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Analysis of the Present Status and Future Prospects for Smart Agriculture Technologies in South Korea Using National R&D Project Data

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ABSTRACT

Food security and its sovereignty have become among the most important key issues due to changes in the international situation. Regarding these issues, many countries now give attention to smart agriculture, which would increase production efficiency through a data-based system. The Korean government also has attempted to promote smart agriculture by 1) implementing the agri-food ICT (information and communications technology) policy, and 2) increasing the R&D budget by more than double in recent years. However, its endeavors only centered on large-scale farms which a number of domestic farmers rarely utilized in their farming. To promote smart agriculture more effectively, we diagnosed the government R&D trends of smart agriculture based on NTIS (National Science and Technology Information Service) data. We identified the research trends for each R&D period by analyzing three pieces of information: the regional information, research actor, and topic. Based on these findings, we could suggest systematic R&D directions and implications.

Keywords: smart agriculture, national R&D project, R&D policy, R&D trend, NTIS data

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1. INTRODUCTION

Food security and its sovereignty are becoming more important than ever in terms of national security because of changes in the international situation, including trade disputes, disasters such as COVID-19, and climate change. Accordingly, countries around the world are paying attention to smart agriculture, which can respond to risks and solve current issues, such as climate change, demand diversification, farm labor shortages, and deterioration of supply and demand for agricultural products. As well, they are striving to establish a flexible and stable agricultural production system.

Smart agriculture promotes smartization by converging advanced ICT (information and communications technology) throughout the agricultural value chain, including seed development, production, management, processing, distribution, and consumption. Unlike conventional agricultural methods, smart agriculture, which applies advanced technologies such as IoT, robots, drones, and artificial intelligence, remotely monitors agricultural products, optimizes manpower and resources, and increases production efficiency through data-based decision-making (Yoo & Yeo, 2021). The smart agriculture market is growing rapidly due to the increase in food demand according to population growth. Additionally, the demand for productivity improvement due to the decrease in cultivated land is accelerating the growth of this market (Jang & Kim, 2019). The smart agriculture market is expected to reach $20.7 billion in 2026 from $12.3 billion in 2020, growing at a compound annual growth rate (CAGR) of 10.1% due to the U-shaped recovery after the pandemic (MarketsandMarkets, 2021).

In response to market growth, a large number of R&D projects for smart agriculture also have been carried out in South Korea. To conduct these projects successfully, the Korean government has attempted to establish step-by-step policies as a way to solve current agricultural problems and increase productivity. In 2013, MAFRA (Ministry of Agriculture, Food and Rural Affairs) drew up the *ICT Convergence Expansion Plan* (Ministry of Agriculture, Food and Rural Affairs, 2013). The basic outline of the agri-food ICT policy was to 1) develop and spread the agri-food ICT convergence model, 2) improve productivity and reduce manpower, 3) create an agri-food ICT ecosystem, and expand basic infrastructure. To enhance these plans, the *Smart Farm Expansion Plan* was accordingly issued in 2018 (Joint Ministries, 2018). The government selected smart farms as eight leading tasks for innovative growth. In this process, they promoted 1) the creation of a smart farm innovation valley, 2) securing high-quality data, and 3) spreading smart agriculture centered on controlled horticulture and livestock farms.

However, by focusing on the R&D centered on horticulture and livestock farms, and policies centered on large-scale farms, most small-scale farms are not introducing smart agricultural technologies because of their financial burden. In addition, various other issues had also been raised; for instance, the lack of acceptability of farms, insufficient adoption of smart agriculture centered on small businesses, and insufficient agricultural data integration. In response to the need to expand a policy that could solve the issues derived from current domestic agriculture, the Korean government implemented *the Comprehensive Measures for Spreading Smart Agriculture Based on Big Data and Artificial Intelligence* in December 2021 (Joint Ministries, 2021). The policy target was expanded to all fields of agriculture, from controlled horticulture and livestock farms to outdoor agriculture, and not only ICT equipment (HW) but also big data and artificial intelligence (SW) aspects were strengthened. The policy also encompasses forward and backward linkage such as processing, distribution, equipment, and materials, as well as production. This process can promote the cultivation of human resources such as youth farmers, research and industrial manpower, and existing farmers.

In response, it is necessary to identify whether previous R&D research trends could align with policies issued in 2021. Agricultural R&D requires a longer period of technology development compared to R&D in other fields because it has several characteristics such as a public nature, uncertainty, non-exclusivity, and locality (Lee, 2013). In addition, there is a unique mechanism called a guidance system that transfers R&D research results to the agricultural field. This mechanism has brought difficulty where the speed at which new technology trends are reflected is slower than for other fields (Yun et al., 2020).

However, to identify the research trends for smart agriculture, previous studies have tended to focus on research and technical reports rather than project data (Lee & Kim, 2021; Yeo et al., 2016). A few of the researchers attempted to analyze the characteristics of projects through research project data (Kim & Kim, 2021; Yun et al., 2021). There were some limitations that these studies rarely considered: 1) different aspects of information, and 2) the research period. To overcome these limitations, we propose a stepwise approach to identifying the research trends for smart agriculture systematically. We analyzed three types of project information that have unique implications for research trends respectively. In addition, to diagnose the previous technology trends for smart agriculture, we analyzed the R&D trend by classifying national R&D projects into three phases in consideration of the government's mid-to-long-term policy. Based on these results, the R&D direction and implications of smart agriculture are suggested for the Korean government and related stakeholders.

2. LITERATURE REVIEW

2.1. Smart Agriculture

Agriculture is one of the most important fields for every country. To maintain the competitiveness of these technologies, there is a great need for introducing a new paradigm of agriculture. Among these, many people pay attention to smart agriculture to increase agricultural productivity. As ICT converged with agriculture, the academic literature and mass media stated several terms such as smart agriculture, digital agriculture, and e-agriculture. Although they were used interchangeably, these terms could be distinguished according to the scope of integration of ICT into agriculture (Yoo & Yeo, 2021). For instance, one of the most common terms was *precision agriculture* when discussing operations at the farm level. In Gebbers and Adamchuk (2010), precision agriculture was defined as comprising a set of technologies that combined sensors, information systems, enhanced machinery, and informed management to optimize production by accounting for variability and uncertainties within agricultural systems. Smart agriculture is more intensively integrated ICT into the agricultural value chain, including production and distribution. In KPMG (2020), smart agriculture is defined as applying state-of-the-art ICT throughout the business value chain to implement automation and intelligence for the farming process.

Smart agriculture could offer opportunities to solve the faced challenges of previous cultivation. First, climate change could reduce agricultural productivity (Porter et al., 2014; Vermeulen et al., 2012). Particularly, global warming has caused negative effects on stabilized crop growth. Moreover, many old processes for agriculture have generated large amounts of greenhouse gas. Hence, it is necessary to revise the out-of-date process in agriculture (Dinesh et al., 2018). In addition, by 2050 agricultural systems will need to enhance food production by more than 60% due to the rapid increase of population (Alexandratos & Bruinsma, 2012). To overcome these issues, various experts have suggested smart agriculture as an alternative farming process. These digitalization processes could relieve the effect on the environment by controlling agricultural by-products. Moreover, smart agriculture is also influenced by external influences such as human error and climate change, and so smart agriculture could assure the amount of output. For this reason, government officials have attempted to supply digitalization tools such as farm management advice to smallholders (Birner et al., 2021). Therefore, smart agriculture is the appropriate solution that could enhance food security as well as reduce greenhouse gas emissions by integrating ICT into cultivation (Issad et al., 2019). This means that research on smart agriculture could have valuable implications for food security and its sovereignty.

2.2. Research Trend Analysis for Smart Agriculture

Research in the agricultural sector requires a longer period of technology development compared to research in other fields. Its characteristics, especially the nature of publicity, uncertainty, non-exclusivity, and regionality, interrupt setting clear development directions and the following of them. Therefore, it has taken a long time for the new technologies, which were the results of R&D research, to be disseminated to the agricultural field. Accordingly, it was necessary to identify research trends and limitations for agricultural R&D and thereby establish the policy direction depending on the situation. For instance, Yeo et al. (2016) briefly introduced domestic and international research trends and core technologies based on ICT to materialize smart agriculture. Lee and Kim (2021) also analyzed the research on ICT-agriculture convergence through literature and expert opinions. These studies tended to present solutions to the limitations of ICT applications by relying on technical reports with expert opinions.

In response, a few of the studies analyze the characteristics of R&D project data (Kim & Kim, 2021; Yun et al., 2021). For instance, Kim and Kim (2021) examined agricultural research trends by analyzing keywords of the research based on NTIS (National Science and Technology Information Service) data. This study looked at past research trends and thereby has significance as a basic study for establishing agricultural R&D strategy, but the authors only analyzed keyword data with an overall dataset. In this study, changes in research trends over time were examined in consideration of the mid-to-long-term policies announced by the government. Based on these results, our research would suggest research strategies for smart agriculture.

3. METHODS

3.1. Data Acquisition and Project Classification

We utilized NTIS data to investigate the government's smart agriculture R&D investment status and R&D research trends. NTIS provides detailed information on national R&D projects, such as R&D projects, tasks, research expenses, research actors, research fields, and application fields, so that R&D trends can be understood from an overall perspective. The data collected by NTIS was limited to smart agriculture in the production stage, and a total of 4,935 national R&D projects were derived from 2012 to 2020 through a search formula that reflected the opinions of experts. According to the scope of application in the field, detailed technologies were classified into infrastructure, outdoor agriculture, and facility agriculture, excluding livestock.

In addition, we classified the R&D projects into three phases. Among various research policies for smart agriculture, two ICT-based policies mainly influenced the direction of smart agriculture research. First, the *ICT Convergence Expansion Plan* was implemented in 2013. This plan set the first outline regarding the convergence between ICT and agriculture. Second, in the *Smart Farm Expansion Plan* (2018), the government focused more on Smart Farm systems which could cover facility agriculture with infrastructure. Many research projects were planned after the execution of a policy, so the impacts of policies tended to appear a few years later. However, the *Smart Farm Expansion Plan* was designed as a follow-up policy, since the Korean government selected smart agriculture as one of the innovative growth technologies in Korea. Accordingly, we suggest three time periods for smart agriculture as follows: Phase I (2012-2014), Phase II (2015-2017), and Phase III (2018-2020).

3.2. Analysis

After the classification, we calculated the descriptive statistics of national R&D projects. We carried out three types of analysis: 1) frequency analysis, which counted the R&D projects included in a specific category; 2) R&D budget analysis, which calculated the sum of the weighted R&D budget for each project; and 3) topic analysis, which counted the number of topics/keywords included in a specific time phase.

Firstly, we analyzed the number and scale of projects per year. The growth of national investment in smart agriculture projects would fluctuate with the ICT-agriculture policy. These changes indicated the level of interest in smart agriculture fields from the Korean government and related stakeholders. In addition, many policymakers also considered regional factors, because the farming and related works were influenced by the environment and culture. We also analyzed the R&D budget in regional R&D projects by investigating the regional characteristics of R&D in the agricultural sector.

Then, we investigated the research actors for national R&D projects. Various actors have different goals for research, so their research directions and expected outcomes also were varied. For instance, universities usually concentrated on developing theoretical backgrounds, whereas commercial enterprises attempted to turn their research into businesses by providing the latest technologies of smart agriculture. We largely classified the research actors as industries, universities, research institutes, and government, and counted the number of projects in a specific category for each phase. Based on these results, we endeavored to identify the research interests of actors which could be strongly influenced by their positions. These interests in a specific period also represented the trends of national R&D projects.

Lastly, we extracted the core fields of smart agriculture with topic and keyword analysis. To understand the main topics and the purpose of projects, the topics covered by R&D projects were analyzed. In South Korea, it was emphasized that six technology fields will raise national competitiveness in response to globalization. Thus, we classified the projects using the 6T (IT [Information Technology], CT [Culture Technology], BT [Bio Technology], NT [Nano Technology], ST [Space Technology], ET [Environment Technology]) classification in South Korea. Then, we analyzed the keywords for each project to concrete research topics and core fields in each phase. In this process, we extracted *frequent keywords* if the number of keywords was more than a threshold value. In addition, we also selected *interesting keywords* which seemed to be significantly important by the proportion of keywords regarding the time phase. The history of core issues could strongly reveal the trends of national R&D projects which would denote more specific directions and implications for advanced smart agriculture.

4. RESULT AND DISCUSSION

4.1. R&D Budget

4.1.1. Overall

To analyze the trends of national R&D projects concerning smart agriculture, we calculated 1) the number of projects and 2) the scale of the R&D budget. We gathered the information of selected projects from NTIS data which could provide the latest information on national R&D projects in Korea. The result is shown in Fig. 1.

According to Fig. 1, both the number and budget of national R&D projects have steadily increased. The R&D budget in the smart agriculture field tended to be steadily increased, and it has been dramatically increasing over the past three years. The amount of investment increased from 38,533 million won in 2012 to 112,920 million won in 2020, with a CAGR of 14.38%. The number of R&D projects decreased slightly in 2016, but it has risen rapidly since 2018. This is because many researchers launched various fresh projects dealing with data analysis and metadata implementation. In particular, many projects were also started to research agriculture data platforms in connection with the Smart Valley project in Korea. Hence, the R&D budget per project also increased significantly in Phase III.

4.1.2. Regional Distribution

Then, we analyzed the regional distribution of the R&D projects for smart agriculture. We classified the R&D project according to 17 provinces (including eight metropolitan cities) in Korea. The descriptive statistics in Table 1 were calculated as the cumulative sum of the results generated by the R&D projects conducted in a certain region.

As shown in Table 1, Jeollabuk-do has been the most invested among all provinces regarding the R&D budget for smart agriculture. In Phase III, Jeollabuk-do dramatically increased the R&D budget. Since 2018, various smart farms and their related infrastructures were created in Gimje under the Smart Farm Innovation Valley Project. This project aimed at establishing industrial infrastructure through ICT equipment standardization, big data analysis, and smart agriculture R&D processes. Gyeongsangnam-do and Jeollanam-do also increased the R&D budget after 2018 for a similar reason. Gwangju also increased the R&D investment regarding smart agriculture, because

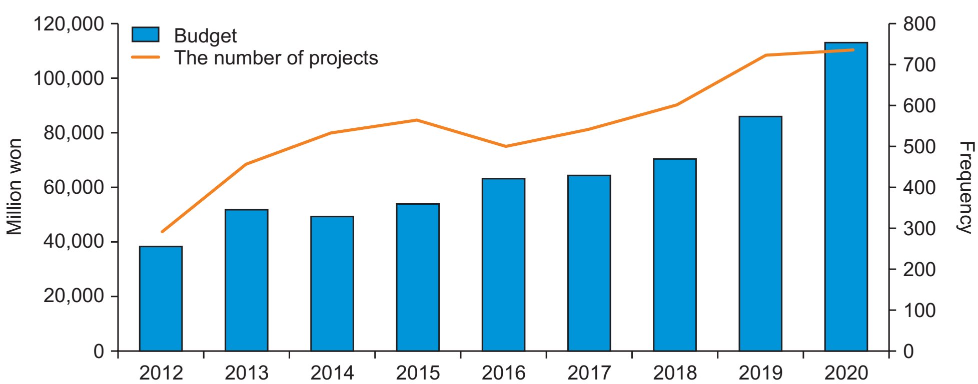

Fig. 1. Descriptive statistics of National R&D projects for smart agriculture.

Table 1. Result of regional R&D investment analysis (representing only top 10 provinces)

Provinces	Phase I	Phase II	Phase III	Total
Jeollabuk-do	283.44	293.91	604.65	1,182.00
Gyeonggi-do	354.37	315.59	271.57	941.53
Seoul	185.56	259.53	346.74	791.83
Daejeon	132.19	175.78	139.85	447.82
Gangwon-do	48.65	262.08	108.45	419.18
Jeollanam-do	66.08	109.77	174.51	350.36
Gwangju	48.38	87.25	197	332.63
Chungcheongnam-do	38.5	80.83	148.61	267.94
Gyeongsangnam-do	58.41	41.06	142.81	242.28
Daegu	40.05	62.05	103.06	205.16

Unit: 100 million won.

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there were many companies researching infrastructure technologies applied in smart farms rather than establishing smart agricultural facilities.

On the other hand, in Gyeonggi-do, the amount of R&D investment has decreased over time. The budget for infrastructure and outdoor agriculture technologies rarely fluctuated, but the investment in facility agriculture technologies of smart agriculture significantly decreased. Smart agriculture in Gyeonggi-do mainly produced crops through smart facilities. However, the increasing rate of these facilities has slowed recently. In addition, the research institutes, companies, and farming facilities located in Gyeonggi-do relocated to local areas. Smart agriculture has been centered in the provinces due to the shortage of farmers in rural areas. The investment center of smart agriculture has been gradually moving from the capital area, including Seoul (39.3→24.0%), to the local area (60.7→76.0%).

4.2. Research Actor

The next process is to identify the development directions of smart agriculture research through the research actors. Table 2 represents these analysis results.

According to Table 2, the amount of national R&D investment in fundamental research decreased in Phase III, but the R&D budget significantly increased in development research and application research. Thus, both development and application research of smart agriculture have been conducted rather than fundamental research since 2018.

In detail, as regards fundamental research, there was a slight increase in universities, but a significant decrease in research institutes. Universities mainly established the basis of the latest prediction models on data analysis and related systems. They steadily improved these topics, which could be based on data analysis platforms in the introduction stage. In contrast, research institutes intensively invested fundamental research in Phase II. The main topics for them were soil quality and research on crops responding to climate change. These related projects were finished in Phase III, and so the proportion of the R&D budget was decreased in Phase III. Next, industries mainly conducted development research in Phase III. A number of companies attempted to utilize the data in developed agriculture models and construct the integrated data platform for smart agriculture. In university, renewable energy and the greenhouse environment were the majority topics, but the proportion of projects regarding mentioned research themes have declined after Phase II. The application research for smart agriculture steadily increased in overall

Table 2. Result of the research actor analysis

R&D stage/Research actor	Phase I	Phase II	Phase III
Fundamental	452.8	706.3	433.3
Industry	24.4	42.9	14.3
University	186.4	206.9	233.7
Research Institute	230.6	444.8	165.4
Government	1.7	0.8	0
Development	613.5	558.8	967.2
Industry	187.7	279.4	636.3
University	352.3	123	129.6
Research Institute	56.9	84.1	148.4
Government	-	1.4	3
Application	249.3	406.9	935
Industry	68.1	73.4	220.6
University	71.6	108.4	234.7
Research Institute	100.2	202.6	392
Government	2.8	12.5	11.6
Other	82.1	140	354.4

Unit: 100 million won.

research actors. In this process, many researchers mostly conducted empirical studies related to system developments for smart agriculture. In Phase III, there were many empirical pieces of research on convergence platforms and meta-systems, which included various technological components. For instance, many industrial companies attempted to set their operating logic in terms of autonomous unmanned robots. They also suggested optimal cultivation systems based on sensing and processing for the agricultural environment. Universities developed and improved prediction and control models for facility agriculture. The government conducted R&D projects which were investigating the current status of smart agriculture in rural areas or consulting to handle smart systems, but their proportion was relatively low.

4.3. Topics

4.3.1. Topic Classification

We could identify that various research actors have carried out numerous overall R&D stages of research concerning smart agriculture. To suggest significant implications, we would analyze what topics were deeply discussed and developed. To do this, we firstly extracted the major concerning technologies in each time phase as follows in Table 3.

According to Table 3, the major topics of Phase I were biotechnology and energy. Early smart agriculture focused on improving the utilization of agricultural resources. In this phase, various researchers set a goal of an increase in profit by expanding the potential market for food biotechnology. In addition, many R&D projects with respect to energy technology were also identified. These projects mainly dealt with 1) energy conservation technologies by introducing alternative energy, and 2) facility automation technologies to manage farms and buildings more efficiently. In Phase II, Many R&D projects undertook farming environment studies for smart agriculture. To reduce the impact of climate change such as global warming, these projects endeavored how to maintain a stable growth environment in agriculture. Several other projects also researched prediction or classification models for cultivation environment through the gathered environment data. Based on these models, the decision support model was introduced for the overall farming process. In Phase III, there were many R&D projects related to ICT and data analysis technologies. Numerous R&D projects started focusing on how to construct and manage the agriculture database. Based on these studies, many researchers also attempted to construct advanced data platforms which could cover real-time cultivation data for big-data analysis models. In addition, there were many convergent studies

Table 3. Major topics of each phase

Phase	Code	6T	Technology
Phase I	020312	BT	Conservation and utilization technology for agricultural & marine biological resources
	050218	ET	Other energy technologies
	020119	BT	Other generic technologies
	050216	ET	Bio-energy technology
	020218	BT	Food biotechnology
	050116	ET	Other environment-based technologies
Phase II	050115	ET	Environmental management, information & system technology
	050112	ET	Natural environment restoration technology
	010315	IT	Information retrieval and database technology
Phase III	010214	IT	Other network technologies
	020113	BT	Bioinformatics technology
	040312	ST	Intelligent autonomous flying unmanned aerial vehicle system (UAV) technology
	020215	BT	Functional biomaterial-based technology
	010155	IT	Other components technologies for ICT (Information and Communications Technology)
	020312	BT	Conservation and utilization technology for agricultural & marine biological resources

BT, Bio Technology; ET, Environment Technology; IT, Information Technology; ST, Space Technology.

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to enhance reasonable decision processes in farming. For instance, Intelligent UAV and ICT-based network systems were also developed for improving the sensing in cultivation.

Therefore, we could summarize the history of R&D projects for smart agriculture as follows. In the early stage of smart agriculture (2012-2014), researchers mainly focused on two directions: 1) biotechnologies for production improvement, and 2) energy technologies for improving facility efficiency. For the next three years (2015-2017), R&D projects dealt with environmental technologies responding to climate change. In Phase III (2018-2020), integrated data sensing and processing technologies for smart agriculture were the main research contents.

4.3.2. Keyword Analysis

Finally, we analyzed the keywords of the R&D projects to extract interesting technological issues from smart agriculture by each phase. Table 4 showed the results: 1) frequent keywords, and 2) interesting keywords that were intensively identified in a specific phase.

As shown in Table 4, the representative keywords of Phase I were 'Control' and 'Automation.' In this phase, research on smart agriculture focused on improving user convenience and reducing production costs. Thus, the main issue of R&D projects was how to improve the efficiency of agricultural production in agriculture. Contrary to our expectations, we also identified several data analysis keywords in projects before 2014; i.e., database, 3D image analysis, and growth data analysis. These projects suggested precedent studies and their related models on how to predict the growth conditions for crops and diagnose the cultivation process. Consequently, it is estimated that the research actors considered data-based smart agriculture projects with agricultural data.

In Phase II, more advanced smart agriculture projects were started to catch up with advanced countries. Rather than independent scientific knowledge, researchers proposed technological developments with ICT-based convergence. In particular, they gradually focused on research for decision support systems with intelligent information processing. In response, they also intensively initiated research on several technological compositions for systems such as growth prediction models, artificial intelligence, cloud, and deep-learning models. From Phase II on, numerous R&D projects were contributed to problem solving and life-cycle management for the overall farming process, as well as improvement of the cultivated situation.

Lastly, R&D projects in Phase III set research focus on integrated data platforms for smart agriculture. A number

Table 4. Result of keyword analysis

Phase	Frequent keyword	Interesting keyword
Phase I	• Soil information system • Fertilizer usage prescription • Database • Environmental control • Automation • Energy saving	• Automatic growth sensor • Crop prediction • Diagnosis • 3D image analysis • Growth data analysis
Phase II	• Climate change • IoT • ICT convergence • Big data • Robots • Soil-plant-weather research • Drone • Growth prediction model	• Production prediction • Pest control • Artificial intelligence • Cloud • Deep learning • Environment optimization
Phase III	• Artificial intelligence • Cloud • Platform • Standardization • Image processing • Deep learning • Smart pest control • Image analysis • Growth diagnosis	• Professional labor training • Renewable energy • Female-friendly agricultural machinery

ICT, information and communications technology.

of R&D projects attempted to construct cloud-based intelligent big data platforms for real-time data sharing and data-based decision support with deep learning and image processing technology. In addition, the government also intensively invested in data and equipment standardization for the digital transformation of the overall agricultural process. Based on this, various institutes contributed to improving the compatibility of equipment and spreading related systems. As smart agriculture technology advanced more and more, the importance of farm laborers who have considerable expertise in dealing with ICT has increased. Many types of systematic education programs and their related infrastructures are also emerging issues to raise the effectiveness of digital transformations.

Therefore, the issues of smart agriculture have evolved from improving the convenience of the system to constructing standardized and integrated platforms for lifecycle management of the value chain. With the development of ICT, the technological level of smart agriculture has also gradually advanced, and the government has invested in non-technical fields such as education programs.

5. CONCLUSION

The scale of R&D investment by step increased at an average annual rate of 14.38% from 2012 to 2020, with rapid increment of its value after 2018. The research on big data platforms based on cloud systems for diffusing smart agriculture sharply grew in Phase III. From the viewpoint of R&D characteristics by region, the R&D investment amount of Jeollabuk-do, which is the selected area for the Smart Farm Innovation Valley project, increased significantly in Phase III with government policy and R&D budget shifting gradually from the metropolitan area to the provinces. The study in Phase I was conducted mainly for the preparation of the basis of data construction and for improvement in convenience through remote monitoring and control. In Phase II, the primary research was performed by applying ICT convergence technology for smart farming and unmanned automation using harvest robots, drones, and intelligent agricultural machines, and for supporting decision-making (prediction, confrontation, management, and so on) to produce crops optimally based on the data related to cultivation environment and growth. Also, it was found in Phase III that the research was focused on the spread of smart agriculture including (1) the optimal management of complex energy using new and renewable energy (energy saving), (2) the establishment of the cloud-based big data platform for arrangement in the foundation of data connection, sharing, and utilization, (3) the standardization of environment and growth data and apparatuses for enhancement in the compatibility between devices, and (4) the training of professional manpower.

We considered the time phase of national R&D projects on the basis of the major policies for smart agriculture. These policies have a strong influence on R&D trends, and our research could capture these changing trends. In addition, we identified several technical issues based on the projects registered in NTIS, which allowed us to access the latest information. From these data, we identified underlying issues through three pieces of information: regional information, research actor, and topic. Therefore, our frameworks could systematically identify the R&D trends for smart agriculture, and these comprehensive approaches could represent the insufficient R&D parts for the Korean government and related stakeholders. Based on these findings, we proposed the R&D directions of smart agriculture for the Korean government as follows.

- First of all, the Korean government should prepare comprehensive strategies for the diffusion of smart agriculture in order to 1) reflect the properties of domestic agriculture, and 2) extend the R&D fields. To conduct these strategies, the government should promote four continuous R&D directions: (1) the expansion of application areas, (2) the reinforcement of software, (3) the inclusion of the forward and backward linkage throughout the agricultural value chain, and (4) the training of human resources.
- In addition, it is also necessary to expand research fields on data standardization closely related to service applications. Since 2021, governments and institutes have collected agricultural data as a result of the national R&D projects. They shared these data, such as on soil, weather, pests, and environment, for free use. These data could promote the understanding and cooperation of several research actors if a standardized process for the agricultural data and equipment could be constructed.
- Ultimately, for the realization of sustainable agriculture, the government should construct a cooperative ecosystem between stakeholders. This ecosystem could improve productivity, safety, economic feasibility, and quality of the entire production-distribution-sale-consumption cycle.

However, our research has some limitations. First, our gathered data itself has limitations. We attempted to investigate the recent R&D trends for smart agriculture, but the information on national R&D research projects from 2021 to 2022 has not been aggregated yet. In addition, the R&D budget in the private sector was higher than that of the public sector. It is also necessary to construct the database for the R&D budget of private institutes. Our future studies will validate the usability of the suggested framework by analyzing the extended time range and a wider variety of R&D projects from the private sector. Second, we rarely considered the outcome of R&D projects in the suggested framework. To analyze the R&D trends, we should identify the leading technologies in smart agriculture by analyzing the realized outcomes as well as the R&D budget. We intend to plan further R&D performance analysis by analyzing the academic performance (paper, patent) and technical performance (technology alliance and transfers) from NTIS data. In this process, various analyzable indicators such as diversity index and the attractive index will also be introduced in future research.

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CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

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