iceberg lettuce production • The farm management information system of lettuce industry • Multifunctional field management machine for edamame production • Underwater 3D image recognition technology to measure fish body length • The intelligent feeding system in cage culture • Intelligent breeder selection system for chicken breeding • Expert system for dairy cow by robot service

Technology Readiness Levels TRL			Technical achievements
			• Pig house environmental parameter sensing data integration system
	TRL 8	Actual technology completed and qualified through tests and demonstrations	• Facility to improve cut flower for orchid production • Leafy vegetable harvester • Leafy vegetable transplanter • The remote-control system in the seedling Industry • Intelligent vegetable seedling production and sale management system • Harvesting system for mushroom production • Precise environmental control system of Mushroom cultivation • Intelligent insect-control equipment in rice warehouse • Mounted video assistance system for edamame harvester • Unmanned aerial vehicle sprayer for tea plantation • Automatic drip irrigation system for tea plantation • Multiple automatic detecting system device for marine vibrio • Recognition technology for fish body length • Breeder monitoring and management system • Identification and weighing system for breeding duck • Chicken poultry automatic cutting equipment
	TRL 9	Actual technology proven through successful deployment in an operational setting	• Mushroom liquid fermentation and inoculation system • Domestic packing machine for mushroom

To further elaborate the overall value and achievement of implementing the Smart Agriculture Program, this section reviews the achievement of the industries in the sectors of crops, fishery, and animal industry from 2017 to 2020 in the aspect of industrial economy and that of society and policies. Among them, the aspect of industrial economy comprises R&D technology transfer, building of demonstration site, promotion of investment, establishment of innovative industries or models, *etc*. The aspect of society and policies covers reducing production costs, increasing farmers' employment, improving energy and resource efficiency, energy conservation, and other items that are related to the maintenance of social welfare and sustainability.

(1) In terms of the social and economic benefits of pilot industries in the sector of crops, such as orchids, seedlings, mushrooms, rice, agricultural facilities, and industries of the major export crops, the Smart Agriculture Program have provided substantial support for intelligence development to the industries, which, due to climate change and the reduction of rural populations, are faced with problems of labor shortage, high costs for production and collection, difficulties in standardization of agricultural equipment, difficulties in quality control, unstable sales channels, *etc*. In general,

the sector of crops has attained considerable achievements in technology transfer, technology licensing and derivative benefits, demonstration site construction and testing services. With the proliferation and application of R&D achievements, various types of investment benefits such as R&D, production, and new ventures are produced every year. In 2019, the investment amount has hit a record high as the industries of orchids, seedlings, mushrooms, rice, agricultural facilities, and industries of the major export crops established new plants and expanded facilities, and upgraded their equipment. Take the mushroom industry as an example. The operators invested to introduce automation equipment, build smart production modules, and conduct more effective production and operation through scientific management. In addition to solving the problem of labor shortage, it also reduced costs, raised efficiency, promoted the transformation of the mushroom farming industry, and drove the overall competitive advantage. The sector of crops as a whole, due to technological innovation, has increased the output value and reduced costs, helping farmers to enjoy high income from the contract year by year. Besides, there was a reduction of energy consumption for over 40% due to the reduction of carbon dioxide emissions.

(2) In terms of the fishery sector, including industries of aquaculture and marine fishery, the problems and risks faced by the aquaculture industry include the impact of environmental changes, climate disasters, diseases, etc. and the marine fishery industry is bothered with the high costs, labor shortage, and the energy consumption of fishing gear. To solve the problems, the support of the Smart Agriculture Program is mainly directed to the systematic R&D in the automation and systematic development of the industries. Based on the achievements of the R&D technology transfer and the establishment of innovative industrial development models, the R&D investment results have been manifested in the fishery sector since 2018. Among them, the marine fishery industry has attracted investments in the smart technology of LED fishing lamps. Furthermore, the smart cage culture system developed by the aquaculture industry has taken advantage of the added value and support of ICT to establish a standardized operation process, which, through the innovative function of aquaculture traceability, manages the automatic monitoring and catch the traceability. This system significantly saves labor, reduces feed costs, and also brings about the benefits of improving energy efficiency rate and saving energy consumption by more than 10% per year.

(3) As for the social and economic benefits of poultry and livestock industries in the sector of animal industry, the problems faced include the aging of the practitioners, labor shortage, and difficulty in livestock information collection. In order to overcome the problems of labor shortage in the dairy industry and the lack of integration of information of water usage and electricity consumption in cattle raising, the Smart Agriculture Program has made substantial investment in the introduction of smart R&D and digital services at the demonstration site. In summary, the benefits for the animal industry sector are mainly manifested in the investment on R&D and production, and in the establishment of innovative industrial development and business models, bringing substantial benefits. An average of five cases of investment is achieved per year. In the dairy industry, using intelligent robots into the five major daily workflow lines of cattle (milking, feeding, cleaning, health care and delivery) has successfully saved labor and reduced costs but increased production with technological innovation and improvement. The energy efficiency rate has been lifted by 20% per year.

In the past, farming relied a lot on climate factors. With the help of smart technologies, digitized production is practiced, and various technologies of monitoring, management and analysis are available to apply accurate fertilization and pesticides, so as to achieve efficiency in the use of materials and the quality of agricultural products and environmental friendliness. In the face of climate change, precautionary mechanisms can be established to minimize losses and risks. In terms of production value of the industry, the promotion of smart agriculture has encouraged the farmers to accept the new technologies and to engage in industrial transformation and upgrading to realize the vision of efficiency, safety, and low risk.

CONCLUSION

Since the start of the Smart Agriculture Program in 2017, through the introduction of smart agriculture in different links of the agricultural industry chain, the application of technologies towards smart development has shown results. Multiple industrial benefits are manifested, not only through the development of labor-saving and time-saving machinery and remote monitoring and expert systems and other innovations to enhance the advantages of agricultural science and technology, but also through certifying demonstration sites, guiding farmers to adopt intelligent technologies, systems or products,

promoting innovation and development, value-added sustainable operation, and catalyzing new innovations in agricultural services. As for the future development of smart agriculture, the solid foundation laid in the first phase needs to be further applied in the future to complete the work in the last mile. Besides, with the emerging technologies introduced, the needs of the consumers must be taken seriously to realize the application benefits and added values of the agricultural value chain of production and sales.

Therefore, moving towards the next phase of smart agriculture, in the pursuit of intelligent production and digitized production and marketing, the focus needs to be on "the accurate and effective integration of a variety of agricultural knowledge and technologies for R&D and application", "the use of labor-saving technological products to fill in the gap of labor shortage", and "the promotion of popular application of achievement results through the ecosystem and agricultural service mechanism." What needs to be planned for includes the development of assistive equipment, construction of expert systems, digital service applications, farming operation support and their integrated applications and the technological innovation. This will benefit the promotion of smart agriculture in the future, to achieve the strategic goals of information sharing in the production and marketing chain and intelligent value enhancement.

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AUTHORS' CONTRIBUTIONS

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COMPETING INTERESTS

The authors declare no conflicts of interest.