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Evaluation of Environment on Rice Production for the Rice Terraces in Hoshino Village

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Variables characterizing ambient environmental conditions (such as barometric pressure, solar radiation, rainfall, temperature, relative humidity, and wind speed) were measured between June and October in 2006 at the rice terraces in Hoshino village, Fukuoka prefecture. Differences in the environmental conditions of the three paddy fields located at different elevations in the same water system were assessed. Also, environmental factors that affected rice quality were identified using data collected during the beginning of a ripening period (20 days after heading) by principal component analysis.

The study results demonstrated that the paddy field midstream in the water system had the least solar radiation because it was surrounded by slightly elevated mountains and forest. Average temperatures at three paddy fields during the ripening stage were in the range of an optimal temperature while the temperature during the tillering stage was below the optimal range at the fields upstream and midstream. The field downstream was the only case that the diurnal range of temperature was larger than that in the plain area.

As the results of principal component analysis, average temperature, average relative humidity, and solar radiation during the beginning of a ripening season were shown as major environmental factors that affected rice quality. Average temperature had a positive effect on rice quality, and this effect could be explained by the negative correlation between temperature and amylose content. Relative humidity had positive effect, and solar radiation had positive effect.

INTRODUCTION

The rice terraces in Hoshino village, Fukuoka prefecture have been designated as one of the best one hundred rice terraces in Japan, and these rice fields can seemingly ensure the prosperity of the village. However, the real situation is not as bright as it should be. Due to the aging of the farming population, the rice terraces in the region, which have been passed on from generation to generation, could be removed from agricultural production in a near future. Rice terraces have been providing us with various functions, such as land preservation from floods and landslide, amenity, biodiversity, preservation of culture and history, etc, as listed by Haruyama (2004). On the other hand, conservation of rice terraces is becoming hard due to low market price of rice, low productivity in terms of labor and land, and severe working conditions.

Considering the conservation of rice terraces, it is important to establish a system that people can utilize in such regions for revitalizing the community and ensuring better working conditions. Recently, rice terrace ownership system, direct sales of agricultural products, and community events to ensure that the city population can experience farm work have actively been introduced as measures for conservation (Nakashima, 1999). These measures have been promoting the understanding of farm work in rice terraces and interest in the region. However, these measures obviously cannot provide the ultimate solution for the conservation of the rice fields. Therefore, in order to ensure labor, it is necessary to address the fundamental problems that prevent farmers from working in rice terraces, such as adverse labor conditions in a mountainous area, low income from rice production, and therefore the general appeal of agriculture as profession.

Rice terraces are said to be an ideal environment for rice production because of a large diurnal range of temperature (Kitaura *et al.*, 1986). However, since scientific proof of the importance of environmental conditions on rice quality is still very limited, it is advantageous for rice producers in the regions if these assumed environmental effects are validated and the knowledge gained is used for further improvement of rice quality. Also, because rice terraces are located upstream in a water system, agriculture practice in the regions needs to be environmentally friendly as it can impact on the environment downstream. In this study, a decision support system for farmers has been developed based on environmental information on rice production to ensure

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production of high quality rice with a low environmental impact. Through the system, farmers will be able to access a variety of information on rice production, thus farmers will be able to improve quality of their agricultural products. The system is envisaged to make the work of farmers more information based and thus potentially more creative.

Information technologies that are expected to be used as a part of a farmers' decision support system have been widely studied. The realtime soil spectrophotometer made it possible to assess spatial variability of soil qualities in a field such as soil moisture, organic matter, nitrate, pH, and EC (I Made Anom *et al.*, 2002). Chosa *et al.* (2004) has developed the yield monitoring system for a Head–Feeding Combine. Fukatsu and Hirafuji (2003) developed the field server that can monitor weather information and crop growth in real time via a Web browser. Also, GIS (geographical information system) has been becoming popular as a tool of managing information on agricultural production (Shibusawa, 2006). As mentioned above, sensors to acquire information and software to manage information acquired have been rapidly developed recently in many areas. However, because the relationship between environmental factors on agricultural production, methods of cultivation, and quality of products has not been understood well, useful indications that support a farmers' decision have not been proposed sufficiently.

The objectives of this study were to evaluate the effects of environment on rice production for rice terraces in Hoshino village and to investigate the relationship between environmental factors and rice quality. To achieve these objectives, weather indicators during a rice growth season were assessed among three paddy fields located at different elevations in the same water system. Also, environmental factors that potentially affected rice quality were examined by principal component analysis using data during the beginning of a ripening period.

MATERIALS AND METHODS

Experimental sites and apparatus

Environmental factors were measured at three paddy fields in Hoshino village, Fukuoka prefecture. The three paddy fields are located upstream (elevation:475m), midstream (elevation:369 m), and downstream (elevation:265 m) in the same water system, respectively. A weather station manufactured by Onset Computer Corporation was installed at the side of each paddy field (Fig. 1). Data was measured from June 12th, June 17th, and July 3rd for upstream, midstream, and downstream, respectively until October 9th. The weather stations were collected from September 17th to 19th due to the typhoon. The weather station includes sensors of barometric pressure, solar radiation, rainfall, temperature, relative humidity, wind speed, and wind velocity, and a data logger. Specifications of each sensor are described in Table 1. Errors among three sensors of temperature and relative humidity used for each experimental site were corrected by using Humidity and Temperature Meter (VAISALA, HM34) as a criterion. The accuracy was ±0.3 ˚C for temperature, and ±2% for 0 to 90% and ±3% for 90 to 100% of relative humidity. Each sensor and a data logger were located as shown in Fig. 1. A barometric pressure sensor was put inside a data logger. Temperature and humidity sensors were set inside a solar radiation shield (Onset Computer Corporation, M–RSA).

Experimental and analytical methods

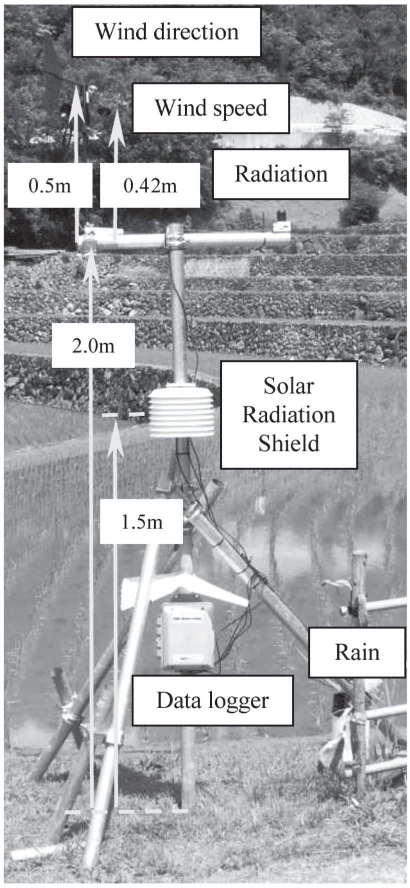

Fig. 1. Weather station.

Table 1. Specifications of sensors

Sensor type	Accuracy
Temperature	±0.7 °C@25 °C
Relative Humidity	±3% (±4% in condensation)
Barometric Pressure	±1.5 mbar@25 °C
Silicon Pyranometer	±10 W/m^2 or ±5%
Wind Speed	±0.5 m/s, ±3% for 17 to 30 m/s
Wind Direction	±5°
Rain Gauge	±1% at up to 20 mm/hour

Data was logged at an interval of 10 minutes. A diurnal range of temperature was assessed by concentrating on weather parameters in a plain area near Hoshino village. The measurement point of weather in the plain area was located in Ooazaizumi in Chikugo city, which is around 20 km west of Hoshino village. The weather data was provided by National Agricultural

Table 2. Cultivar, earliness and cultivation information

Exp. site	Cultivar	Earliness	Transplant	Heading	Harvest
Upstream	YUMETSUKUSHI	very early	6/6	8/16	9/26
Midstream	TSUKUSHIROMAN	early	6/7	8/27	10/10
Downstream	MINEASAHI	very early	6/9	8/20	9/24

Table 3. Average temperature during each growth stage

Exp. site	Tillering	Temp, °C	Panicle	Temp, °C	Ripening	Temp, °C
Upstream	6/16–7/15	23.0	7/17–8/15	25.1	8/16–9/26	22.2
Midstream	6/17–7/16	24.1	7/28–8/26	26.1	8/27–10/9	21.3
Downstream	ND	ND	7/21–8/19	26.7	8/20–9/24	24.0

* ND represents No Data.

Research Center for Kyushu Okinawa Region.

Cultivar and earliness of rice in each experimental site, and cultivation information are shown in Table 2. Transplant, cultivation, harvest, and drying were practiced in the conventional way of each farmer, and the date of heading (80% heading) was determined by communicating with each farmer directly.

Physical and chemical properties of rice were also analyzed for each five sample harvested at three experimental sites. Protein, amylose, moisture, and fatty acid for polished rice were analyzed by the rice taste analyzer for rice grain (Satake, Infraalyzer 260). Also, hardness, stikiness, degree of balance, and taste value were analyzed by the rice taste analyzer for cooked rice (Satake, Rice Taste Analyzer STA1A). Tukey's method was used to compare treatment means. Significance is reported at $P<0.01$ for moisture and hardness, and at $P<0.05$ for others.

Principal component analysis was conducted to investigate relationships between environmental factors and physicochemical properties of rice. Generally, weather during the beginning of a ripening stage significantly affects rice quality. Thus, data on weather environment for 20 days after heading was used for the analysis. Note that data during different period was used for the analysis due to different date of heading at each experimental site. Based on the data shown in Table 5 and Table 6, coefficients of structure on the first principal component were calculated by the method explained in Honda and Shimada (1977). Wind direction was removed from data for calculation judging that its effect on rice quality is low.

RESULTS AND DISCUSION

Evaluation of weather conditions on rice production

Temperature is one of the most influential factors on rice growth. It has been reported that optimal temperatures are from 25 to 31 °C and from 20 to 25 °C for a tillering stage and a ripening stage, respectively (Yoshida, 1986). For a panicle development stage, the temperature from 15 to 20 °C is shown as lower limitation. Average temperatures at three experimental sites during each growth stage are shown in Table 3. A tillering stage, a panicle development stage, and a ripening stage were defined as 30 days from the 10th day after transplant, 30 days before heading, and after heading, respectively. The average temperatures upstream and midstream during a tillering stage was below the optimal temperature, while the temperatures during a ripening period were in the range of an optimal temperature. The temperatures during a panicle development stage were above the lower limitation.

The average values of a diurnal range of temperature, low temperature, high temperature, and solar radiation from 7/3 to 10/9 are shown in Table 4. The diurnal range was the largest downstream, while those at the paddy fields upstream and downstream were smaller compared to that in the plain area. The average low temperatures from 7/3 to 10/9 were 19.9 °C, 20.8 °C, and 21.0 °C for upstream, midstream, and downstream, respectively, and they were significantly lower than that in the plain area (22.4 °C). On the other hand, the average high temperatures during the same period were 27.2 °C, 28.0 °C, and 29.7 °C for upstream, midstream, and downstream, respectively, and only the temperature upstream was close to that in the plain area (30.4 °C). Namely, low and high temperatures were prominent in only downstream, and it resulted in large diurnal range of temperature. Thus, it was demonstrated that environment downstream was advantageous for rice production as it had a large diurnal range of temperature. Further, Yang *et al.* (2005) reported that high night temperature decreased the translation of dry matter. This implied that low night temperature was an advantageous factor in rice terraces.

The paddy field midstream was surrounded by

Table 4. Diurnal range of temperature, high and low temperature, and solar radiation from 7/3 to 10/9

Exp. site	Diurnal range, °C	High, °C	Low, °C	Radiation, MJ/m²
Upstream	7.3	27.2	19.9	13.59
Midstream	7.3	28.0	20.8	11.61
Downstream	8.7	29.7	21.0	13.27
Plain	8.0	30.4	22.4	17.27

slightly elevated mountains and forest, and this feature of the landscape reduced solar radiation for the midstream paddy field. The average solar radiation from 7/3 to 10/9 was 13.59, 11.61, 13.27, and 17.27 MJ/m^2 for upstream, midstream, downstream, and the plain area, respectively. Also, solar radiation in the rice terraces was much lower than that in the plain area.

Physicochemical properties of rice

The results describing the physical and chemical properties of rice are shown in Table 5. Amylose content downstream was significantly different from other experimental sites. It is reported that high temperatures during the ripening stage leads to low amylose content (Terashima *et al*., 2001). Average temperatures for 20 days after heading were 24.1 °C, 23.1 °C, and 25.5 °C, for upstream, midstream, and downstream, respectively. It is very likely that the high average temperature measured downstream during this stage was the reason for the low amylose content. Protein content upstream was also significantly different ($p<0.05$) from all other experimental sites.

Moisture content was also significantly different among three experimental sites. The main reason was considered to be the different drying methods used at the experimental sites. Rack drying was practiced upstream and midstream, and timing of threshing depended on labor, weather, and experience of each farmer. As the result, rice grain became relatively dry at the two experimental sites. For taste value, the values in all experimental sites were above 80 and indicated high quality of rice produced at rice terraces in Hoshino village.

Examination of environmental factors on rice quality by principal component analysis

The structural coefficients on the first principal component are graphically shown in Fig. 2. The coefficients were calculated based on the data shown in Table 5 and Table 6. Because taste value had a positive coefficient, and protein content and amylose had negative coefficients, it was thought that the first principal component indicated rice quality. Rice quality is affected by two main variable groups, which are environment and physicochemical properties of rice. The changes in variables were explained by the first component up to 81%. As Fig. 2 shows, average temperature had positive effect on rice quality while amylose had negative effect. The result can be explained by the reported decrease in amylose content under the high temperature ripening period (Terashima *et al*., 2001).

Relative humidity had positive effect. Hirai *et al.* (1992) reported that high relative humidity (90%) promoted nitrogen absorption under day temperature of 28 °C (12 hours) and night temperature of 24 °C (12 hours) compared to low relative humidity (60%). The result shows a positive correlation between humidity and nitrogen absorption, and these results are different from our current experimental result. However, the effect of humidity on nitrogen absorption is still controversial, and we need further examination on the current result to fully understand the underlying effects. Barometric pressure and wind speed seemingly had positive and negative effect on rice quality, respectively. However, it would be reasonable that these factors indi-

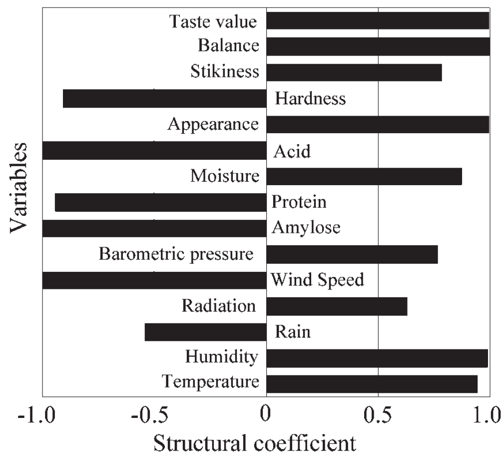

Fig. 2. Structural coefficients of the first principal component.

Table 5. Physicochemical properties of polished and cooked rice

(a)Polished rice

Exp. site	Amylose, %	Protein, %	Moistute, %	Fatty acid
Upstream	19.3a	7.2a	14.8a	7.0a
Midstream	19.6a	7.0a	14.4b	7.0a
Downstream	18b	6.4b	15.1c	6.9a

(b)Cooked rice

Exp. site	Appearance	Hardness	Stikiness	Balance	Taste value
Upstream	8.0a	5.9a	8.9a	8.5a	82a
Midstream	8.1a	5.7b	8.5b	8.4a	81a
Downstream	8.7b	5.3c	9.1a	8.9b	86b

* Values followed by the same letter in the same column are not significantly different ($P<0.01$ for moisture and hardness, $P<0.05$ for other variables).
** Full score for fatty acid, appearance, hardness, stikiness, balance is 10, and full score for taste value is 100.

Table 6. Environmental variables used for principal component analysis

Exp. site	Average Temp., °C	Relative Humidity, %	Rain, mm	Radiation, MJ/m^2	Wind Speed, m/sec	Barometric Pressure,bar
Upstream	24.1	81.5	22.5	12.65	0.74	954
Midstream	23.1	81.7	11.4	9.09	0.8	968
Downstream	25.5	86.2	9.3	12.91	0.37	979

rectly affected rice quality by their effects on temperature and humidity. Interaction among weather factors need to be investigated further including the effect of geographical features. Although solar radiation had less effect on rice quality compared to temperature and relative humidity, it played a positive effect. From the results above, it was concluded that temperature, relative humidity, and solar radiation were major environmental variables that affected rice quality.

Next, environment of each paddy field was ranked based on the first principal component value using only environmental variables. As the result, environment downstream was the best due to high temperature and high relative humidity. Environment upstream was the second, and midstream was the third due to low temperature and less solar radiation.

Finally, the effect of different varieties cultivated at experimental site was examined. Figure 3 and Figure 4 show protein and amylose contents of the three varieties from 2002 to 2004. The varieties were cultivated and analyzed by Fukuoka Agricultural Research Center.

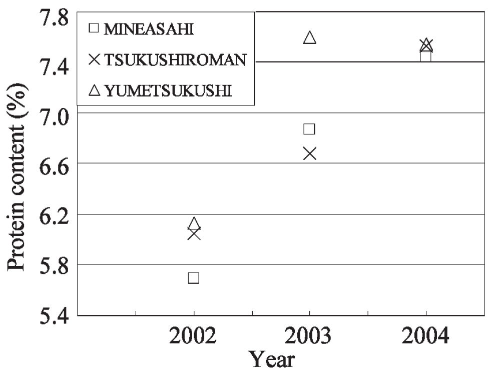

Fig. 3. Protein content of three variables.

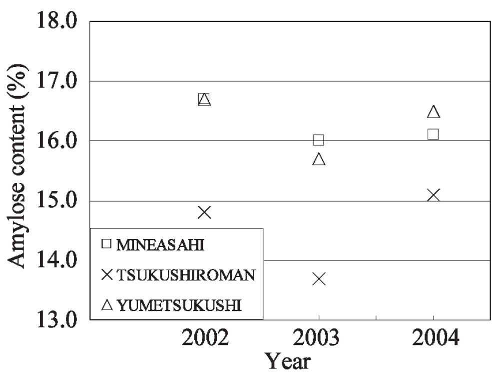

Fig. 4. Amylose content of three variables.

Protein contents of each variety changed each year, and the order among three varieties also changed. This fluctuation implies that weather factors are dominant on protein content than characteristics of varieties. On the other hand, amylose content in "TSUKUSHIROMAN" variety is always the lowest from 2002 to 2004. It suggests that "TSUKUSHIROMAN" variety would be a kind of low amylose. Hamachi *et al.* (2003) also mention the possibility of a low amylose characteristic for "TSUKUSHIROMAN" variety. However, the result in our experiment was that the amylose content in "TSUKUSHIROMAN", which was grown midstream, was the highest. It indicated that environment significantly affected on amylose content in our experiment. In summary, our experimental results clearly demonstrated the effect of different environmental variables on rice quality in agreement with previous studies.

CONCLUSIONS

Weather indicators during a rice growth season were assessed for the rice terraces in Hoshino village, Fukuoka prefecture. Also, environmental factors that potentially affected rice quality were examined by principal component analysis. Following conclusions were drawn from this study.

1) The average temperatures upstream and midstream during a tillering stage were below the optimal temperature, while the temperatures during a ripening period were in the range of an optimal temperature. The temperatures during a panicle development stage were above the lower limitation.
2) The diurnal range was the highest at the downstream paddy field.
3) Low temperature during night was considered as an advantageous factor in rice terraces.
4) The paddy field midstream was surrounded by slightly elevated mountains and forest, and this feature of the landscape reduced solar radiation for the midstream paddy field. Also, solar radiation in the rice terraces was much lower than that in the plain area.
5) Taste values in all experimental sites were above 80 and indicated high quality of rice produced at rice terraces in Hoshino village.
6) From the principal component analysis, it was concluded that temperature, humidity, and solar radiation were major environmental variables that affected rice quality.

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