Impacts and policy implication of smart farming technologies on rice production in Japan

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Abstract

The paper discussed impacts and policy implication of smart farming technologies on rice production in Japan based the series of research projects started from "Noshonavi1000". First, the research flamework and smart farming technologies in the project are illustrated. The projects collected many kinds of data by farming technologies from large-scale advanced rice farms involved in the project. This data set is used for empirical analyses of production efficiency determinants, production cost as well as impacts of smart farming technologies on the farm. The results indicate that smart agriculture improves agricultural production efficiency through utilizing technical support such as data collection and mining. The results also show that smart farming technologies have positive impacts on rice production in Japan. However, the results also show that more practical smart farming technologies may have larger impacts on real rice production in Japan than more advanced technologies. This implies that only appropriate technologies for real farms can contribute to agricultural innovation.

Keywords: cost, efficiency, yield, automatic paddy water supply, robot tractor

Introduction

Rice is the most important staple crop in Japan as well as many Asian countries. It accounted for the largest proportion of 19% in Japanese gross agriculture output and by 2018. Although slightly increased since 2015, the gross production of rice has been decreasing in the latest decades, while the production cost is high. 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 the further agricultural development in Japan.

Since the 1990s, smart farming technologies have been widely applied in the western developed countries, to monitor and analyze the farming condition and yields, and optimize the management accordingly (Nanseki et al. 2016, Nanseki 2019a). Within the latest decades, agricultural legal person including corporation become to be important farm management in agricultural sector. Some of them are "corporation qualified to own cropland" (formerly, agricultural production legal person), who can possess and transact farmland like a farmer. They have made dramatic growth in Japan, from 2,740 in 1970 to 19,550 by 2020 (MAFF 2021), covering all agricultural sectors. Comparing with the small-scale farms mostly operated by family labors, farming corporations are operated by hired labors. Many of larger farms are agricultural legal persons have larger farm size and better market channels as well as capable human resources (Nanseki 2021). Thus, it is feasible to adopt the smart farming technologies by the farming corporations. And it is necessary for further development of corporations.

This paper presents both the research framework and major findings of impacts of smart paddy farming on rice production in Japan base on several research projects, which are organized by the first author of this paper. This paper also shows policy implications of smart agriculture on rice farming.

In the project, we aimed to build the big data on paddy farming in light of the findings of yields and quality analysis, soil analysis, plant growth, environmental observation of air temperature, water temperature, water depth, records of cultivation and management. Furthermore, by the analysis on 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.

Methodology

The research flamework 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 is collected and visualized using the farming visualization system (FVS); (2)

big data visualization and analysis in the cloud system; and (3) optimized production and operational management against the risks of meteorological and market changes. The application of these technologies led to mainly the stabilized and improved yield and quality, through visualized soil properties, meteorology, high-precision cultivation responding to meteorological changes; and the efficient, time and costs saving operation by visualized know-how, IT agriculture machinery, labor and inputs saving cultivation.

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 yield of each parcel of all paddy fields of the farm. So far, this is only possible in research paddy fields of research institute and university. So far this is not feasible in actual farm operation in real farm. Smart farming technologies make it possible in real farm, however.

Fig.1. The research flamework and smart farming technologies in the project

Source: Nanseki (2019a, p163)

There are several types of yield measuring both the quantity and quality of rice in Japan (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 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. Yield of brown rice (Y3) is then sampled and estimated after hulling, and the sorted one (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 in this estimating process, indicate the grain quality of each paddy field. In addition, average weights of the milled and perfect grain can also indicate rice quality, due to their closer link to the market value in Japan.

Fig.2. Process of estimating the rice yields from raw paddy to milled and perfectly shaped grains

Source: Nanseki (2019a, p166)

To identify the determinants of rice yield, we conducted series empirical studies, using data of the 1000 paddy fields scaled 330 ha, from four farming corporations scattering in different regions of Japan. The yields of Y1 through Y6 defined above are used as the output variables. The inputs included (1) fields 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, etc.; (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, 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 analysis 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

Source: Nanseki (2019a, p167)

Results and Discussion

Rice production cost and the reduction

Empirical findings of the project (Nanseki 2019a and Nanseki *et al.* 2016) contribute to increase yield of rice in real farming. This causes to deduce the production cost of rice. The cost of rice production is mainly comprised of the property costs and labor costs. The percentage of labor cost to total cost is 67.41% for over 15ha farm average of Japan nationwide statistics. The percentage is 67.64% for the 30 ha size farms and 62.69% of over 100 ha size in the project, respectively. Thus, major costs of rice production which has highest percentage at all farm size in Fig.4 is labor cost.

In farms scaled over 15 ha of Japan 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 of the 30 ha size farms and 150 JPY of over 100 ha size in the project, respectively. The average labor time of over 15 ha of nationwide statistics is 149 hours per ha. On the other hand, the average labor time per ha of farms involved in the projects decreased to 118 hours per ha of the 30 ha size farms and 98 hours per ha of over 100 ha size, respectively (Fig. 4(b)).

Fig.4. Production cost and labor time of the farms in the project

Source: Nanseki et. al (2016, p9-10)

Fig. 5 shows cost curves of existing farms, present frontiers of advanced farms and future frontiers of advanced farms. The cost curve of existing farm is drawn based on government statistics. The cost curve of present frontiers of advanced farms is drawn based on actual data of farms involved in the projects. The cost curve of future frontiers of advanced farms is drawn based on 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 an efficient and competitive rice production. By further technological innovation, the cost curve of future frontiers of advanced farms can be shifted to near 100 JPY per kg. To achieve the production cost down to 100 JPY per kg, it is necessary to increase yield of rice by 20% as well as 20 % decrease of both fixed and variable costs (Nanseki 2020).

Fig.5. Rice production cost and planted area in Japan

Source: Nanseki *et al.* (2016, p5)

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

Determinants of rice yield by bigdata analysis

The results of bigdata analysis (Li and Nanseki 2021) show 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 that of the water depth, and the 25 days from heading to grain filling is important to improve technical efficiency. Therefore, proper better water management based on real time sensing of paddy environment and plant is important under climate changes.

As an example of results, summary result of impacts of water temperature and depth on yields is shown in the below (Table 1, Li and 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 stage. 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, i.e., the early-middle maturity stage, and S4 consisted of the remaining days until complete maturity. The water depth and water temperature were measured by sensors at 10-minute intervals. According to the previous research results and expert opinions (Nanseki 2019), the daily data of 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 existed in water temperature between S2 and S3 in farm Y (Table 1). Therefore, the results show that water depth and water temperature had a stronger impact on rice yield.

Table 1. Average water depth and water temperature of High-10 and low-10 paddy fields in terms of efficiency

Furthermore, the results show that the water temperature had a stronger impact on rice yield than water depth, especially 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 ℃, 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 possible in real farm. However, control of the water depth of paddy fields is possible and much easier than control of the water temperature in real farm. The results also shows that the water temperature of paddy fields is affected by the water depth of paddy fields. This implies that better control of the water depth of paddy fields make possible to increase yields of rice.

Cost-benefit analysis of automatic paddy water supply systems

Based on results of the big data, we developed several types of automatic water supply systems and conducted field tests of the systems. One type is IoT(Internet of Things) type and the other type is basic type (Fig. 6). The system of IoT type has Internet connection and digital camera. The system can be controlled by smart phone through Internet to supply and stop water as well as by setting upper limit and lower limit by hands. It can send images of paddy captured by equipped digital camera. This enables farmers to monitor both water and rice plant through Internet. Basic type has no Internet connection and digital camera. The system can be controlled to supply and stop water by setting upper limit and lower limit by hands.

Fig.6. Automatic Paddy Water Supply Systems

Source: IoT type: photo by the author.

Basic type: https://www.facebook.com/watch/?v=260776628541439

Then we estimated the benefits and costs of both systems of automatic paddy water supply systems for a 50ha rice farm (Table 2). 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 enough. 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 view.

Optimal farm planning analysis: Impact of robot tractor on real farm

One of the most famous smart farming technologies in Japan is robot tractor. The robot tractor can run and tillage automatically without human operator. We estimated the impact of future robot tractor, baby rice plant planting robot, harvester robot and water supply robot on rice farm by stochastic optimal farm planning analysis (Nasneki 2019a, b). The results show that physical farm size expansion effect is less than 8% for all kind of farming robots. This implies that the impacts of these smart agriculture technologies on the expansion of both physical and economical farm size are limited. Furthermore, the cost of introducing these robots overcome the benefit. As the result, production cost of a farm which introduces these robots is higher than the cost of a farm without these robots. 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 & ploughing. They also can be used in only specific season of one year. This is unlike dairy farm which introduces many kinds of farming robots.

Table 2. Cost-benefit analysis of automatic paddy water supply systems

Conclusion and Implication

The challenge of our research project on rice production in 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 information and communication technology (e.g., robotic agricultural machines, Internet of things sensors, management optimization systems, artificial intelligence, etc.) according to the management strategy, and further research and development on these topics is expected.

These results of the project show that smart farming technologies have positive impacts on rice production in Japan. However, the results also show that more practical smart farming technologies, such as the basic type of water supply system, may have larger impacts on real rice production in Japan 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. The results also show that the impacts of advanced smart farming technologies (e.g., agricultural robots) are limited in terms of expansion of farm size. Our new results in printing show that the impacts of these advanced smart agriculture technologies have much larger impacts on labor saving on farm. R&D and extension of advanced smart farming technologies are promoted by the policy of the government. R&D of practical technologies which have more impacts on real farm should be also promoted in policy.

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.

An important topic for further research is to estimate impacts of smart farming technologies on environment issues. It is reported that paddy field is a source of methane which accelerate climatic change, but better water depth control can decrease methane emissions from paddy field (http://www.naro.affrc.go.jp/archive/niaes/techdoc/methane_manual.pdf). From these aspects, estimate of impacts of automatic paddy water supply system on methane emissions will be an important and practical research topic for a next step.

Acknowledgement:

This study was supported by JSPS KAKENHI Grant Number JP19H00960. This paper bases on Nanseki *et al.* (2016), Nanseki (2019a,b) and Li and Nanseki (2021).

Note

The ASAE presentations related to this presentation are in the below:

Mi J., Nanseki T., Chomei Y., Uenishi Y., Nguyen T. L. (2021) Determinants of ICT and smart farming technology adoption by agricultural corporations in Japan, The 10th ASAE (The Asian Society of Agricultural Economists) International Conference, http://www.asae2020.pku.edu.cn/index.htm

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Tables

Table 1. Average water depth and water temperature of High-10 and low-10 paddy fields in terms of efficiency

Farm	Mean of paddy fields	Peer count	Technical efficiency	Water depth (mean of 18:30, mm)				Water temperature (mean of 18:30, ℃)			
				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.

Source: Summary of Li and Nanseki (2021, pp.131-166)

Table 2. Cost-benefit analysis of automatic paddy water supply systems

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 450kg/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 450kg/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	

Source: Revised version of Nanseki (2019b).

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

Figures

Fig.1. The research flamework and smart farming technologies in the project

Source: Nanseki (2019a, p163)

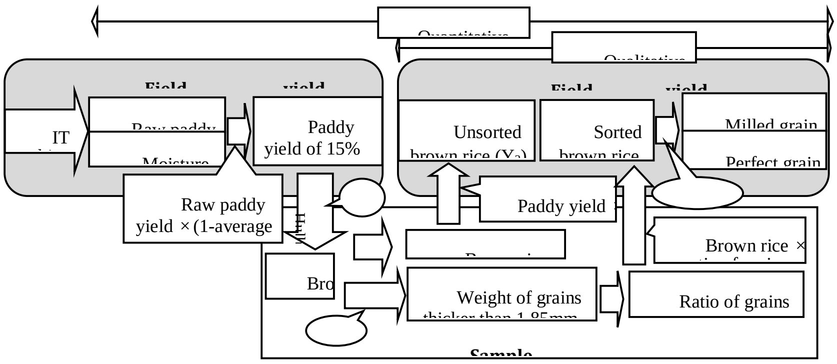

Fig.2. Process of estimating the rice yields from raw paddy to milled and perfectly shaped grains

Source: Nanseki (2019a, p166)

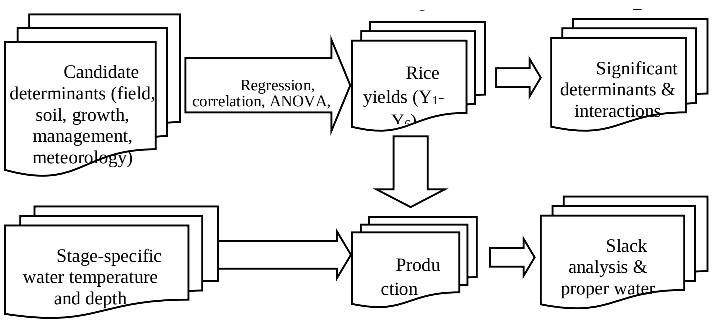

Fig.3. General scenario of estimating the results in empirical analyses summarized in this research

Source: Nanseki (2019a, p167)

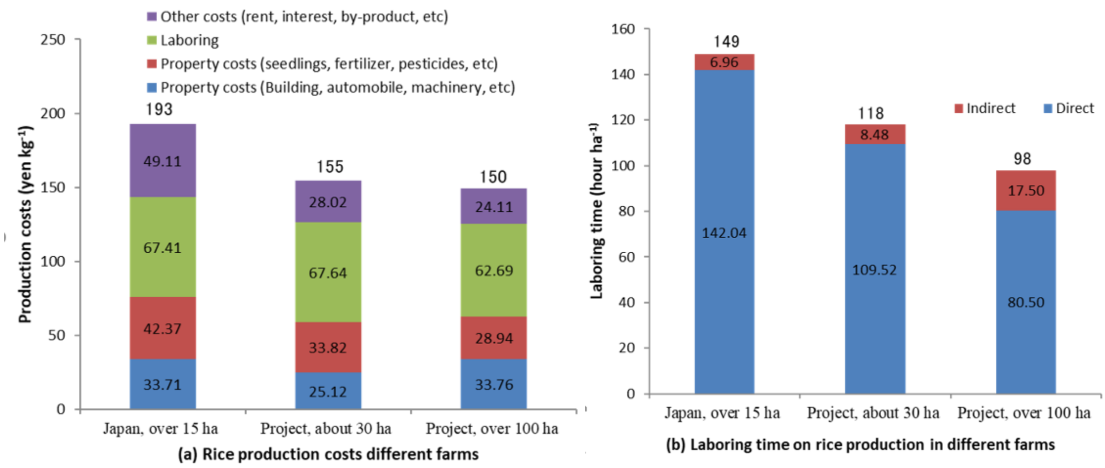

Fig.4. Production cost and labor time of the farms in the project

Source: Nanseki et. al (2016, p9-10)

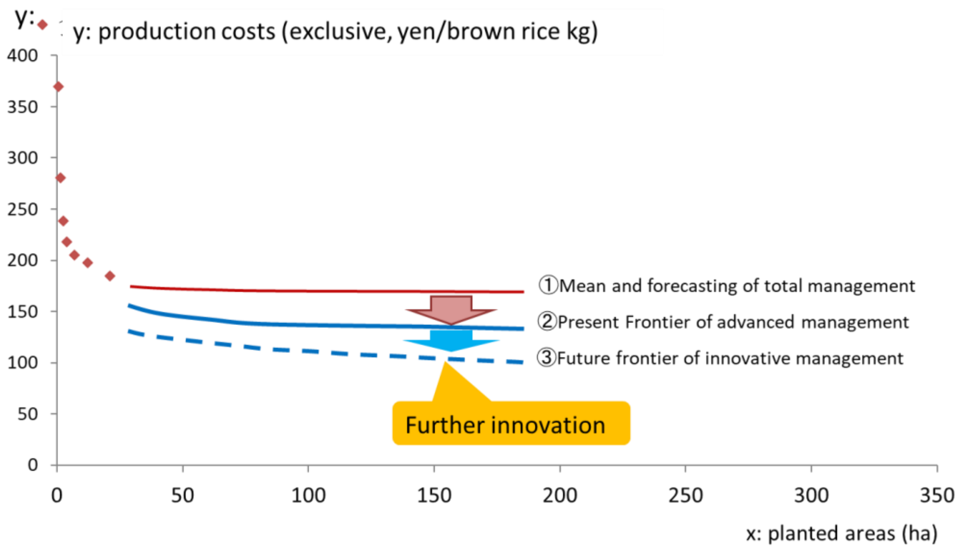

Fig.5. Rice production cost and planted area in Japan

Source: Nanseki *et al.* (2016, p5)

Fig.6. Automatic Paddy Water Supply Systems

Source: IoT type: photo by the author.

Basic type: https://www.facebook.com/watch/?v=260776628541439