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Impact Assessment of the Varieties and Cultivation Methods on Paddy Yield: Evidence from a Large–scale Farm in the Kanto Region of Japan

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This study aims to identify the impact of variety and cultivation method to paddy yield within the large–scale farms, which have been increasing over the latest decades in Japan. The study objects are 351 paddy fields in a farm corporation over 113 ha, locating in the Kanto region of Japan, and the yield is measured by smart combine. The result of ANOVA (Analysis of Variance) indicates that variety of paddy is a significant factor affecting the yield; although the cultivation method is not significant, it is significant interacting with the effect of variety. According to the result of Duncan's new multiple range test (DNMRT), the varieties are divided into three groups. Further analyses with the adoption of four factors and results of the following ANOVAs show that time of transplanting or sowing, growth duration from transplanting or sowing to earring, total Nitrogen amount and field area are effective factors. Finally, the key points for higher paddy yield are summarized, including suitable variety adoption, earlier transplanting or sowing and hence longer period for vegetative accumulation, sufficient Nitrogen application, and appropriate field areas.

Key words: ANOVA, Cultivation method, Paddy, Variety, Yield

INTRODUCTION

In recent decades, the recession of Japanese agriculture has drawn attention from scholars, officials, industrialists and so on. In 1985 to 2013, gross agriculture output decreased by 27% from 11.62 trillion JPY to 8.47 trillion JPY. Simultaneously, paddy output has decreased by 53.51%, from 3.83 trillion JPY to 1.78 trillion JPY. Although still accounting for the largest proportion, output of paddy in agriculture has decreased from 32.93% to 21.03% (MAFF, 2014a). Hence, the decreasing paddy production has dragged down the agricultural growth to a large extent (K. Ohizumi, 2014).

After came back to power in end of 2012, the LDP government 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, equipments, managerial models, etc. 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 has been designated to the UNESCO's Intangible Cultural Heritage List on 4th Dec., 2013. The government hopes to enhance global recognition and boost the exports of Japan's agricultural products including paddy.

However, the paddy agriculture of Japan is facing to high production costs, in addition to the market fluctuations, climate changes and other uncertainties. Despite of the decreasing trend over recent years, the average production costs of paddy in Japan was 253.82 JPY per kg, with the yield of 5.36 ton per ha by 2013 (MAFF, 2014b). In the same year, cost of paddy production was merely 30.03 JPY per kg, and the average yield was 10.17 ton per ha in the USA (USDA, 2014). Meanwhile, family farms especially the full–time ones have been reducing over the latest decades. In 1960, the number of farms was 6.07 million, within which the full–time farms were 2.08 million. By 2010, the two numbers have reduced to 2.53 and 0.45 million, respectively (MAFF, 2014c). By contrast, agricultural production corporations have made dramatic growth, from 2740 in 1970 to 14333 in 2014 (MAFF, 2014d). The top reasons include that different from family management, they possess stronger managerial ability, easier access to credit, diversified business development, better welfare and hence sufficient HR, etc. Hereby much more attention needs to be paid to agro–corps, which represent the trend of agricultural development. To increase paddy production with high quality and lower costs in Japan, it is urgent to establish an innovative technology system within the large–scale paddy farming. Meanwhile, to establish proactive paddy management coping with the uncertainties, another essential issue should be the organization and integration of cultivation, production and business management. Hereby the Japanese paddy is hoped to be competitive in the international market, with much added–value through both high quality and increased yield.

Some scholars have studied the determinants of paddy yield in Japan, as conducted by Y. Hirai *et al.* (2012), K. Tanaka *et al.* (2014), etc. In the concerning literature, variety and cultivation method have been proved to be important determinants of paddy yield (e.g.,

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Y. Nishiura and T. Wada 2012; A. Muazu *et al*., 2014; C. Ju *et al*., 2015). Accordingly, this research aims to identify the yield determinants from the perspective of paddy varieties and cultivation methods. Different from most the prior studies using experimental data, we use yield measured by smart combine, and other data from 351 paddy fields of a large–scale farm corporation locating in the Kanto Region of Japan.

MATERIALS AND METHODS

Paddy production in the 351 fields

All the 351 fields scatter compactly in a plain area within 2 km, thus paddy production can be carried out with relatively fewer agro–machinery by only 2 officers, 11 full–time staff and 5 temporary employees. Area of the fields range from 200 m^2 to 21148 m^2, and the average area is 3237.7 m^2. The major soil types include peat soil and gray lowland soil, accounting for 317 and 34 fields, 91.97 percent and 8.03 percent in total size, respectively.

Fig. 1 presents the shares of field number and areas of paddy fields being surveyed, according to the variety. Within the 7 varieties, Koshihikari takes the largest share in both number of fields and area. Akitakomachi is the second variety by the number of fields, while Yumehitachi ranked secondly in terms of the area. Meanwhile, among the 5 cultivation methods, the Conventional transplant takes the dominant position, with almost 70% in number of fields and 60% in area, followed by the Special transplant (Fig. 2).

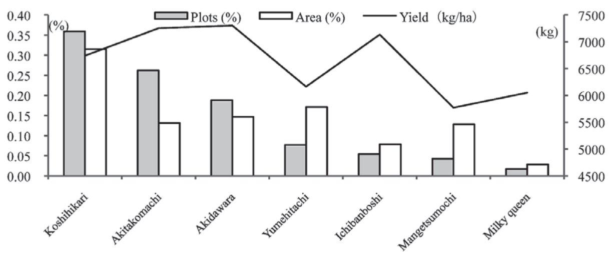

Fig. 1. Yield, share of field number and area among varieties.

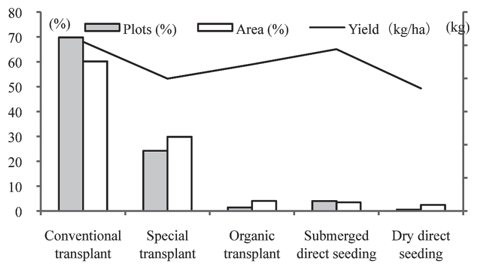

Fig. 2. Yield, share of field number and area among cultivation methods.

Statistical analysis

The effects of varieties and cultivation methods on paddy yield are analyzed using Two–way ANOVA. For the significant parameters, the means are compared using Duncan's new multiple range test (DNMRT), a post hoc multiple comparison method with the assumption of equal error variance. Within the varieties possessing plural cultivation methods, effects of the latter are further estimated using One–way ANOVA. All the analyses are performed using SPSS 13.0 for Windows.

RESULT AND DISCUSSION

Result of ANOVA analysis

As shown in Table 1, the model of Two–way ANOVA is significant at the level of 0.01, and variety is measured as being significant affecting paddy yield at the same level. Cultivation method is insignificant to the yield, but its interacting effect with the variety is shown as significant at 5 percent. Levene's test of equality of error variances ($p>0.10$) indicates that, the null hypothesis is acceptable, and thus no significant error variance of the dependent variable exits across the groups. The summary statistics of different varieties and cultivation methods are shown in Table 2, including paddy yield per ha converted by 15% of moisture, standardized deviation and the Coefficient of Variance (CV). Meanwhile, corresponding yield curves are available for reference in Fig. 1 and Fig. 2.

Moreover, as equality of error variances is testified in Table 1, the grouping information of yields based on DNMRT is provided as well in Table 2. As to effect of the varieties, average yields are divided into three subsets. The upper subset (A) includes Akidawara (7303.14 kg/ha), Akitakomachi (7253.93 kg/ha) and Ichibanboshi

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 method	3373552.89	1	3373552.89	6.70**	0.010
F_{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 study is the yield per ha converted by 15% of moisture Software: SPSS 13.0
b: Tests the null hypothesis that the error variance of the dependent variable is equal across groups
***and** denote significant at 1%, 5% respectively Source: survey by the authors in 2014

Table 2. Paddy yield by the varieties and cultivation methods

Variety and Cultivation method		N	Averageyield (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[AB]	715.81	10.03
	Mangetsumochi	15	5771.73[C]	751.05	13.01
	Milky queen	6	6050.08[C]	318.45	5.26
Cultivation method	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 method	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
	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: being ratio of the standard deviation to mean, CV (Coefficient of Variance) showcases 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 Duncan's new multiple range test (DNMRT); ***and** denote significant at 1%, 5% respectively
Source: survey by the authors in 2014 Software: SPSS 13.0

Table 3. One-way ANOVA of cultivation method within 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			

Source: survey by the authors in 2014 Software: SPSS 13.0

Table 4. Yield determinants within varieties and subsets

Variety		Date of transplanting/ sowing [a]	Growthduration (day) [b]	Nitrogenamount (kg/ha) [c]	Fieldarea (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=0; b: days from transplanting/sowing to earring; c: Calculation based on the amounts of chicken manure, Chemical fertilizer, Ammonium sulfate and urea fertilizers, according to the corresponding contents of Nitrogen; d: Degree of freedom (df) of Nitrogen amount is (6, 342,), the others are (6, 344); e: Ichibanboshi excluded, and the df of Nitrogen amount is (2, 327), while the others are (2, 329); f: *** denotes significant at 1%   Source: survey by the authors in 2014

(7134.20 kg/ha); the moderate subset (B) consists of Ichibanboshi (7134.20 kg/ha) and Koshihikari (6740.11 kg/ha); while the lower subset (C) comprises Yumehitachi (6162.95 kg/ha), Milky queen (6050.08 kg/ha) and Mangetsumochi (5771.73 kg/ha). Except for Ichibanboshi which covers the two subsets of both (A) and (B), the grouped varieties are different from those of other subsets in terms of the average yield. By contrast, average yields cannot be divided to different subsets, from the perspective of the cultivation methods. Hence it is insignificant to identify yield variance and be in agreement with the result of ANOVA.

With respect to the significantly interacting effect of variety and cultivation method, One–way ANOVA is adopted to test the effect of the plural levels of cultivation methods within some varieties. The result indicates that cultivation method is significant with Koshihikari and Akidawara, at the significance level of 0.01 and 0.05, respectively, while insignificant with Yumehitachi (Table 3).

Discussion on the effect of variety

For further analysis on effect of the different varieties, we adopt other four factors: time of transplanting or sowing, growth duration from transplanting or sowing to earring, total Nitrogen amount by fertilizing and field area. In our prior study (D. Li *et al.*, 2015), all of these factors are demonstrated as significant determinants of paddy yield. To measure the effects of these factors, we divide the fields into 3 subsets same with those shown in Table 2. Results of ANOVA indicate that mean values of all the 4 factors are significantly different across theses varieties and subsets (Table 4).

The transplanting dates range from April 14 to June 22. In most of the fields, paddy is transplanted in May, amounting for the largest share of areas in total simultaneously (Fig. 3). Meanwhile, there is a clear trend that growth duration goes shortened, when the transplanting season is relatively later. For instance, the paddy transplanted during April 11–20 can grow for 109 days before earring, while those transplanted during June 21–30 can grow only for 58.5 days on average. For easier analysis, we converted the time of transplanting or sowing to continuous numerals, with the earliest date of April 14 equals to1, while the latest date of June 22 equals to 70. Ichibanboshi is transplanted earlier than the other varieties, and the average growth duration is amounted to more than 72 days. By contrast, Mangetsumochi has the latest average time of transplanting and the shortest growth duration of less than 60 days. Nitrogen is an essential element for paddy growth, and the insufficiency may result in yield decrease. In the sampled paddy fields,

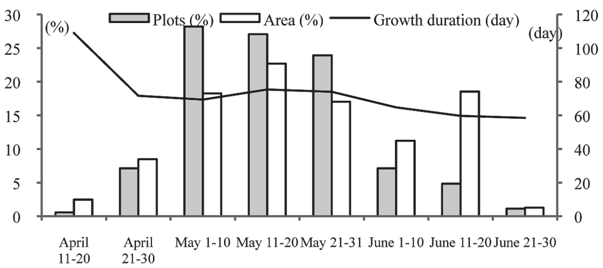

Fig. 3. Transplanting/sowing time and growth duration
(Growth duration refers to the days from transplanting/sowing to earring)
Source: survey by the authors in 2014

Table 5. Yield of different levels within each factor

Factor and level	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 significant at 1%, 10% respectively
Source: survey by the authors in 2014

total Nitrogen amount is calculated by the amounts of chicken manure, chemical fertilizer, Ammonium sulfate and urea fertilizers, multiplying with the corresponding percentages of Nitrogen. Among the varieties, Yumehitachi is applied with the largest Nitrogen amount of 95.56 kg per ha from fertilization, while the lowest amount of Nitrogen is applied to Koshihikari with 52.12 kg per ha. As for the field area, the biggest and smallest average value occurs in Akidawara and Mangetsumochi, respectively (Table 4).

Although readable by individual varieties, it is much easier to analyze the relationship between yield and the factors in subsets. The highest–yielding subset (A) has the earliest date of transplanting or sowing, the longest growth duration and mostly compact field, while the lowest–yielding subset (C) holds the latest time of transplanting or sowing, the shortest growth duration and the broadest field. As for the Nitrogen, subset (A) uses the moderate amount, and largest amount is used in subset (C). The reasons can be summarized as follow: (1) Earlier transplanting or sowing time and longer growth duration are propitious to the vegetative accumulation, and hence more nutrients to increase the plant height and panicle numbers in full–heading stage, and help to increase the yield from the respects of larger spikelet number, higher percentage of ripened grains and heavier grains. (2) Although Nitrogen is indispensible, the excessively use can lead to thinner cell wall of the plant and weakened disease resistance, thus result in yield reduction. (3) Within the 351 fields, a significant ($p<0.01$) negative correlation coefficient of –0.160 is observed between the yield and field area. It may indicate that relatively compact field area favors the evenness of fertilizer spread, and increase yield in the general cases.

Table 5 presents the yield of different levels of the four factors across the three subsets, where the data follows roughly the Normal distribution in general. In other words, the high yields are gathering near the medium levels of each factor, i.e., those transplanted or seeded in May, growing for 60–70 days, 40–100 kg of Nitrogen per ha, field of 2000–8000 m^2. In most of the levels, subset (A) yields higher than the other two subsets, including those transplanted or seeded in May, growing for 70–79 days before earring, Nitrogen amounted more than 40 kg per ha and fields scaled less than 6000 m^2, according to the division in this study. In addition, relationship between the factors and yield across subsets shown in Table 4 can be proved upon factor levels. For instances, subset (B) and (C) have the highest yield when being transplanted or seeded during May 1–10 and April 11–20, respectively. The significant correlation coefficients of the yield with some factors are generally in agreement with the findings demonstrated above, including the negative correlation with transplanting or sowing time of subset (B), and positive correlation with field area in subset (B) and (C).

CONCLUSIONS

In Japan, the keynote policy for paddy production is changing from acreage reduction, to expand the exports actively and improve the international competitiveness. Hence the increasing of paddy yield is essential in terms of improving the exports and reducing the high production costs. Over the latest decades, agricultural production corporations have made dramatic growth, and they represent the trend of agricultural production in Japan.

Using yield data measured by smart combine and other data from 351 paddy fields, this study analyzed the impact of variety and cultivation method to paddy yield within an incorporated large–scale farm over 113 ha, locating in the Kanto region of Japan. Result of the ANOVA indicated that variety is a significant factor affecting paddy yield; the cultivation method is found to be not significant, but it is significant to effect interactively with the variety.

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

To sum up the key points for higher paddy yield, it is essential to adopt appropriate varieties in the first place. Moreover, relatively earlier transplanting or sowing and hence longer growth duration are propitious to the vegetative accumulation. Sufficient supply of Nitrogen is of great importance to paddy growth, but the excessive application must be avoided. The fields need to be kept in appropriate area, for the balance between scale economy, e.g., saving managerial costs and bearing larger sink size (spikelet number per unit land area) with a relatively spacious filed, and the evenness spread of fertilizer and pesticides with a relatively compact field.

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