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Improvement of Yielding Ability in Japonica Rice Cultivars and its Impact on Regional Yield Increase in Kinki District, Japan

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ABSTRACT

*The objective of this study is to evaluate the yielding ability of fourteen rice cultivars planted in Kinki District since 1961 and to quantify the contribution of cultivar improvement to regional yield trends in three high yielding regions. Performance trials for recommended cultivars from 1956 to 1985 in three prefectural agricultural experiment stations provided the data base. Differential Yielding Ability (*DYA*) for each cultivar showed Nipponbare had higher yielding ability except for Biwaminori. Analysis of covariance of the yield difference,* YD, *from the standard cultivar in relation to nitrogen application rate, planting time, year and location showed that Nipponbare, Biwaminori, and Kinpa had high adaptability to higher N rate. Year and location effects were negligible excepting Koshihikari and Kinmaze, suggesting that* YD *is useful for the long term and inter-regional yield analyses. The* DYA *values weighted by the regional popularity of each cultivar (*R-DYA*), showed that the contribution of cultivar improvement amounted to less than 20% of the actual regional yield increase from 1961 to 1986 in any of three regions. Therefore, we concluded that cultivar improvement as a single factor did not have a large degree of contribution to the regional rice yield increases.*

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INTRODUCTION

Rice (*Oryza sativa* L.) yield in Japan has increased steadily from the mid 1950s through the early 1970s as a result of improvement in major agronomic technologies such as cultivar improvement, fertilizer practices, early planting procedures, and weed and insect control. From the mid 1970s to the present, however, rice yield has fluctuated widely basically with the variation of the weather without noticeable increase. Kinki District has had a similar tendency during the same period but yield has been consistently lower than the national average.

The yield trends are different among regions in Kinki district; the region where the yield has been continuously increasing, the region where no further yield increase has been observed, and the region which even showed a downward tendency. An analysis of the agronomic factors affecting these variations is important in order to provide practical suggestions on how to further increase and stabilize rice yield in this district.

Cultivar improvement is often recognized as one of the most important factors contributing to the regional crop yield. In wheat, Silvey (1978) and Feyerherm *et al.* (1984) have evaluated the impact of cultivar improvement on regional yield. In corn, Russel (1984), Derieux *et al.* (1987), and Tollenaar (1989) have estimated the yield increase due to new cultivars. In rice, however, few studies have tried to assess the impact of cultivar improvement on regional yield in Japan. Furthermore, there have been few studies that have quantified cultivar yielding ability in relation to agronomic practices based on a broad data set. Therefore, the objective of this study is first to evaluate the varietal differences in yielding ability and then to estimate the degree of cultivar contribution to the regional yield.

In the present study, the differences in the yielding ability will first be evaluated by means of differential yielding ability (DYA), proposed by Feyerherm *et al.* (1984). Then the effects of nitrogen rate, transplanting date, year, and location on DYA will be examined by analysis of covariance. Lastly, the degree of cultivar contribution to actual yield increase will be estimated for Kameoka, Mineyama (Naka-gun and Takeno-gun), and Omihachiman. These areas were chosen for the present study because they belong to relatively high yielding areas in Kinki but have different yield trends during a period 1961–1986.

MATERIALS AND METHODS

Performance Tests for Recommended Rice Cultivars conducted by Hyogo, Kyoto, and Shiga prefectural agricultural experiment stations (1956–1985) provided the data base (see details in Table 1).

TABLE 1
Locations of Experimental Stations

Prefecture	*Experimental station*	*Location*
Hyogo	Akashi	Akashi-shi
	Tajima	Wadayama-cho
Kyoto	Kameoka	Kameoka-shi
	Tango	Yasaka-cho
Shiga	Kusatsu	Kusatsu-shi (until 1973)
	Dainaka	Azuchi-cho (since 1974)
	Kohoku	Kinomoto-cho
	Kosei	Adogawa-cho (since 1970)

The varietal differences in the yielding ability were evaluated by means of the differential yielding ability, DYA, defined as the mean yield difference between a given cultivar, C, and a standard cultivar, S, over treatments, locations, and years (Feyerherm *et al.*, 1984):

$$YD(C)_{ijk} = YIELD(C)_{ijk} - YIELD(S)_{ijk} \quad (1)$$

$$DYA(C) = \frac{1}{n}\sum_i \sum_j \sum_k YD(C)_{ijk} \quad (2)$$

where, n is the number of cultivar, C, and standard, S, (Nipponbare) pairs. $YIELD(C)_{ijk}$ is the average yield of cultivar, C, in the treatment i, at the location j, and in the year k. Likewise, $YIELD(S)_{ijk}$ is the average yield of the standard cultivar in the treatment i, at the location j, and in the year k. Fourteen cultivars widely grown in this district during the period 1961–1986 were available for this analysis (Table 2). Nipponbare was used as standard because it has been one of the most widely grown cultivars and data were available from all eight locations for most of the period.

In the performance tests for recommended rice cultivars, a range of different fertilizer levels and planting dates have been used in most of the locations. In addition, years and locations are also sources of the variance in YD. Therefore, the following model was used to account for YD responses to various conditions and agronomic practices. Eight cultivars, which had a sufficient number of data were provided for this analysis (Table 2).

$$YD(C)_{ijk} = \mu + \alpha \,.\, N + (TP\text{-}DATE)_i + (YEAR)_j + (LOC)_k + e_{ijk} \quad (3)$$

where, μ is the grand mean, N is the total nitrogen application rate (kg/ha)

TABLE 2
List of Cultivars used in the Analyses

Cultivar	*Year of release*	*Maturity*[a]
Nipponbare**[b]	1963	3
Akibare	1962	3
Asahi 4	1935[d]	4
Biwahikari	1972	1
Biwaminori*[c]	1971	3
Honenwase*	1955	1
Kinmase*	1948	4
Kinpa*	1965	1
Koshihikari*	1956	2
Manryo*	1959	3
Nakateshinsenbon*	1950	4
Norin 22	1943	3
Wakaba	1950	3
Yamabiko*	1958	3

[a] Maturity is classified into five levels mainly based on Shiga Experimental Station (1956–1985), where, 1–3: Early, 4: Medium, 5: Late.
[b] ** the standard cultivar.
[c] * cultivars used in the analysis of covariance.
[d] First appearance on the list of recommended cultivars in Kyoto.

which ranged from about 60 to 130 kg/ha, *TP-DATE* is the effect of transplanting date where six decads from May to June were labeled from 1 to 6, *YEAR* is the year effect, and (*LOC*) is the location effect, respectively. The year and location effects were assumed to be fixed in this analysis. The interactions could not be tested because of the missing treatment combination.

Lastly, the regional *DYA*-values (*R-DYA*) were calculated so as to estimate the contribution of cultivar improvement to the regional yield increase:

$$R\text{-}DYA = \frac{1}{\sum_{c} w_c} \cdot \sum_{c} (DYA(C) \cdot w_c) \qquad (4)$$

where, w_c is the percentage of the planted area of cultivar c over the total area of paddy field in a given year. The data were obtained from Food Institute, Kyoto (1967–1983), Kyoto Prefecture (1967–1983), and Food Institute, Shiga (1961–1987). Computations were made mainly by the Statistical Analysis System (SAS) at the Kyoto University Computer Center and by the Minitab at the College of Agriculture and Life Sciences of University of Wisconsin-Madison.

RESULTS AND DISCUSSION

Varietal difference in yielding ability

DYA was calculated to compare yielding abilities of the major cultivars in comparison to the standard cultivar, Nipponbare. Table 3 shows the *DYA* values obtained by eqn (1). *DYA* for thirteen cultivars ranged from −1047 to 106 kg/ha. The largest yield difference was found in an 'old cultivar', Asahi 4, which was planted about 30–50 years ago. This difference is similar to what has been found for wheat in the US during the past 100 years (Feyerherm *et al.*, 1984). A significantly positive *DYA* ($HO: DYA = 0$) was observed only in Biwaminori, and seven cultivars had significantly negative *DYA* values. This implies that the standard cultivar, Nipponbare, has higher yielding ability than most of the cultivars provided for this analysis.

TABLE 3
DYA Values and Correlation Coefficients (r) Between the Yield of Standard Cultivar and Those of Other Major Cultivars

Cultivar	n[a]	*DYA (kg/ha)*	r
Akibare	12	−195·6 (145·0)[d]	0·692*[c]
Asahi 4[b]	30	−1 047·1 (110·8)**[c]	—
Biwahikari	17	−477·3 (129·4)**	0·593*
Biwaminori	52	105·8 (41·1)*	0·920**
Honenwase	73	−629·9 (76·5)**	0·961**
Kinmaze	64	−28·8 (57·7)	0·703**
Kinpa	86	7·7 (26·8)	0·919**
Koshihikari	157	−428·3 (51·4)**	0·708**
Manryo	38	−49·7 (44·3)	0·852**
Nakateshinsenbon	65	−186·4 (52·8)**	0·813**
Norin 22	11	−308·2 (102·9)*	0·691*
Wakaba	16	−239·7 (128·6)*	0·433
Yamabiko	99	−29·1 (27·1)	0·925**

[a] n is the number of the observations.
[b] The *DYA* value was calculated by means of the secondary standard cultivar, Nakateshinsenbon, where the standard error was weighted by each degree of freedom.
[c] * and ** stand for 5% and 1% significance levels, respectively.
[d] Parentheses indicate standard deviations.

The variations in DYA values can be related to cultivars' maturing characteristics. Cultivars with similar maturity to the standard such as Kinpa, Manryo, and Akibare showed no significant DYA. On the other hand, cultivars with earlier (Biwahikari, Koshihikari and Norin 22) or later (Nakateshinsenbon and Kinmaze) maturity had smaller DYA's. Thus, cultivars with intermediate maturity such as Kinpa, Manryo, Akibare, Biwaminori and Nipponbare have the highest yielding ability in Kinki District.

In order to investigate the difference in yield response to various environments, correlation coefficients between the yields of cultivar, c, and the standard cultivar, Nipponbare, are presented in Table 3. All cultivars except Wakaba 3 showed significantly high linear associations with the standard cultivar. Notably, Kinpa, Yamabiko and Biwaminori showed quite similar yield responses to that of Nipponbare. These cultivars had non-significant DYA values. Cultivars with significantly negative DYA such as Koshihikari, Honenwase, Biwahikari and Norin 22, showed comparatively low correlation coefficients. This indicates that cultivars with the same yield level generally have similar yield responses to environments. Kinmaze, however, showed a relatively low correlation though this has a non-significant DYA value. It is possible that this type of cultivar has a different yield response to planting seasons, fertilizer levels, years, or locations, though the overall mean of the yield level did not differ.

Effects of agronomic factors on yield differences

Equation (3) was employed to identify the sources of variance in cultivar differences in yield responses to environments and agronomic factors. The results of analysis of covariance were presented in Table 4. Nitrogen rate had a negative effect on YD for almost all cultivars, suggesting that Nipponbare has higher adaptability to heavy nitrogen application. Considerably lower yields would be expected for Koshihikari, Kinmaze and Yamabiko, if a higher rate of nitrogen is applied. Nipponbare's higher adaptability can be ascribed to its shorter stature in comparison to Yamabiko and Koshihikari.

Transplanting date did not appear to have a significant effects on YD in any of the cultivars. However, some cultivars showed a consistent tendency in the $TP\text{-}DATE$ effects according to the least square means for each decad presented in Table 4, so that the early planting procedure seemed to increase YD for Kinmaze, Kinpa, Koshihikari and Yamabiko. While early planting procedure generally increased rice yield in Japan (Matsushima, 1976), the effect of early planting might be more noticeable for these cultivars. No such tendency could be found in Manryo and Nakateshinsenbon.

TABLE 4

Analysis of Covariance Based on Eqn (3)

Cultivars		*Biwaminori*	*Honenwase*	*Kinmaze*	*Kinpa*	*Manryo*	*Koshihikari*	*Nakateshinsenbon*	*Yamabiko*
α[a]		20·6	−26·6	−86·4**[d]	11·9	−1·1	−102·2**	−27·8	−37·5*
± se		±27·9	±36·2	±29·3	±21·0	±30·3	±30·0	±27·4	±17·4
Least square	1[b]	168·0	−746·3	209·7	36·3	−11·9	−547·6	−225·4	0·67
Means of each	2	250·6	−730·2	—	97·4	−195·7	−524·4	−147·9	—
transplanting	3	−162·2	−598·0	355·3	132·1	186·1	−271·9	−156·1	21·4
date adjusted	4	−39·4	—	−151·1	−98·1	−170·5	−948·1	−206·1	−45·6
by the co-	5	—	−530·3	−217·6	−162·0	153·4	−644·4	−342·1	−25·8
variant, N	6	—	−1 123·4	−460·1	—	—	−825·1	−166·3	−169·4
Source of variance									
Transplanting date		NS (3)[c]	NS (4)	NS (4)	NS (4)	NS (4)	NS (5)	NS (5)	NS (4)
Location		NS[e] (3)	NS (3)	* (2)	NS (3)	NS (1)	* (6)	NS (2)	NS (3)
Year		* (13)	* (19)	** (11)	NS (19)	NS (8)	** (22)	NS (15)	NS (21)
MSE		218 (31)	503 (45)	351 (35)	246 (58)	224 (23)	564 (122)	388 (41)	267 (35)
R^2		0·67	0·68	0·68	0·33	0·58	0·40	0·47	0·33

[a] α is the coefficient of nitrogen application rate which ranged from about 60 kg–130 kg/ha.
[b] The numbers from 1 to 6 indicate the transplanting date from the first decad of May to the third decad of June.
[c] Degrees of freedom for each factor are indicated in parentheses.
[d] * and ** stand for 5% and 1% significance levels, respectively.
[e] NS not significant.

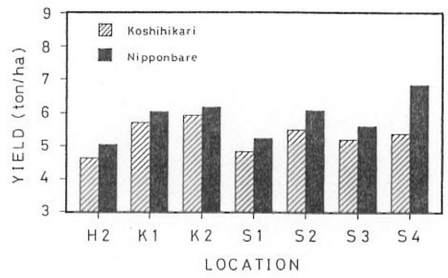

Fig. 1. Mean yields of Koshihikari and Nipponbare in seven experiment stations (H2:Tajima, K1:Kameoka, K2:Tango, S1:Kusatsu, S2:Dainaka, S3:Kohoku, S4:Kosei). The yield data of each cultivar were obtained from the experiment where both cultivars were provided in the same treatment in each location (In Akashi experiment station, the data for both cultivars were available but not in the same treatment).

No significant location effects were observed in Honenwase, Biwaminori, Kinpa, Manryo, Nakateshinsenbon and Yamabiko, suggesting that while each location may have different yield levels, the yield differences to Nipponbare (*YD*) are similar in any location in these cultivars. Whereas the yield responses of Kinmaze and Koshihikari to locations were different from that of Nipponbare.

Year effects were significant for four cultivars. Among the cultivars with a significant effect, Honenwase and Biwahikari had 5% significance level, where the data set covered 20 and 14 years for each cultivar, respectively. Considering the high degrees of freedom, we would hestitate to attach much importance to 5% significance level. Therefore, it can be concluded that for the majority of cultivars excepting Koshihikari and Kinmaze, there was no significant variation in *YD* that could be related to different year and location effects.

Koshihikari is a major cultivar extensively planted all over Japan. Koshihikari's popularity is due to its good eating quality and higher price. Nipponbare, which is used as a standard cultivar in this study, is another major cultivar in Japan mainly because of its high yield performance to heavy fertilization. In Fig. 1, the actual yield levels of the two cultivars in each location were presented. A considerable variation in the actual yield level exists across the locations. In each location, however, Nipponbare showed a consistently higher yield than Koshihikari and the yield difference did not vary with the locations to a large degree except in the Kosei Station (S4).

Figure 2 presents the yield comparison between Koshihikari and Nipponbare in each year. In twenty-one out of the twenty-three years studied, the yield of Nipponbare was higher than that of Koshihikari. It was also found that in most of the years, the yield difference of the two cultivars was consistent despite the fact that there is a considerable year to year variation in the actual yield level. Although the analysis of covariance found the significant year and location effects in the yield difference between the two cultivars, it is likely that these two cultivars generally show a similar yield response to the environment, so that the yield difference stays at about the same level in most of the years and the locations studied.

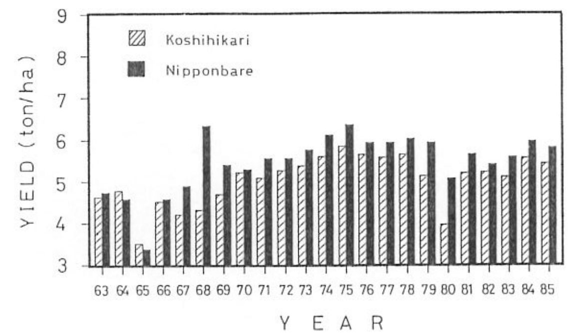

Fig. 2. Yearly mean yields of Koshihikari and Nipponbare across the seven experimental stations. The yield data of each cultivar were obtained from the experiment where both cultivars were provided in the same treatment.

The results and discussions above indicate that the yield difference from the standard cultivar, *YD*, is the index of yielding ability that is not strongly influenced by different soil types and climatic conditions within this district. Consequently, it is not too unreasonable to use *DYA*, the average value of *YD*, to estimate the shift in the regional yielding ability that is brought about by the newly introduced cultivars. Furthermore, the analysis of covariance in relation to *YD* may serve to provide useful information in evaluating the cultivar yield responses to such agronomic factors as fertilizer levels and planting dates.

Contribution of cultivar improvement to regional yield

Figure 3 shows the shifts to relative popularity of major cultivars in the three areas. In Kameoka, before the middle of the 1970s when Nipponbare extended its planted area rapidly, there were various cultivars such as Asahi 4, Yamabiko, Akibare and Wakaba 3 (not in the figure). Nipponbare has dominated since around 1970 and occupied about 80% of the total planted area in 1983. Another major cultivar is Nakateshinsenbon though it

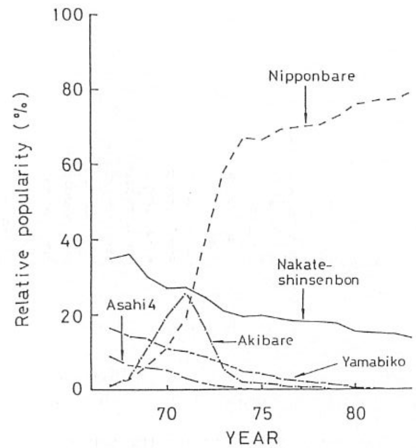

Fig. 3(a). Shifts in relative popularity of the major cultivars in Kameoka from 1967–1983. From Food Institute, Kyoto (1967–1983).

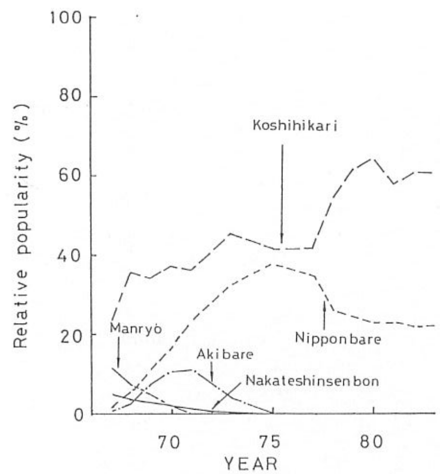

Fig. 3(b). Shifts in relative popularity of the major cultivars in Mineyama from 1967 to 1983. From Kyoto Prefecture (1967–1983).

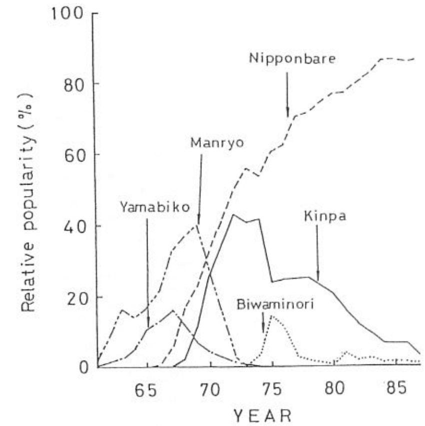

Fig. 3(c). Shifts in relative popularity of the major cultivars in Omihachiman from 1961 to 1987. From Food Institute, Shiga (1961–1987).

has been gradually decreasing since 1967. Thus, Kameoka can be called a 'Nipponbare dominant area.'

Mineyama area is located in the northern part of Kinki District facing the Sea of Japan. Diverse cultivars were planted before 1975 such as Manryo, Akibare and Nakateshinsenbon in addition to the two major cultivars of Nipponbare and Koshihikari. These cultivars had higher yielding ability than Koshihikari. However, Koshihikari, which is one of the highly priced cultivars, has been a dominant cultivar since around 1970 and is still increasing at the expense of the area grown to Nipponbare. Thus, Mineyama is a 'Koshihikari dominant area.'

Omihachiman is another 'Nipponbare dominant area.' Manryo and Yamabiko were planted widely during the 1960s, but Nipponbare has been dominant since around 1975 and covered 80% of total planted area in 1986. Kinpa and Nipponbare's planted areas increased almost simultaneously around 1965–1970, but Kinpa showed a rapid downward trend after 1972. Biwaminori, which has higher yielding ability than Nipponbare, planted in about 12% of the total area around 1975 but soon decreased to less than 5%. Among the cultivars which disappeared during this period, Manryo, Yamabiko, Kinpa and Biwaminori were not inferior to Nipponbare in terms of yielding ability.

Based on the data in Fig. 3, the regional yeilding ability, *R-DYA* (eqn (4)), was calculated so as to estimate the yield increase attributed to the cultivar improvement in three areas during the period 1961–1986 (Fig. 4). Fourteen

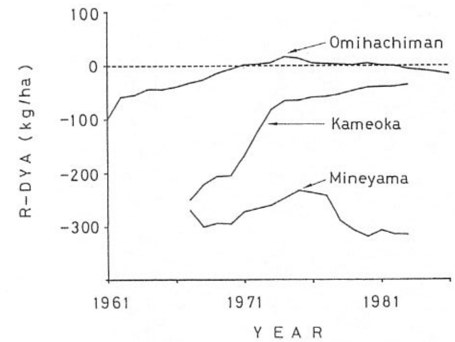

Fig. 4. Shifts in Regional Differential Yielding Ability (*R-DYA*) in three areas.

cultivars were offered for the calculation. In this calculation, *DYA* of the standard cultivar, Nipponbare, was set 0 kg/ha.

R-DYA grew steadily from 1967 to 1983 in Kameoka. The increase was parallel to the Nipponbare's extension in this area. The increment of *R-DYA* amounted to 210 kg/ha during this period. In Mineyama, *R-DYA* did not increase. We could even find the slight decrease after the mid 1970s. This can be attributed to the extensive cultivation of Koshihikari, which has a highly negative *DYA* value. The decrease of *R-DYA* was approximately 50 kg/ha. In Omihachiman, the increase of *R-DYA* began from 1961 and seemed to have hit the peak around the mid 1970s. Likewise, in Kameoka, Nipponbare is thought to have contributed to the upward shift in *R-DYA*, but the increment of *R-DYA*, 90 kg/ha, was not as large as in Kameoka. This can be attributed to the fact that various cultivars planted here before the rapid extension of Nipponbare had generally higher *DYA* values than those in Kameoka. The actual yield increases in these areas during the same period were about 1100 kg in Kameoka, 550 kg in Mineyama, and 1000 kg/ha in Omihachiman (Fig. 5). Yield increases attributable to cultivar improvement in each region account for about 19%, 0%, 9% of the actual yield increase, respectively.

In wheat, Feyerherm *et al.* (1984) found a range from 193 to 550 kg/ha increase due to new cultivars from 1954 to 1979 in the US. Russel (1984), Derieux *et al.* (1987), and Tollenaar (1989) concluded that genetic improvement accounts for 50–100% of actual yield increase during the past 30–50 years in corn. Thus, the magnitude of cultivar contribution to the regional rice yield in Kinki was small when compared to other major crops. It is therefore concluded that cultivar improvement as a single factor did not have a large degree of contribution to regional yield but the combination of cultivar and other agronomic factors increased rice yield in Kinki District.

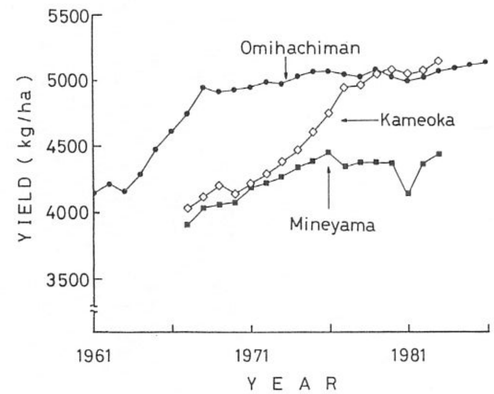

Fig. 5. Five year running average of rice yield in the three areas.

Among other major agronomic factors that have changed dramatically during this period were fertilizer practice and transplanting date. As shown in Table 4, Nipponbare has higher adaptability to heavy nitrogen application. It is likely that the rapid extension of Nipponbare along with the larger input of nitrogen fertilizer drove a large yield increase in Nipponbare dominant areas such as Kameoka and Omihachiman. On the other hand, in Koshihikari dominant areas such as Mineyama, no contribution of newly introduced cultivars would be expected because of its lower yielding ability. In addition, a larger input of nitrogen does not guarantee the improved yield as indicated by analysis of covariance (Table 4). Nevertheless, Mineyama's regional yield increased about 550 kg/ha during the period. It is quite possible that agronomic factors other than cultivar improvement have been associated with the yield increase in Mineyama. Further study is necessary in order to identify other agronomic factors that have improved rice yield in these areas.

CONCLUDING REMARKS

Nipponbare and Koshihikari are the two major cultivars that are now planted widely in Kinki District. In Nipponbare dominant areas, 9–19% of the regional yield increase was attributed to the cultivar improvement. Like other recent cultivars, Nipponbare is shorter in height and larger in number of tillers. These characteristics have conferred higher tolerance to lodging, so that larger yields resulting from heavier fertilization are possible. In this respect, the contribution of cultivar improvement to yield increase in the

Nipponbare dominant areas might have been higher than the estimated values in our analysis.

Another dominant cultivar, Koshihikari, showed lower yielding ability than the cultivars which are no longer planted in this area such as Manryo, Nakateshinsenbon and Yamabiko. In addition, it is a tall variety which is not suitable to heavy fertilizer application. Nevertheless, the area grown to Koshihikari, the most widely planted cultivar in Japan due to its higher price, is still increasing in many parts of Kinki District. Because of its low yielding ability and poor adaptability to heavy fertilizer application, Koshihikari did not contribute to the regional yield increase.

If the general tendency in the future will be toward the highly priced cultivars and the branded cultivars, like Koshihikari, cultivar improvement is unlikely to play an important role in increasing and stabilizing future rice yield becase these cultivars are apt to have lower yielding ability. On the other hand, if farmers choose a Nipponbare type cultivar with large and stable yield, we may expect that regional yield will be higher and more stable than what one can expect in a Koshihikari dominant area. However, the question still remains whether or not a Nipponbare type cultivar will be able to drive yield increase any further for future rice production. Takeda *et al.* (1984) found that recent rice cultivars such as Nipponbare have increased yields because of higher harvest index but not because of higher total dry matter production and concluded that the characteristics of these new cultivars may set an upper limit to yield increase. Whereas in corn, 85% of yield increase due to genetic improvement was attributed to higher dry matter accumulation (Tollenaar, 1989). This may suggest that plant breeding toward cultivars with higher dry matter accumulation will be of greater importance in increasing the future rice production in Kinki District, Japan.

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