Chapter 13
Impacts and Policy Implication of Smart Farming Technologies on Rice Production in Japan

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1 Introduction

Rice is the most important staple crop in Japan as well as many Asian countries. It accounted for the largest proportion in the gross agriculture output in long period as a single crop. However, the gross production of rice has been decreasing in recent decades, although it slightly increased since 2015. In this context, Japanese government decided to promote efficient and competitive rice production. According to the *Japan Revitalization Strategy* released in 2013, the costs of rice production need to be reduced by 40% in the following 10 years. To this end, the adoption of advanced technologies and optimized farm management are essential for further agricultural development.

Since the 1990s, smart farming technologies have been widely applied in developed western countries to monitor and analyze the farming condition and yields, and optimize management accordingly (Nanseki, 2019a; Nanseki et al., 2016). Within the latest decades, agricultural legal persons/entities including corporations have become important in farm management in the agricultural sector. Some are "*corporation qualified to own cropland*" (formerly, *agricultural production legal person*), who can possess and transact farmland like a farmer. They have grown significantly in

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number from 2,740 in 1970 to 19,550 by 2020 (MAFF, 2021), covering all agricultural sectors. Compared with the small-scale farms mostly operated by family labor, farming corporations are operated by hired labor. Many larger farms are agricultural legal persons that have larger farm size and better market channels as well as capable human resources (Nanseki, 2021). Thus, it is feasible for farming corporations to adopt smart farming technologies for their further development.

This chapter aims to discuss impacts and policy implications of smart farming technologies on rice production in Japan. Based on several research projects, which are organized by the first author of this chapter, research framework and major findings of impacts of smart farming on rice production are outlined in this chapter. Then policy implications, in terms of impacts of smart agriculture on rice farming, are discussed based on these findings.

2 Research Framework and Methodology

In the project, we aimed to build big data on rice farming in light of the findings on yields and quality analysis, soil analysis, plant growth, environmental observation of air temperature, water temperature, water depth, and records of cultivation and management. Furthermore, via the analysis of this large database, we developed and demonstrated the new generation large-scale rice farming technology system, integrating with the agricultural machinery, field sensors, farming visualization and skill-transferring system. The system can be useful to increase yield and reduce production cost of rice. This chapter is based on Nanseki et al. (2016, 2021), Nanseki (2019a, 2019b), and Li and Nanseki (2021).

The research framework and smart farming technologies in the project are illustrated in Fig. 1. They are summarized in three stages: (1) The field-specific data of farming, meteorology, soil and cropping, collected and visualized using the farming visualization system (FVS). (2) Big data visualization and analysis in the cloud system. (3) Optimized production and operational management against the risks of meteorological and market changes. The application of these technologies mainly led to stabilized and improved yield and quality, through visualized soil properties, meteorology, high-precision cultivation responding to meteorological changes, and efficient, time and costs saving operation by visualized know-how, IT agriculture machinery, labor, and inputs saving cultivation.

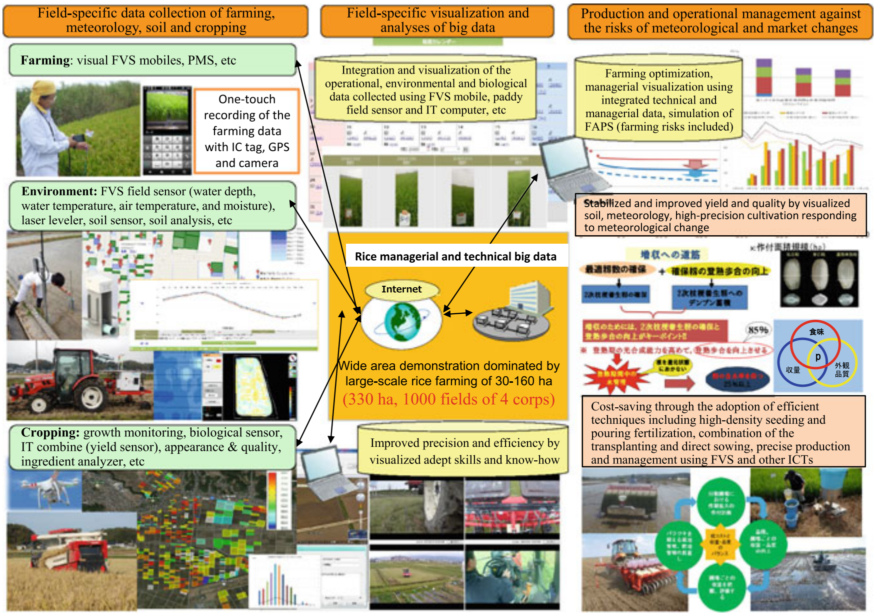

Fig. 1 Research flamework and smart farming technologies in the project (Reproduced from Nanseki, 2019a, p. 163)

2.1 Rice Production Cost

To propose the actions to decrease unit production cost (e.g. JPN/kg) of rice, it is important to increase yield (e.g. ton/ha) of rice as well as to decrease total cost of the farm. Therefore, it is crucial to measure cost of rice production based on farm records including both economic and physical inputs as well as both outputs. Yield is important physical output. This makes it possible to estimate unit production cost of rice shown in this chapter.

2.2 Rice Yield and Its Determinants

To increase yield at farm level, it is important to measure yield of each parcel of all paddy fields of the farm. To date, this was only possible in research paddy fields of research institutes and universities and was not feasible in actual farm operation on real farms. However, smart farming technologies make this possible in real farms recently.

There are several types of yield measuring both the quantity and quality of rice (Fig. 2). First, the data of raw paddy yield (Y1) and moisture is collected using the IT combines, where a small matchbox sized sensor is set at the input slot of

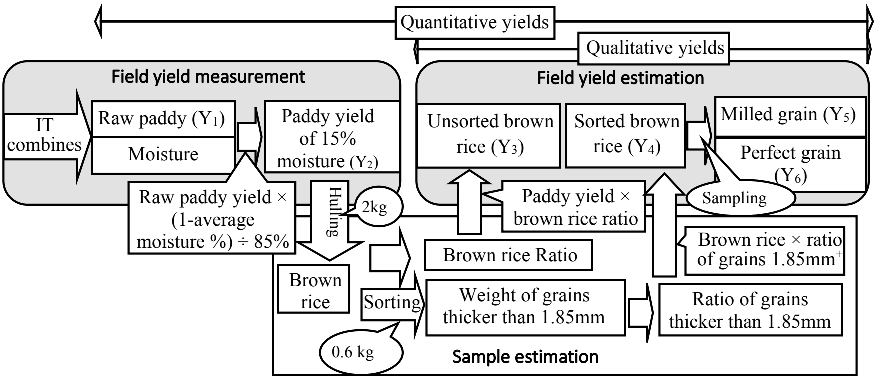

Fig. 2 Process of estimating the rice yields from raw paddy to milled and perfectly shaped grains (Reproduced from Nanseki, 2019a, p. 166)

the grain tank. Thereafter, the field-specific data with the global navigation satellite system (GNSS) is conveyed to the cloud server shared by the company, institutes, and farms. Furthermore, the yield of the paddy with 15% moisture (Y2) is calculated. Brown rice yield (Y3) is then sampled and estimated after hulling, and the sorted yield (Y4) retains only grains thicker than 1.85 mm. Finally, rice yield is estimated in terms of the sampled weight of milled rice (Y5), and perfectly shaped rice (Y6). Since the unsorted brown rice, ratios of a certain yield to another, prior to this estimating process, indicate the grain quality of each paddy field. In addition, due to their closer link to the market value in Japan, average weights of the milled and perfect grain can also indicate rice quality.

To identify the determinants of rice yield, we conducted series empirical studies, using data of the 1000 paddy fields totaling 330 ha, from four farming corporations in different regions of Japan. The yields of Y1 through Y6 defined above are used as the output variables. The inputs included (1) field properties of the area, soil property and farming condition, (2) production management of the transplanting or sowing date and fertilized nitrogen amount, (3) stage-specific growth indices of panicles per hill, culm length, and so on, (4) average temperature and solar radiation of 20 days since heading, (5) water temperature and depth in four growth stages, and (6) rice variety, cultivation regime, and soil type. The major empirical models included multivariate regression, analysis of variance (ANOVA), and correlation analysis. Path analysis was adopted to include the interacting effects of the yield determinants. Data envelopment analysis and Tobit regression were applied to analyze production efficiency and significant determinants of individual paddy fields (Fig. 3).

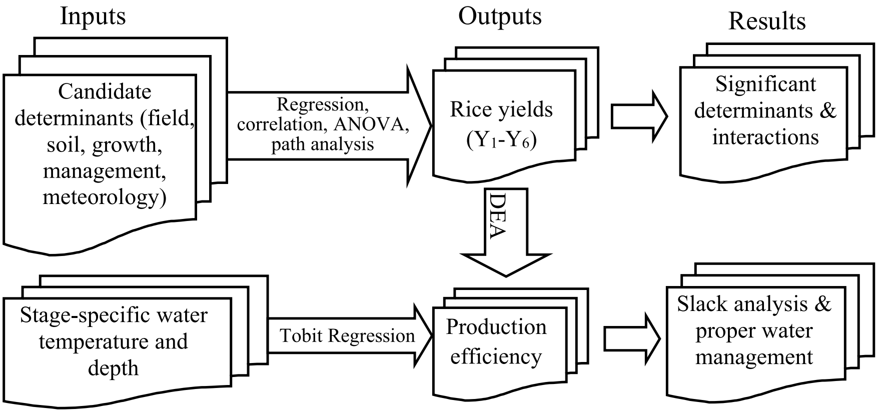

Fig. 3 General scenario of estimating the results in empirical analyses summarized in this research (Reproduced from Nanseki, 2019a, p. 167)

2.3 Cost–benefit Analysis of Automatic Paddy Water Supply Systems

Based on results of the big data, it was considered that improving water management is one of feasible way to increase efficiency and yield in rice production. Thus, we developed several types of automatic water supply systems and conducted field tests of these. One type is the Internet of Things (IoT) type and the other type is basic type. The IoT–type system has an Internet connection and digital camera. The system can be controlled by smart phone to supply and stop water as well as setting upper and lower limits manually. It can send images of paddy captured by equipped digital camera. This enables farmers to monitor both water and rice plants via the Internet. Basic type has no Internet connection or digital camera. The system can be controlled to supply and stop water by setting upper and lower limits manually. We then estimated the benefits and costs of both automatic paddy water supply systems for a 50 ha rice farm.

3 Results and Discussion

3.1 Rice Production Cost and the Reduction

Empirical findings of the project (Nanseki, 2019a; Nanseki et al., 2016) find factors contribute to increase rice yields in real farming. This leads to a reduction in the production cost of rice. The cost is mainly comprised of the property and labor costs. The percentage of labor cost to total cost is 67.41% for over 15 ha farm average of Japan nationwide statistics. In the project, the percentage is 67.64% for farms of

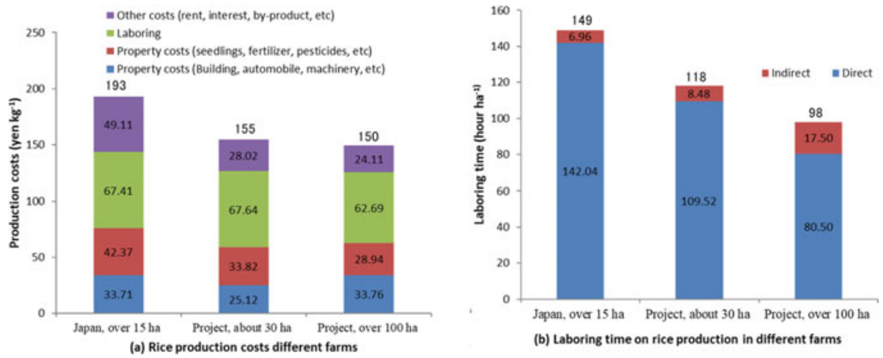

Fig. 4 Production cost and labor time of the farms in the project (Reproduced from Nanseki et al., 2016, pp. 9–10)

30 ha and 62.69% for those over 100 ha. Thus, as shown in Fig. 4, labor costs account for the highest percentage of costs in all farms involved in the project.

In farms scaled over 15 ha of the nationwide statistics, the average production cost of sorted rice was 193 JPY per kilogram (Fig. 4(a)). On the other hand, the average cost per kg of farms involved in the projects decreased to 155 JPY for 30 ha farms and 150 JPY for those over 100 ha. According to national statistics, the average labor time for farms over 15 ha is 149 h per ha. On the other hand, that for farms involved in the projects decreased to 118 h and 98 h per ha for farms over 30 ha and over 100 ha, respectively (Fig. 4(b)).

Cost curves of existing farms, present frontiers of advanced farms, and future frontiers of advanced farms are illustrated in Fig. 5. The cost curve of existing farms is drawn based on government statistics. That of present frontiers of advanced farms is drawn based on actual data of farms involved in the projects. For future frontiers of advanced farms, it is drawn based on the perspective based on the analysis in the project. The cost typically decreases when farming scale increases, by adopting new management and technologies. Nevertheless, it is difficult to further reduce production cost by merely increasing scale without any innovation. Hence, it is essential to adopt smart technologies to increase yield for efficient and competitive rice production. Through further technological innovation, the cost curve of future frontiers of advanced farms can be shifted to approximately 100 JPY per kg. To achieve this, it is necessary to increase yield by 20% as well as a 20% decrease in both fixed and variable costs (Nanseki, 2020).

For improving the average yield of an entire farm by 20%, we need to reduce the yield gap between fields by developing and introducing new high-yield varieties that meet demand and smart agriculture technologies represented by advanced production management utilizing information and communication technology (ICT). For reducing fixed costs by 20%, those such as depreciation expenses need to be reduced by increasing the scale of complexes (e.g., more than 200 ha) and expanding each parcel of paddy (e.g., 1 ha), as well as improving operation skills of machines and

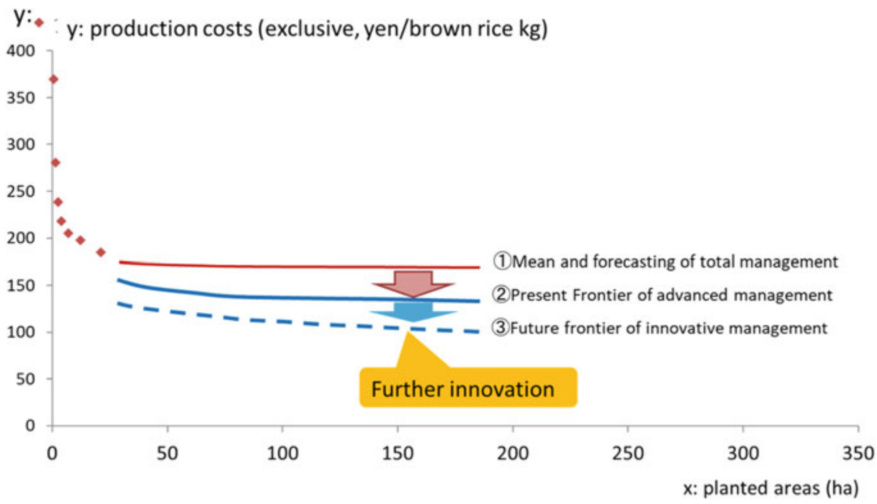

Fig. 5 Rice production cost and planted area in Japan (Reproduced from Nanseki et al., 2016, p. 5)

facilities. For reducing variable cost by 20%, we need to reduce variable expenses by optimizing the prices and input volumes of input materials, such as fertilizers and pesticides and machinery facilities, as well as land rent levels.

3.2 Rice Yield of Each Paddy Field and Its Determinants

The results of big data analysis (Li & Nanseki, 2021) indicate that the significant determinants of rice yield include suitable variety adoption, earlier transplanting or sowing and hence longer period for vegetative accumulation, sufficient nitrogen application, temperature and solar radiation, appropriate field areas as well as both temperature and depth of paddy water. Water temperature affects the technical efficiency more than water depth, and the 25 days from heading to grain filling is important to improve technical efficiency. Therefore, better water management based on real time sensing of paddy environment and plant is important under the situation of climate changes.

A summary of the results regarding the impact of water temperature and depth on yields is reported in Table 1 (Li & Nanseki, 2021, pp. 131–166). In the second stage DEA of two farms of the project (Farm B and Y), 10 paddy fields with the highest and lowest technical efficiency were selected for comparison. From the average values of the two groups, Farm B (0.026) was smaller than that of Farm Y (0.054), which indicates that the disparity of technical efficiency between paddy fields was smaller in Farm B. The growth stage was divided into four stages. S1 included the 40 days from transplanting to fully tillering, S2 covered the duration from fully tillering to heading, S3 referred to the 25 days from heading to grain filling, that

Table 1 Average water depth and water temperature of High-10 and Low-10 paddy fields in terms of efficiency (Li & Nanseki, 2021, pp.131–166)

Farm	Mean of paddy fields	Peer count	Technical efficiency	Water depth (mean of 18:30, mm)				Water temperature (mean of 18:30, °C)			
				S_1	S_2	S_3	S_4	S_1	S_2	S_3	S_4
B	High-10	24.9	1.000	36.72	22.18	16.43	5.58	23.26	26.23	26.16	23.00
	Low-10	0.0	0.974	51.68	29.90	12.75	9.55	24.42	26.36	27.39	24.24
	Differ (high-low)	24.9	0.026	–14.96**	–7.71	3.68	–3.97	–1.16**	–0.13	–1.23**	–1.24***
Y	High-10	18.4	1.000	45.62	19.90	35.82	11.21	24.63	27.54	26.67	22.93
	Low-10	0.0	0.946	43.45	18.65	39.50	8.19	24.31	26.46	27.94	22.82
	Differ (high-low)	18.4	0.054	2.17	1.25	–3.68	3.02	0.32	1.08***	–1.27**	0.11

Note Peer is a model reference for evaluating the efficiency of other paddy fields. *** and **: significant at 1% and 5%, respectively is, the early-middle maturity stage, and S4 consisted of the remaining days until complete maturity. The water depth and temperature were measured by sensors at 10-min intervals. According to the previous research results and expert opinions (Nanseki, 2019a, 2019b), the daily data of specific time (18:30), with the greatest impact of water depth on water temperature, was selected for analysis. According to the average values of 10 paddy fields with the highest and lowest technical efficiency, there are significant differences between S1 water depth and water temperature of all the stages except S2 in Farm B, while significant differences were observed in water temperature between S2 and S3 in Farm Y (Table 1). Therefore, the results indicate that water depth and water temperature had a stronger impact on rice y ield.

Furthermore, the results reveal that the water temperature had a stronger impact on rice yield than water depth; specifically, the lower the average water temperature of S3, the higher the technical efficiency of production. According to Tsujimoto et al. (2009), rice is most sensitive to water temperature in the early booting stage. When the measured temperature is higher than 26 °C, it is beneficial to maintain the activity of root and stem and promote the growth of rice grain.

Direct control of the water temperature of paddy fields is not practically possible in real farms because of the cost. However, control of the water depth is possible and much easier than that of water temperature. The results also empirically confirm that the water temperature is affected by the water depth based on the data of real farm as expected. This implies that better control of the water depth makes it possible to increase yields of rice.

3.3 Cost and Benefit Analysis of Automatic Paddy Water Supply Systems

Figure 6 shows the Internet of Things (IoT) type and the basic type of automatic paddy water supply systems. Table 2 shows the results of both types of costs-benefit analysis of automatic paddy water supply systems for a 50 ha rice farm. In the case of the IoT-type system, which can be controlled through Internet, the benefit of labor-saving effect and revenue (yield) increase effect are 2.80 and 3.38 million JPY, respectively. The total benefit is thus 6.18 million JPY. On the other hand, the cost is 5.60 million JPY. Consequently, the net balance for the IoT-type is plus 0.58 million JPY. This result implies that if both the effects of labor-saving and revenue (yield) increase can be realized, the IoT-type system should be introduced. Furthermore, this result implies that any single effect is not sufficient. This is also true in the case of the basic type; the advantage of the basic type exceeds that of the IoT-type. This implies that the basic type is more useful than IoT-type from an economic viewpoint.

Additionally, the impacts of advanced smart farming technologies are introduced and discussed here based on our research. One of the most well-known smart farming technologies in Japan is the robot tractor, which can run and tillage automatically without a human operator. We estimated the impact of future robot tractor, baby rice

Fig. 6 Automatic paddy water supply systems (IoT type: photo by the author. Basic type: reproduced from https://www.facebook.com/watch/?v=260776628541439)

plant planting robot, harvester robot and water supply robot via stochastic optimal farm planning analysis (Nanseki, 2019a, 2019b, 2022). The results reveal that physical farm size expansion effect is less than 8% at maximum for all kinds of farming robots. This implies that the impacts of these smart agriculture technologies on the expansion of both physical and economic farm size are limited. Furthermore, the cost of introducing these robots overcomes the benefit. As a result, production costs of a farm that introduces these robots is higher than the cost of a farm without these. The reason is that they are for only specific farming operations such as baby rice plant planting, water depth control, and harvesting, as well as tillage and plowing. Additionally, they can be used in only specific season of the year. This is unlike dairy farms, which utilize many kinds of farming robots every day. Our latest results (Nanseki, 2022, pp. 183–208) demonstrate that these advanced smart agriculture technologies have much larger impacts on labor saving.

4 Conclusion and Implications

The challenge of our research project on rice production Japan is demonstrating that a technology package (Nanseki 2019a, 2020) can achieve a production cost of 100 yen for brown rice at the actual production scale. The technology package should optimally combine the elemental technologies of agricultural technology (e.g., transplanting, dense seedling, direct sowing cultivation, etc.) and ICT (e.g., robotic agricultural machines, IoT sensors, management optimization systems, artificial intelligence, etc.) according to the management strategy. Further research and development on these topics are expected.

These results of the project reveal that smart farming technologies have positive impacts on rice production. However, the results also indicate that more practical smart farming technologies, such as the basic type of water supply system, may have

Table 2 Cost–benefit analysis of automatic paddy water supply systems (Revised version of Nanseki, 2019b)

Type	Benefits/ costs	In million JPY	Assumption (based on local demonstration results)
IoT type	1. Labor-saving effect by introducing IoT type	2.80	80% reduction in water management (labor cost: 5600 JPY/10a)
	2. Revenue increase effect by introduction of IoT type	3.38	Yield increased by 5% from 450 kg/10a, unit price 300 JPY/kg
	3. Cost increase due to introduction of IoT type	5.60	One automatic water supply system is installed at 25a (Practical target price of 80,000 JPY, service life of 5 years). System operation cost for agricultural platform etc. is 12,000 JPY/year Total annual cost increased by 28,000 JPY/25a
	4. IoT type balance (=1 + 2–3)	0.58	
Basic type	5. Labor saving effect by introduction of basic type	1.75	50% reduction in water management (labor costs 3,500 JPY/10a)
	6. Increased sales due to introduction of basic type	1.69	Yield increased by 2.5% from 450 kg/10a, unit price 300 JPY/kg
	7. Cost increase due to introduction of basic type	2.00	One automatic water supply system is installed at 25a (Practical target price of 50,000 JPY, useful life of 5 years). Annual cost increase of 10,000 JPY/25a
	8. Basic type balance (=5 + 6–7)	1.44	

Note 50 ha rice farm is assumed for estimation of cost and benefit

larger impacts on real rice production than more advanced technologies, such as the IoT-type of water supply system at this moment. This implies that only appropriate technologies for real farms can contribute to agricultural innovation.

Research and development (R&D) and extension of advanced smart farming technologies are now strongly promoted by the policy of the government. As shown in this chapter, the results of our research projects imply that R&D of practical technologies that have more impacts on real farms should be also promoted in policy. Advanced technologies are not always useful for real farms in developing countries but also in developed countries.

The cost reductions can be made through management efforts, such as increasing yield by improving cultivation management technology and skills, optimizing the amount of input materials, using machinery and facilities efficiently by improving operation technology and skills, and expanding the management scale, accumulating farmland, and performing large compartmentalization. However, none of the following cost reductions can be achieved solely through the efforts of farmers, and policy support is also essential: the development of high-yield new varieties and smart agricultural technology, improvements in the service life of machinery facilities, the optimization of agricultural materials, machinery prices, and land rent levels, and the expansion of the management scale, the accumulation of farmland, and large compartmentalization, all at regional level.

A remain topic for further research is to estimate impacts of smart farming technologies on the environment. It has been reported that paddy fields are a source of methane, which accelerate climatic change. Better water depth control can decrease methane emissions from paddy field (NARO, 2012). From these aspects, estimates of the impact of automatic paddy water supply system on methane emissions will be an important and practical research topic. As shown in Nanseki (2022), smart farming is expected to contribute to environmentally friendly agriculture in EU. These issues will become to be more important in Asia.

On smart farming in general, an important topic which we do not discuss in this chapter is risk of smart farming. Any technology has benefits, limitations and risks. This is true for smart farming technology. Evaluation of risk of smart farming is needed for better understanding the technology. The other topic is differences in impacts of smart farming among crops. Nanseki (2022) gives details explanations and discussions on these points.

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