Identifying the Rice Yield Determinants Among Comprehensive Factors

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Paddy production in Japan is currently undergoing a transition, moving away from the former acreage reduction policies of the 1970s to improve the sector's efficiency and competitiveness. Meanwhile, agricultural production corporations and the adoption of ICT and GAP have been steadily increasing over last decades. This chapter aimed to identify the determinants of paddy yield measured by smart combine harvester within large-scale farms. The sample included 351 paddy fields from a farm corporation scaled over 113 hectares, located in the Kanto region of Japan. The candidate determinants included the continuous variables of field area and condition evaluation scores, transplanting or sowing time, and amount of nitrogen, as well as the stage-specific growth indicators for chlorophyll contain, number of panicles, plant height, and leaf plate value. Meanwhile, three discrete variables including variety, cultivation regime, and soil type were also adopted. Empirical analysis was conducted using a multivariate linear regression, with logarithmic transformations of the continuous

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variables. Within the continuous variables, transplanting or sowing time was identified as possessing the largest absolute standardized regression coefficient, and thus be the most important determinant. The negative coefficient indicated that earlier transplanting or sowing benefits vegetative growth, thus panicle number and plant height in heading stage, which were identified as positively significant together with field area, and amount of nitrogen. Within the discrete determinants, Akidawara was measured as a productive variety, while the well-drained and submerged direct sowing were identified as negatively affecting yield.

1 Introduction

As the staple crop in Japan, paddy accounted for the largest proportion of gross agriculture output in 2013 at 21.03% (MAFF 2014a). However, recently, paddy production has been decreasing and, consequently, overall agricultural growth has decreased (Ohizumi 2014). In 2014, paddy yielded 8.43 million metric tons, which was a decrease of 40.27% from 11.83 million metric tons in 1985. Within the same period, the planted area of paddy decreased by 45.58% from 2.29 million hectares to 1.57 million hectares. Since 2000, the average yield of paddy per hectare has been stagnant at approximately 5.30–5.40 metric tons. Especially during 2012–2014, paddy yield decreased from 5.40 to 5.36 metric tons per hectare (Komenet 2020), while the average paddy yield in the US amounted to 10.17 metric tons per hectare. Meanwhile, paddy production in Japan is faced with high costs examined by per weight unit. In 2013, the average production cost of paddy in Japan was 258 JPY per kilogram of brown rice (MAFF 2016), which was much higher than the average of merely about 35 JPY per kilogram of brown rice in the US (USDA 2014). Thus, according to the Japan Revitalization Strategy released in 2014, paddy production cost must be reduced by 40% over the next 10 years, as compared with the current national average value (PMJHC 2014).

Since recapturing control of the government at end of 2012, the government of liberal democratic party (LDP) has been pushing forward a series of measures under the program "Creating dynamism in agriculture, forestry and fisheries", to increase the efficiency and competitiveness of these sectors in Japan. Regarding agriculture, it is essential to reduce production costs and to improve yields through the fiscal subsides aimed at the adoption of efficient technologies, equipment, and managerial models. To increase paddy yield per unit of land area and, hence, reduce average production costs per kilogram, the government has declared that since 2018, the rice acreage reduction policy adopted in the early 1970s had been abolished, to expand production and exports for improved international competitiveness (Nikkei 2013).

Within the last decades, the number of agricultural production corporations has grown dramatically, from 2,740 in 1970, to 14,333 in 2014 (MAFF 2014b), and they have become important producers of paddy. The major reasons behind this boom include greater access to larger arable lands, stronger managerial ability, easier access to credit, diversified business development opportunities, better welfare, and, hence, ample human resource capabilities. Thus, more attention should be paid to agricultural corporations, which represent the current trend of agricultural development in Japan. Nevertheless, such large-scale farms usually own scattered paddy fields, with different scales, soil properties, altitudes, humidity, and exposure to the sun (JSAI 2014). At the same time, to address the problems related to agriculture, food, and the environment, the notion of GAP has spread throughout Japan. With respect to paddy production, GAP can improve an individual's work and consuming conditions, environmental protection (i.e., through the appropriate application of agro-chemicals and concerns for biodiversity), and food safety (i.e., food that is free from contamination and has balanced nutrition) (Li et al. 2014). Under these circumstances, to increase yield through reduced paddy production costs and according to GAP, ICT has been adopted and promoted to process the enormous amount of information available in sectors with innovative cultivation, production, and managerial technologies (JSAI 2014; Nanseki 2015).

In this chapter, we investigated paddy production and identify the yield determinants of large-scale farming in Japan, based on a case study of 351 paddy fields. There are prior studies on the determinants of paddy yield up to field-level on-farm data overseas include Abdullah and Ali (2014), Barrett et al. (2010), or using the experimental data sampled in Japan include Hirai et al. (2012). However, we found few similar studies sampling on-farm data of field-level in Japan. In the studies using samples from agricultural experiment institutions, the field areas are usually relatively small, rarely considering the costs and time, and the analyses are apt to be limited in cultivation test from the perspectives of agronomy and crop sciences. By contrast, the studies of "NoshoNavi1000" aimed to conduct empirical analysis obtaining practical results, using actual data collected in large-scale paddy farms with the consideration of costs and time. In addition, we adopted an explanatory variable, score of field evaluation, to reflect the field height, former crop, uneven soil fertility, illumination and herbicide application, water depth, leakage and inletting, all of which are difficult to be considered in experimental samples.

In this chapter, all the field-level data were sampled from a corporation farm locates in Ibaraki Prefecture, the Kanto Region of Japan. In this large-scale farm, yield data of each field was measured by smart combine harvester, besides which we collected other data with the cooperation of farm managers and fieldwork practitioners. It aimed to develop and demonstrate the smart paddy agriculture models implemented by the agricultural production corporations with the integration of ICT agro-machinery, field sensors, visualization farming, and skills transfer systems. Thereafter, it is indispensable to not only save the average fixed costs of rice production, but also provide clues to reduce the costs per kilogram directly, from less inputs respect to the significant determinants.

2 Materials and Methods

2.1 Yield Definition

In this chapter, paddy refers to the raw rice grain before threshing the hull, as illustrated in Fig. 7 in chapter "Smart Rice Farming, Managerial Model and Empirical Analysis". This definition is in accordance with the measurement of rice yield in most countries, e.g., the US, China, and Korea. According to the national standards of brown rice inspection in Japan (MAFF 2014c), the yield used in the following analyses was converted paddy with 15% moisture. At the same time, paddy weight and the percentage of moisture content applied were monitored directly by smart combine harvester equipped with a global navigation satellite system (GNSS) (Isemura et al. 2015). Accordingly, these measurements were more accurate than those of the estimated weight of brown rice by sampling. The calculations of the paddy yield for the 351 fields were shown in Table 1. Specifically, paddy yield was determined by

Table 1 Calculations of paddy yields of the 351 paddy fields

Field	Raw yield (kg)	Average moisture (%)	Total yield[a] (kg)	Field area (m^2)	Average yield[a] (kg/ha)
	(a)	(b)	(c) $= (a) \times [100-(b)]/85$	(d)	(e) $= 10{,}000 \times (c)/(d)$
No. 1	7894.10	20.80	7355.40	10389.00	7079.99
No. 2	7555.40	23.30	6817.50	10397.00	6557.18
…	…	…	…	…	…
No. 351	4126.30	20.10	3878.70	6000.00	6464.50
Min.	103.60	1.61	100.10	200.00	3484.44
Max.	13388.40	31.60	12871.60	21148.00	9945.93
Mean	2383.68	21.91	2189.89	3237.70	6904.42
Std.D.	2384.19	3.26	2191.54	3428.18	833.32
CV (%)	100.02	14.89	100.08	105.88	12.07

[a]Converted yield using a moisture content of 15%
Source Survey conducted by the authors in 2014

the following four factors: number of panicles, spikelet number per panicle, ratio of filled grains, and grain weight (CSSJ 2002).

2.2 Continuous Explanatory Variables

We constructed an indicator system of 25 continuous variables to outline paddy production and to present the candidate yield determinants of the sampled fields. As shown in Table 2, the continuous variables were divided into 3 types: (1) the basic attributes of the paddy fields showcased by area and the managers' general evaluation of planting conditions; (2) the general situation of growth management presented by date of transplanting or sowing and amount of nitrogen from fertilizer; and (3) detailed growth information, including the chlorophyll meter value of the SPAD, number of stems or panicles per hill, plant height, and individual and community LPV by the stage of panicle growth for the forming, heading, 10 days after full-heading, and maturity stages, as well as panicle length for the maturity stage only.

As denoted in Table 2, in addition to the field height, former crop, uneven soil fertility, illumination and herbicide application, field condition was evaluated by the water depth, water leakage, water inletting. These indicators were included considering that water is of essential importance to paddy planting. The overall score of field evaluation was the sum of these individual aspects, evaluated by the farm managers based on the referential criteria. For instance, a paddy field was scored 2–5 when the field-submerged water can be kept for less than 1 day, 1–2 days, 2–4 days, over 4 days; with a daily leakage of over 5 cm, 3–5 cm, 1–3 cm, less than 1 cm, respectively. Meanwhile, the condition of water inlet was scored 0–5 in terms of the time needed before field-submerged level, varying from over 48 h, 24–48 h, 12–24 h, 6–12 h, 3–6 h to less than 3 h. The date of transplanting or sowing was transformed by setting the earliest date of April 14 as 1, and the latest of June 22 as 70. Nitrogen was calculated based on the amounts of chicken manure, chemical fertilizer, ammonium sulfate, and urea fertilizers, and the corresponding nitrogen contents.

2.3 Discrete Explanatory Variables

This chapter used variety and cultivation regime to analyze the determinants of paddy yield, which was like some prior studies, including Nishiura and Wada (2012), Muazu et al. (2014), and Ju et al. (2015). In addition, soil properties may affect growth and yield from the perspective of nutrition content, water drainage and conservation, and aeration (CSSJ 2002). Therefore, we investigated the soil types of the sampled paddy fields using the soil information navigation system of the national institute for agro-environmental sciences (NIAES 2015). We created a dummy variable named *soil type*, with the binary values of *gray lowland soil* and *peat soil*. A summary of the statistics of paddy yield by discrete variable are shown in Table 2.

Table 2 Summary of the explanatory variables

Continuous variable	Unit	N	Min.	Max.	Mean	Std.D.	CV (%)
Field area	(m^2)	351	200.00	21148.00	3237.70	3428.18	105.88
Score of field evaluation[a]	–	349	0.00	38.90	32.13	4.56	14.18
Date of transplanting/sowing[b]	(day)	351	1.00	70.00	33.66	13.98	41.55
Nitrogen from fertilizers per hectare[c]	(kg/ha)	349	14.00	148.83	66.09	20.02	30.29
SPAD in panicle-forming stage	–	351	26.30	63.30	36.06	4.26	11.82
Stems per hill in panicle-forming stage	(plant/hill)	351	13.80	34.60	24.34	4.18	17.15
Plant height in panicle-forming stage	(cm)	351	57.70	112.70	86.66	10.38	11.98
Individual LPV in panicle-forming stage	–	351	2.60	6.00	4.39	0.58	13.31
Community LPV in panicle-forming stage	–	351	2.00	6.00	4.29	0.73	17.05
SPAD in heading stage	–	347	24.60	50.70	35.60	4.17	11.72
Panicles per hill in heading stage	(plant/hill)	347	13.30	42.40	23.52	4.36	18.55
Plant height in heading stage	(cm)	347	79.50	117.60	102.61	6.71	6.54
Individual LPV in heading stage	–	347	2.60	6.20	4.47	0.67	14.98
Community LPV in heading stage	–	344	2.00	6.00	4.31	0.73	17.02
SPAD 10 days after full-heading	–	350	20.10	46.80	34.93	3.86	11.05
Panicles per hill 10 days after full-heading	(plant/hill)	350	12.60	33.30	23.23	3.92	16.89
Plant height 10 days after full-heading	(cm)	350	80.90	124.20	106.08	6.27	5.91

(continued)

Table 2 (continued)

Continuous variable	Unit	N	Min.	Max.	Mean	Std.D.	CV (%)
Individual LPV 10 days after full-heading	–	350	2.00	6.00	4.05	0.75	18.42
Community LPV 10 days after full-heading	–	349	2.00	6.00	4.02	0.74	18.40
SPAD in maturity stage	–	350	12.80	42.30	31.31	4.71	15.04
Individual LPV in maturity stage	–	350	1.00	6.40	3.18	0.79	24.79
Community LPV in maturity stage	–	350	1.00	6.00	3.13	0.82	26.22
Panicles per hill in maturity stage	(plant/hill)	350	12.80	33.50	23.12	3.86	16.72
Panicle length in maturity stage	(cm)	349	16.90	23.80	19.99	1.23	6.14
Plant height in maturity stage	(cm)	350	65.60	99.30	83.95	5.87	7.00
Dummy variable		N	Yield (kg/ha)				
			Min.	Max.	Mean	Std.D.	CV (%)
Variety	Koshihikari (V_1)	126	4778.10	8544.40	6740.11	674.89	10.01
	Akitakomachi (V_2)	92	5286.40	9945.90	7253.93	839.80	11.58
	Akidawara (V_3)	66	4940.50	9141.80	7303.14	686.28	9.40
	Yumehitachi (V_4)	27	4770.10	7023.60	6162.95	591.29	9.59
	Ichibanboshi (V_5)	19	6120.20	8866.90	7134.20	715.81	10.03
	Mangetsumochi (V_6)	15	3484.40	6848.70	5771.73	751.05	13.01
	Milky queen (V_7)	6	5578.80	6412.00	6050.08	318.45	5.26
Cultivation regime	Conventional transplant	245	3484.40	9945.90	7052.53	870.66	8.75

(continued)

Table 2 (continued)

Continuous variable	Unit	N	Min.	Max.	Mean	Std.D.	CV (%)
	Special transplant[d]	85	4770.10	8380.10	6496.03	589.75	7.04
	Organic transplant[e]	5	6441.10	7080.00	6711.14	310.07	4.38
	Submerged direct sowing[f]	14	6126.50	9085.70	6940.27	761.47	8.38
	Well-drained direct sowing[g]	2	5812.60	6885.50	6349.05	758.65	11.02
Soil type	Gray lowland soil	34	5524.70	8393.30	7068.72	700.05	8.34
	Peat soil	317	3484.40	9945.90	6886.79	845.43	8.50

[a]Evaluation items include variables concerning height difference, water depth, water leakage, former crop, water inletting, uneven soil fertility, illumination, and herbicide application; [b]The earliest date of April 14 = 1 and the latest date of June 22 = 70; [c]Calculation based on the amounts of chicken manure, chemical fertilizer, ammonium sulfate, and urea fertilizers, and the corresponding nitrogen contents. [d]Paddy cultivated by seedlings with a 50% reduction in the amount of nitrogen contained in the fertilizers and pesticides according to national guidelines; [e]Paddy cultivated by seedlings and improved soil fertility by organic fertilizers, rather than chemical fertilizers and pesticides; [f]Direct sowing on flooded paddy field; [g]Direct sowing on well-drained paddy field
Source Survey conducted by the authors in 2014

2.4 Statistical Analysis

The impact of the explanatory variables on paddy yield was analyzed using a multivariate regression. Similar with Barrett et al. (2010), values of the yield and the continuous variables were taken natural logarithmic transformations, to make easier interpretation of the regression coefficients in terms of elasticity (Gujarati 2015). All analyses were performed using SPSS 13.0 for Windows.

3 Results and Discussion

3.1 Relationship Between Yield and the Determinants

In the initial multivariate regression model, the independent variables included all continuous and discrete variables shown in Table 2. For each discrete variable, a dummy variable was formulated taking the value of 1 or 0 to indicate the presence or absence, respectively, of the categorical effect. However, as some of these variables may be redundant, leading to higher occurrence of multicollinearity and inefficient coefficient estimators with over-large variances (Gujarati 2015). Thus, we refined the

Table 3 Results of the log-linear multivariate regression estimation

Independent variable	B[a]	ΔY%[b]	Std. B	t	VIF
(Constant)	5.657			12.792	
Date of transplanting (X_1)	−0.153***	−0.152	−0.620	−7.049	4.846
Number of ears in heading stage (X_2)	0.224***	0.223	0.355	5.921	2.244
Plant height in heading stage (X_3)	0.552***	0.551	0.304	5.243	2.109
Field area (X_4)	0.026***	0.026	0.171	3.641	1.387
Nitrogen from fertilizers per hectare (X_5)	0.052***	0.052	0.128	2.747	1.354
Akidawara (D_1)	0.200***	22.175	0.646	12.124	1.775
Well-drained direct sowing (D_2)	−0.591***	−44.605	−0.370	−6.029	2.353
Submerged direct sowing (D_3)	−0.146***	−13.584	−0.238	−5.006	1.409
Valid $N = 345$; $F = 36.201^{***}$; Adjusted $R^2 = 0.450$; LM test: $0.118 \times 336 = 39.648 < \chi^2$ (0.01, 38) = 61.162					

[a]*** implies significant at the 1% level; [b]Percentage of paddy yield changes due to a 1% increase of X_i by $= 100^*(1.01^B - 1)$; and due to value of D_i shifting from 0 to 1 by $100^*(e^B - 1)$
Variable selection: backward; Software: SPSS 13.0

regressors by adopting the *Backward* method of SPSS. According to the estimation result, five continuous and three discrete variables were included in the final model (Table 3). The value of the adjusted R^2 denoted that 45% of the variation in the dependent variable, for the sample of 345 valid paddy fields, can be explained by eight significant independent variables. The significant values of the F-test and t-statistics showed that both the model and each independent variable can help identify the variation. The VIFs of all dependent variables were less than 10; hence, we eliminated the probability of collinearity. In the standardized residual plot of the regression, as shown in Fig. 1, the expected cumulative probability increases as the observed cumulative probability increases. This indicates that heteroskedasticity does not exist in the final model (Carter et al. 2012). In addition, the Lagrange multiplier (LM) test indicated that there is no significant bias generated due to the variable refinement, with a significant level of 0.01 (Gujarati 2015).

In Table 3, Column "B" contains the unstandardized estimated regression coefficients. For each continuous variable (X_i), the coefficient is the elasticity of yield with respect to X_i. With respect to X_1, the negative coefficient indicated that earlier transplanting or sowing can increase paddy yield. For a certain date, a 1% decrease of the transformed value can increase yield by 0.153%, holding other variables fixed. For a more exact calculation, the estimated yield increased by $1.01^{0.153} - 1 = 0.152\%$ (Wooldridge 2013). Similarly, for the other significant determinants, a 1% increase in the number of panicles in the heading stage, plant height in the heading stage, field area, and amount of nitrogen was estimated to increase yield by roughly 0.224, 0.552, 0.026, and 0.052%, respectively. Table 3 shows the percentage change in paddy yield due to a 1% increase of each X_i. For the dummy independent variable (D_i), the estimated coefficient implies yield changes by $e^B - 1$ when D_i shifts from 0 to 1, keeping other explanatory variables constant (Wooldridge 2013). Thus, for Akidawara, the

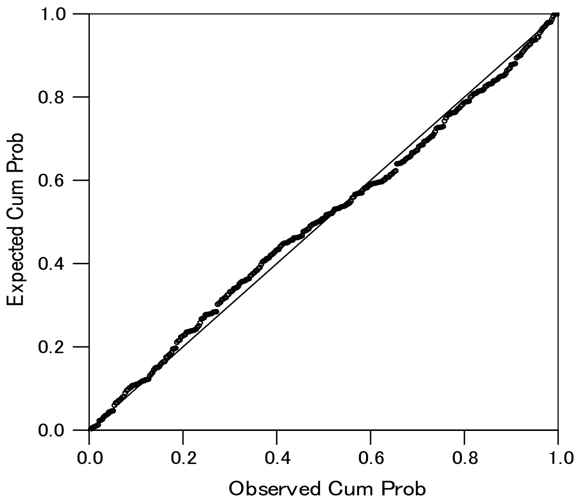

Fig. 1 Plot of standardized residuals

coefficient of 0.2 denoted a 22.14% higher paddy yield, while well-drained direct sowing and submerged direct sowing present a paddy yield of 44.62 and 13.58% less than the average value, respectively, holding other factors constant (Table 3).

Of the continuous variables, the unstandardized coefficient (B) is affected by the unit of measurement. Hence, we calculated the standardized coefficient, the absolute values of which show the relative importance of the explanatory variables. For example, according to the data in Column "Std. B" in Table 3, transplanting or sowing was measured as the most effective continuous factor affecting paddy yield.

3.2 Impact of the Continuous Determinants

(1) We find that earlier transplanting or sowing leads to higher yields. Generally, earlier transplanting or sowing is followed by a longer vegetation period that allows the paddy to accumulate more nutrients and improve growth in later stages. Another study (Li et al. 2015) found that the duration of growth is shortened with later transplanting or sowing. As cited in former chapter, paddy transplanted during April 11–20 can grow for 109 days before heading, while those transplanted or sowed during June 21–30 can grow only for 58.5 days on average. A shortened period of vegetative growth usually results in a reduced number of panicles and spikelet and a poor ripening ratio (NAFRO 2011).

(2) The heading stage refers to the stage when 40–50% of the stalks have finished sprouting panicles. This is an important stage in which to judge the growth and other properties of the variety for the whole year (Goto et al. 2000). Thereafter, the focuses of cultivation management shift from stem and leaf growth, to panicle growth and grain filling. According to the determinants of paddy yield

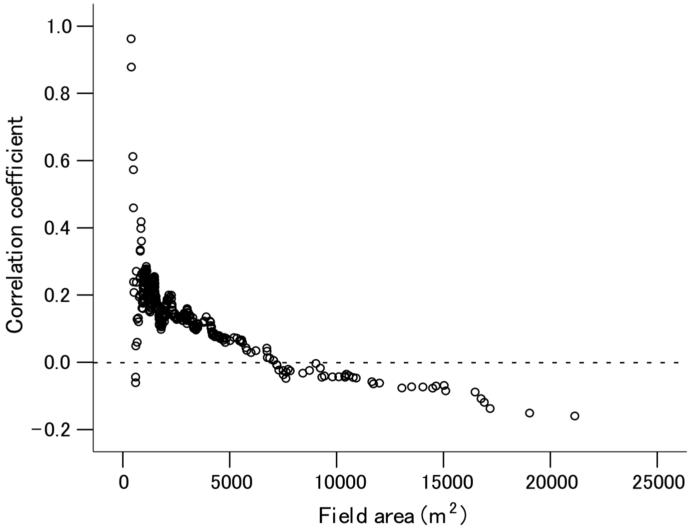

Fig. 2 Correlation coefficient of field area and paddy yield

as defined above, more panicles in this stage directly increase yield. Additionally, a higher plant height can increase yield through longer panicles and, hence, more spikelet per panicle.

(3) Within this sample, positive correlation coefficients were observed between yield and field area for the 312 of the 351 fields comprised of less than 0.7 hectares (Fig. 2). This suggested that with fields scaled less than approximately 0.7 hectares, a larger field area can usually increase yield through an enlarged sink size. Analyzing this result from the perspective of farm management, an appropriately enlarged field area can achieve economies of scale. Specifically, economies of scale include the advantages of savings in fixed costs per unit of yield and reduced variable costs, such as moving the combine harvesters among fields and water and agro-chemicals wasted due to longer ditches and ridges.

(4) As an essential element for paddy growth, nitrogen exists mainly in the form of a protein, particularly rubisco, which accounts for 20–30% of the total amount of nitrogen used in paddy cultivation (CSSJ 2002). Generally, nitrogen increases paddy yield by enhancing photosynthesis. More than 90% of crop biomass is derived from photosynthesis, and rice has been found to possess a high photosynthesis rate, which is 10 times that of some evergreen trees (Makino 2011). Therefore, we found that an increased amount of nitrogen positively relates to paddy yield, when kept at an appropriate level that does not lead to lodging or other negative consequences.

3.3 Impact of the Discrete Determinants

As measured in our earlier study (Li et al. 2015), variety significantly affected the paddy yield of this sample. Akidawara, being a new, lodging-resistant, high-yielding variety, is suitable for cultivation in the Kanto Region. In this chapter, Akidawara yielded 7,303.14 kilograms per hectare on average, possessing the highest yield among the seven varieties. The average yield of the other six varieties was 6,812.08 kilograms per hectare, which was 7.21% lower than that of Akidawara (Table 2). Meanwhile, Akidawara had the longest growth period of 79.55 days from transplanting to heading, which was almost 10 days longer than the average growth period of the other varieties. Thus, according to the analysis above, Akidawara has an advantage because of its prolonged vegetative growth, which leads to more panicles, spikelets, and an increased ripening ratio.

Direct sowing is a conventional cultivation regime that is outstanding in reducing labor and energy. However, due to the general flaws of spatially unbalanced seeding establishment, poor resistance to weed damage, and the occurrence of lodging, directly sowed paddy yields are lower than transplanted paddy yields in most cases. With respect to the well-drained direct sowing, we found problems related to sowing time due to weather and nutrient loss from cracked soil (CSSJ 2002). Reviewing the results of the survey data shown in Table 2, the yield of the paddy cultivated using the well-drained direct sowing was the lowest, showcased the largest data dispersion denoted by the CVs among the five cultivation regimes. In addition, this method reported the smallest number of panicles in heading stage. With respect to submerged direct sowing, this method was only used to cultivate Akidawara; the average yield of submerged direct sowing was less than that of the other cultivation regimes. Plant heights in the heading stage were the lowest in both direct sowing methods, with the similar values of 94.25 and 94.02 for well-drained and submerged direct sowing, respectively.

4 Conclusion

In the initial multivariate regression analysis, the candidate determinants included a variety of continuous variables for yield, field characteristics, transplant time, amount of nitrogen from fertilizer, and growth by stage. In addition, three discrete variables were included to present rice variety, cultivation regime, and soil type. The results of the multivariate regression analysis showed that an earlier transplanting date was the most important determinant of increased paddy yield. Other significant determinants included number of panicles and plant height in the heading stage, field area, and amount of nitrogen, all of which have a positive impact on paddy yield. Of the discrete determinants, Akidawara was measured as the most productive variety, while the direct sowing methods of both well-drained and submerged paddy fields were identified as negatively affecting yield. At the same time, as denoted by the adjusted

R^2, this model did not explained more than half of the yield variation. Hence, it may be necessary to adopt more explanatory variables to conduct further measurements of yield determinants. As paddy yield is affected by the circumstances of planting, we will collect the relevant data, starting with data on meteorology and soil analysis. The meteorological indicators will include temperature, amount of solar radiation, precipitation, water level, and temperature. The soil analysis will present the contents and saturation of the major chemical compositions, such as pH, CEC, and the elements of nitrogen, potassium, phosphorus, calcium, magnesium, silicon, iron, zinc, and copper, among others; humus to reduce fertilizer scorch, conserve water, and maintain permeability; and other substances that assist in the decomposition of organic matter and protect against insects and disease. We adopted more variables in following chapters and hope to improve our empirical estimations.

These empirical findings were referential for farm managers, in terms of the solutions recommended to increase paddy yield, while reduce the production costs per weight unit simultaneously. Nevertheless, paddy production within large-scale farms is a systematic procedure, subject to the constraints of labor, funds, and machinery. For instance, although earlier transplanting or sowing has been shown to increase yield, it may be unrealistic or uneconomical to transplant or sow on many fields simultaneously. Thus, optimal planning is necessary to conduct transplanting or sowing during different times and to make full use of the limited machinery, labor, and funds (Chomei et al. 2015). Meanwhile, fertilizer amount and field allocation need to be optimized in further studies, considering the properties of the different varieties. As analyzed above, the adoption of direct sowing negatively relates to yield increasing; however, the attributes of this method were in line with the sustainable ideas of GAP. Hence, additional rice varieties suitable for direct sowing should be bred and adopted.

In this chapter, we conducted cross-sectional analysis on the yield determinants of individual paddy fields. In the following chapters, we incorporated more variables and data to support further studies, say, analyzing the plot fixed effects through establishing panel-data sets. In particular, as irrigation management of different growth stages is of great importance in further measurement of yield determinants, we were monitoring the soil humidity, water temperature and water level since the following year of 2015, data of which were included and weighed through the adoption of PCA. Furthermore, using the database of the four agricultural production corporations in this research project, we analyzed the farm fixed effects, relationship between farm size and productivity, to improve the yield determinant specification and production efficiency.

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