Impact of Rice Variety and Cultivation Regime Through ANOVA

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This chapter identified the impact of rice variety and cultivation regime on paddy yield in the large-scale farms. The study objects were 351 fields in a farm corporation of over 113 hectares, locating in the Kanto Region, and the yield was measured by smart combine harvester The ANOVA result indicated that rice variety was a significant factor affecting yield; although the cultivation regime was not significant, it had a significant interaction with the effect of rice variety. According to the result of Duncan's new multiple range test (DNMRT), the rice varieties were divided into three groups. Further analyses using four factors and the ANOVA results showed that the time of transplanting or sowing, growth duration from transplanting or sowing stage to earring stage, total nitrogen amount, and field area were determining factors. Finally, the key points for higher paddy yield were summarized.

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1 Introduction

In recent decades, Japanese agriculture has been undergoing a recession. From 1985 to 2013, gross agriculture output decreased by 27% from 11.62 trillion JPY to 8.47 trillion JPY. Simultaneously, paddy output decreased by 53.51%, from 3.83 trillion JPY to 1.78 trillion JPY. Although it still has the largest share, output of paddy in agriculture has decreased from 32.93 to 21.03% (MAFF 2014). The decreasing paddy production has reduced agricultural growth to a large extent (Ohizumi, 2014).

After came back to power in end of 2012, the government led by the Liberal Democratic Party (LDP) of Japan issued the new policy of "proactive agriculture, forestry and fisheries", to increase the efficiency and competitiveness of these sectors in Japan. As to agriculture, it is essential to reduce the production costs and improve the yields, through the fiscal subsides to adopt efficient technologies, equipment, managerial models. Meanwhile, the keynote policy for paddy production is changing from acreage reduction adopted since early 1970s, to expand the exports actively and improve the international competitiveness. On the other hand, Japanese cuisine was designated to the UNESCO's intangible cultural heritage list on December 4, 2013. The government hopes to enhance global recognition and boost the exports of rice among other Japan's agricultural products.

Some scholars have studied the determinants of paddy yield in Japan, like Hirai et al. (2012), Tanaka et al. (2014). In the literature, rice variety and cultivation regime have been shown to be important determinants of paddy yield (Nishiura and Wada 2012; Muazu et al. 2014; Ju et al. 2015). Accordingly, this chapter identified the yield determinants from the perspective of rice variety and cultivation regimes. Unlike the previous studies that used experimental data, we used data of rice yield measured by smart combine harvester, and other data from 351 paddy fields of a large-scale farm corporation located in Ibaraki Prefecture of the Kanto Region.

2 Materials and Methods

2.1 Paddy Production in the 351 Fields

All the 351 fields are scattered compactly in a plain area of 2 sq. km. The paddy production is carried out with relatively fewer machineries utilizing just 2 officers, 11 full-time staff, and 5 temporary employees. The size of the fields ranges from 200 m^2 to 21148 m^2, with the average area of 3237.7 m^2. The major soil types are peat soil and gray lowland soil, accounting for 317 and 34 fields, and 91.97% and 8.03% of the total size, respectively.

Figure 1 presents the proportion in the total number of fields and total areas of fields surveyed, by rice variety. Within the seven varieties, Koshihikari had the largest share in both the number of fields and area cultivated, followed by Akitakomachi in terms of the number of fields cultivated, and Yumehitachi in terms of the area cultivated.

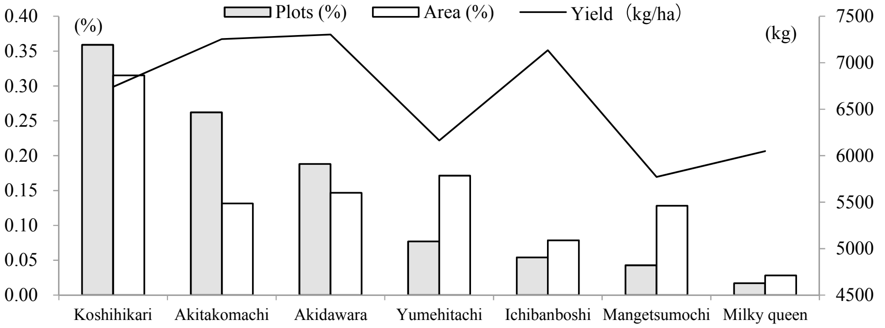

Fig. 1 Yield and proportion in total number of fields, and area among rice varieties

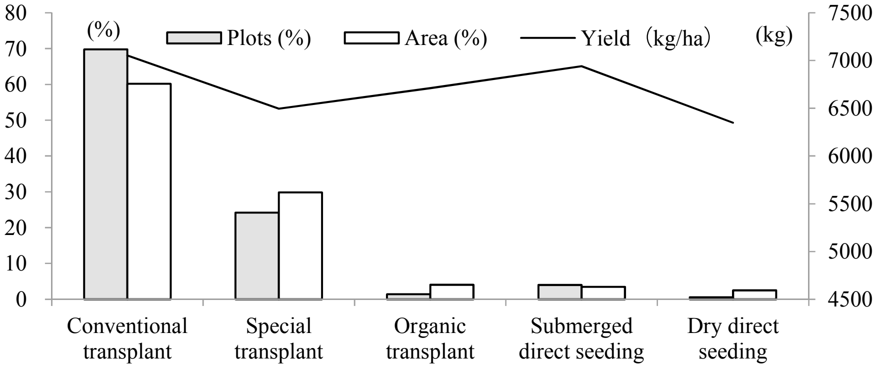

Fig. 2 Yield, proportion of total number of fields and area under different cultivation practices

Among the five cultivation regimes, the conventional transplant was most adopted, with almost 70% of the number of fields and 60% of area cultivated, followed by special transplant (Fig. 2).

2.2 Statistical Analysis

The effects of rice variety and cultivation practices on paddy yield were analyzed using two-way ANOVA. For the significant parameters, the means were compared using DNMRT, a post hoc multiple comparison method assuming equal error variance. For the rice varieties that utilize multiple cultivation practices, the effects of the latter were further estimated using one-way ANOVA. All the analyses were performed using SPSS 13.0 for Windows.

3 Results and Discussion

3.1 *Result of ANOVA*

As shown in Table 1, the model of two-way ANOVA was significant at the level of 0.01, and rice variety was found to be significant in affecting paddy yield at the same level. Cultivation regime was insignificant to yield, but it had a significant effect with rice variety and was found significant at the 5% level. Levene's test of equality of error variances ($p > 0.10$) indicated that, the null hypothesis was acceptable, and hence, there was no significant error variance of the dependent variable across the groups. The summary statistics of different rice varieties and cultivation regimes were shown in Table 2, including yield per hectare converted by 15% moisture, standard deviation, and the CV. The corresponding yield curves were shown in Figs. 1 and 2.

The equality of error variances was shown in Table 1 and the grouping information of yields based on DNMRT was summarized in Table 2. As to effect of rice variety, the average yields were divided into three subsets. The upper subset (A) included Akidawara (7303.14 kg per hectare), Akitakomachi (7253.93 kg per hectare), and Ichibanboshi (7134.20 kg per hectare) varieties; the moderate subset (B) consisted of Ichibanboshi (7134.20 kg per hectare) and Koshihikari (6740.11 kg per hectare) varieties; while the lower subset (C) comprised Yumehitachi (6162.95 kg per hectare), Milky queen (6050.08 kg per hectare), and Mangetsumochi (5771.73 kg per hectare) varieties. Except for the variety of Ichibanboshi, which came under both (A) and (B) subsets, the other subsets were different from each other in terms of average yield. In contrast, average yields cannot be divided into different subsets, from the perspective of cultivation regimes. Hence, it is not possible to identify yield variance in accordance with the result of ANOVA.

With respect to the significant interaction effect of rice variety and cultivation regime, one-way ANOVA was adopted to test the effect of multiple cultivation regimes used for some rice varieties. The result indicated that cultivation regime

Table 1 Result of the two-way ANOVA[a]

Source[b]	Sum of squares	df	Mean Square	F	Sig.
Variety	51965588.58	6	8660931.43	17.20***	0.000
Cultivation	2469156.73	4	617289.18	1.23	0.300
Variety × Cultivation regime	3373552.89	1	3373552.89	6.70**	0.010
$F_{\text{Total}} = 13.060^{***}$	$R^2 = 0.298$		Adjusted $R^2 = 0.275$		
Levene's equality test of error variances[a]		df1	df2	F	Sig.
		11	339	1.566	0.107

[a] Dependent variable in this chapter is yield per hectare converted by 15% moisture Software: SPSS 13.0

[b] Tests the null hypothesis that the error variance of the dependent variable is equal across groups

*** and ** Denote significance at the 1 and 5% levels, respectively

Table 2 Paddy yield by variety and cultivation regimes

Rice variety and cultivation regime		N	Average yield (kg/ha)	Std. D. (kg/ha)	CV^{a} (%)
Variety	Koshihikari	126	6740.11^{B}	674.89	10.01
	Akitakomachi	92	7253.93^{A}	839.80	11.58
	Akidawara	66	7303.14^{A}	686.28	9.40
	Yumehitachi	27	6162.95^{C}	591.29	9.59
	Ichibanboshi	19	7134.20$^{A, B}$	715.81	10.03
	Mangetsumochi	15	5771.73^{C}	751.05	13.01
	Milky queen	6	6050.08^{C}	318.45	5.26
Cultivation regime	Conventional transplant	245	7052.53^{D}	870.66	12.35
	Special transplant	85	6496.03^{D}	589.75	9.08
	Organic transplant	5	6711.14^{D}	310.07	4.62
	Submerged direct sowing	14	6940.27^{D}	761.47	10.97
	Dry direct sowing	2	6349.05^{D}	758.65	11.95
Variety × Cultivation regime	Koshihikari・Conventional transplant	56	6939.93***	738.41	10.64
	Koshihikari・Special transplant	65	6570.20***	592.19	9.01
	Koshihikari・Organic transplant	5	6711.14***	310.07	4.62
	Akitakomachi・Conventional transplant	92	7253.93	839.80	11.58
	Akidawara・Conventional transplant	52	7400.84**	637.65	8.62
	Akidawara・Submerged direct sowing	14	6940.27**	761.47	10.97
	Yumehitachi・Conventional transplant	11	5900.24	533.68	9.05
	Yumehitachi・Special transplant	14	6342.79	580.79	9.16

(continued)

Table 2 (continued)

Rice variety and cultivation regime		N	Average yield (kg/ha)	Std. D. (kg/ha)	CV[a] (%)
	Yumehitachi・Dry direct sowing	2	6349.05	758.65	11.95
	Ichibanboshi・Conventional transplant	19	7134.20	715.81	10.03
	Mangetsumochi・Conventional transplant	15	5771.73	751.05	13.01
	Milky queen・Special transplant	6	6050.08	318.45	5.26
Total	–	351	6904.42	833.32	12.07

[a] CV is the ratio of the standard deviation to mean, CV shows the dispersion of data

$^{A, B, C, D}$Values followed by the same letter(s) within the same column are not significantly different at $P < 0.05$ according to DNMRT; ***and **Denote significance at the 1 and 5% levels, respectively Software used: SPSS 13.0

Table 3 One-way ANOVA of cultivation regime for some varieties

Variety	Source	Sum of squares	df	Mean square	F	Sig.
Koshihikari	Between groups	4116673.67	2	2058336.84	4.793^{***}	0.010
	Within groups	52817561.96	123	429411.07		
	Total	56934235.63	125			
Akidawara	Between groups	2339769.85	1	2339769.85	5.296^{**}	0.025
	Within groups	28274331.97	64	441786.44		
	Total	30614101.82	65			
Yumehitachi	Between groups	1281241.80	2	640620.90	1.969	0.162
	Within groups	7808846.92	24	325368.62		
	Total	9090088.73	26			

Software: SPSS 13.0

was significant with the varieties of Koshihikari and Akidawara, at the significance level of 0.01 and 0.05, respectively, while it was insignificant with the variety of Yumehitachi (Table 3).

3.2 *Discussion on the Effect of Variety*

For further analysis on effect of the different varieties, we adopted four other factors: time of transplanting or sowing, growth duration from transplanting or sowing to earring, total nitrogen amount by fertilization, and field area. In our previous study (Li et al., 2015a), all these factors were demonstrated as significant determinants of paddy yield. To measure the effects of these factors, we divided the fields into three subsets same with those shown in Table 2. Results of ANOVA indicated that average values of all the four factors were significantly different across theses varieties and subsets (Table 4).

The transplanting dates ranged from April 14 to June 22. In most of the fields, paddy was transplanted simultaneously in May, accounting for the largest share in the total areas (Fig. 3). There was a clear trend that the growth duration got shortened when the transplanting season was relatively late. For instance, the paddy transplanted during April 11–20 can grow for 109 days before the earring stage, while those transplanted during April 11–20 can grow only for 58.5 days on average. For an easier analysis, we converted the time of transplanting or sowing to continuous numerals, with the earliest date of April 14 equal to 1 and the latest date of June 22 equal to 70. Ichibanboshi was transplanted earlier than the other varieties and its average growth duration amounted to more than 72 days. In contrast, Mangetsumochi was transplanted later than the other varieties and had the shortest growth duration of less than 60 days. Nitrogen is an essential element for paddy growth and its insufficiency could result in a yield decrease. In the sampled fields, total nitrogen amount was

Table 4 Yield determinants within varieties and subsets

Variety		Date of transplanting/sowing[a]	Growth duration (days)[b]	Nitrogen amount (kg/ha)[c]	Field area (m^2)
Akitakomachi		20.03	68.39	66.55	1625.33
Akidawara		41.26	79.55	74.05	2527.76
Ichibanboshi		13.37	72.53	76.93	4704.53
Koshihikari		34.22	72.27	52.12	2842.65
Yumehitachi		50.78	66.85	95.56	7211.41
Mangetsumochi		67.60	59.47	83.99	9709.40
Milky queen		49.50	67.17	62.94	5360.00
Subset (A)		27.23	72.99	70.46	2292.36
Subset (B)		31.49	72.30	55.37	3086.62
Subset (C)		55.88	64.58	87.53	7760.60
Total		33.66	71.58	66.09	3237.70
F value of one-way ANOVA	Variety[d]	244.611^{***f}	52.097***	40.107***	30.052***
	Subset[e]	132.763***	31.730***	97.898***	83.265***

[a] Time of transplanting or sowing, with the earliest date of April 14 = 1, while the latest date of June 22 = 70; [b] Days from transplanting/sowing stage to earring stage; [c] Calculation based on the amount of chicken manure, chemical fertilizer, ammonium sulfate, and urea fertilizer, according to the corresponding content of nitrogen; [d] Degree of freedom (df) of nitrogen amount is (6,342), the others are (6,344); [e] Ichibanboshi is excluded and the df of nitrogen amount is (2,327), while the others are (2,329); [f] ***Denotes significance at the 1% level

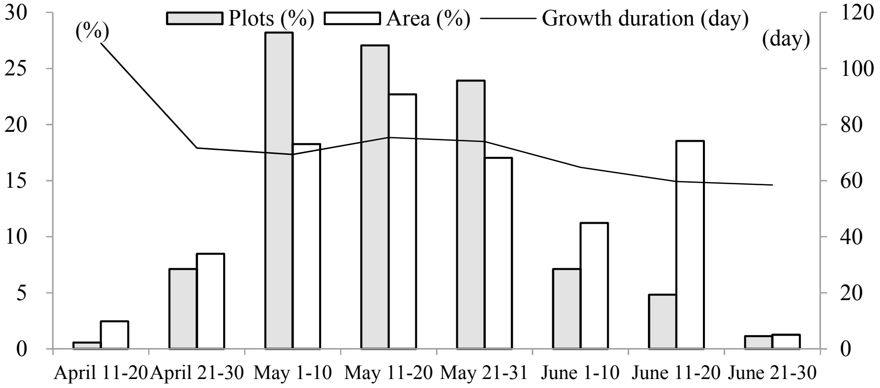

Fig. 3 Transplanting or sowing time and growth duration of 351 paddy fields of farm Y (Growth duration refers to the number of days from transplanting or sowing stage to earring stage)

calculated by the amount of chicken manure, chemical fertilizer, ammonium sulfate, and urea fertilizer, multiplied with the corresponding percentage of nitrogen. Among the seven varieties, Yumehitachi received the largest nitrogen amount of 95.56 kg per hectare from fertilization, while Koshihikari received the least with 52.12 kg per hectare. As for the field area, the highest and lowest average values were for Akidawara and Mangetsumochi, respectively (Table 4).

Although readable by individual varieties, it is much easier to analyze the relationship between yield and the factors by subsets. The highest-yielding subset (A) had the earliest date of transplanting or sowing, the longest growth duration, and most compact fields, while the lowest-yielding subset (C) was transplanted or sown in the latest stage, had the shortest growth duration, and the broadest fields. As for nitrogen, subset (A) had a moderate amount, while the largest amount was applied to subset (C). The reasons can be summarized as follows. (1) An earlier transplanting or sowing time and a longer growth duration are propitious to vegetative accumulation, hence, there are more nutrients to increase the plant height and panicle numbers in the full-heading stage and increase yield in terms of higher spikelet numbers, higher percentage of ripened grains, and heavier grains. (2) Although nitrogen is indispensable, its excessive use can lead to a thinner cell wall of the plant and weakened disease resistance, resulting in yield reduction. (3) Within the 351 fields, there was a significant ($p < 0.01$) negative correlation coefficient of -0.160 between the yield and field area. This could indicate that a relatively compact field area favors the evenness of fertilizer spread and increase yield in general.

Table 5 presents the yield at different levels of the four factors across the three subsets, where the data roughly follows a normal distribution in general. In other words, the high yields were centered near the medium values of each factor. Namely, those transplanted or seeded in May, growing for 60–70 days, 40–100 kg of nitrogen per hectare, field size of 2000–8000 m^2. For most of the factors, subset (A) had higher yields than the other two subsets, including for those transplanted or seeded in May, growing for 70–79 days before earring stage, nitrogen amount of more than 40 kg per hectare, and fields scaled less than 6000 m^2, according to the classification used in this chapter. In addition, the relationships between the factors and yield across the subsets were shown at the factor levels (Table 4). For instances, subsets (B) and (C) had the highest yield when transplanted or seeded during May 1–10 and April 11–20, respectively. The significant correlation coefficients of the yield with some factors were generally in agreement with the findings demonstrated above, including the negative correlation with transplanting or sowing time of subset (B) and the positive correlation with field area in subsets (B) and (C).

Table 5 Yield of different levels for each factor

Factors and levels	Yield (kg/ha)			Factor and level	Yield (kg/ha)		
	Subset (A)	Subset (B)	Subset (C)		Subset (A)	Subset (B)	Subset (C)
Date of transplanting/sowing				Total nitrogen amount (kg/ha)			
April 11–20			6349.05	<40	6073.25	6244.61	4948.20
April 21–30	6441.73			40–60	7343.20	6751.04	6215.20
May 1–10	7310.60	7153.03		60–80	7230.86	6920.68	6061.18
May 11–20	6940.27	6770.67	4770.10	80–100	8080.20		6018.72
May 21–31	7449.08	6503.37		> = 100	7559.30	6745.70	6266.94
June 1–10	4940.50		6140.12	Correlation	0.091	0.160^{*}	0.249^{*}
June 11–20			6047.95	Field area (m^2)			
June 21–30			5407.50	<1000	7001.59	6131.15	5295.37
Correlation[a]	0.100	-0.290^{***}	−0.081	1000–2000	7357.83	6552.92	5594.94
Growth duration (day)				2000–4000	7390.25	6891.34	5648.45
<60			5921.2833	4000–6000	7228.47	7016.62	6160.37
60–69	7281.24	7509.40	6058.4692	6000–8000	7049.05	7180.63	6169.30
70–79	7333.45	6733.96		8000–10000	4940.50	8380.10	6335.77
> = 80	6940.27		5822.7333	> = 10000		6988.46	6197.55
Correlation	−0.095	0.136	0.023	Correlation	−0.065	0.341^{***}	0.256^{*}

[a] Pearson's linear correlation calculated by SPSS 13.0; ***and *Denote significance at the 1 and 10% levels respectively

4 Conclusion

In Japan, the paddy production policy is transferring from acreage reduction to the expansion of exports with improved international competitiveness. The increased paddy yield is essential for improving exports and reducing the high production costs. Over the recent decades, agricultural corporations had a dramatic growth and they now represent the future of agricultural production in Japan.

Using yield data measured by smart combine harvester and other data from 351 paddy fields, this chapter analyzed the impact of rice variety and cultivation regime to paddy yield in a large-scale farm of over 113 hectares, located in the Kanto Region. The ANOVA result indicated that rice variety is a significant factor affecting paddy yield; the cultivation regime is found to be not significant, but it has a significant interactive effect with rice variety.

The rice varieties were divided into three subsets by adopting DNMRT. We also adopted four other factors: time of transplanting or sowing, growth duration from transplanting or sowing stage to earring stage, total nitrogen amount, and field area. Growth durations were found to be significantly shortened when the transplanting or sowing is later and vice versa. Further ANOVA across the three subsets showed that, a higher yield is possible with an earlier transplanting or sowing time, longer growth duration from transplanting or sowing stage to earring stage, moderate nitrogen amount, and a compact field area. Many of these conclusions were verified by further analyses, from different levels of the factors.

To sum up the key points for a higher paddy yield, it is essential to adopt the appropriate rice varieties in the first place. Moreover, a relatively earlier transplanting or sowing and longer growth duration are propitious to vegetative accumulation. A sufficient supply of nitrogen is important for paddy growth, while excessive application must be avoided. The fields should be of an appropriate size, to balance between scale economies (e.g., saving managerial costs and a larger sink size) and the even spread of fertilizer and pesticides.

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