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https://doi.org/10.5109/16108

出版情報：九州大学大学院農学研究院紀要. 54 (2), pp.305-311, 2009-10-29. 九州大学大学院農学研究院
バージョン：
権利関係：

J. Fac. Agr., Kyushu Univ., **54** (2), 305–311 (2009)

Effects of Air Temperature, Nitrogen Concentration in Irrigation Water, and Cultivation Practices on Rice Production in the Rice Terrace Region

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(*Received June 17, 2009 and accepted July 13, 2009*)

Rice production in the rice terrace region was investigated, using three paddy fields located at different altitudes in different water systems in Hoshino village, Fukuoka prefecture, Japan. The effects of air temperature, nitrogen concentration in irrigation water, and cultivation practices of individual farmers were assessed, based on the growth indicators, yield components, and physicochemical properties of brown rice. It was found that abundant amounts of nitrogen–comparable to the standard nitrogen fertilization for the Yumetsukushi cultivar– were supplied from the irrigation water of field 1. Initial growth was restricted in field 2, due to early transplantation and early basal fertilization, resulting in a large percentage of ripened grains (PRG) and low protein content. The early transplantation resulted in a higher air temperature during the early ripening period and led to low amylose content. The 1000–GW was small in field 3; this was because the accumulation of starch in each grain was insufficient, due to the small production of dry matter per tiller. The underlying reasons were thought to be increased respiration and reduced efficiency of photosynthesis, both caused by excessive growth. Based on these results, the following recommendations for improving rice production in the region are indicated: an earlier transplantation date, to increase air temperature during the early ripening period and restrict initial growth; a reduction of basal nitrogen fertilization, to preclude excessive growth; and avoiding nitrogen–fertilizer applications on fields where abundant nitrogen is supplied from irrigation water.

INTRODUCTION

Agricultural activities in hilly and mountainous areas fulfill a variety of functions, including food production, the preservation of land from floods and landslides, the cultivation of water resources, and enhancements to biodiversity; in the form of rice terraces, agricultural activities also create beautiful landscapes. Approximately 40% of each of Japan's number of farming households, its area of cultivated land, and its agricultural product is found in this area (Uchida, 2004). It is obvious that agricultural activities in hilly and mountainous areas have played important roles in terms of food supply and the creation of safe and comfortable living environments; however, as young people have tended to migrate into urban areas–especially when farming conditions are severe–Japan has seen an aging and shortage of farmers and an increased number of abandoned farmlands.

Recently, more measures have been taken to conserve and revitalize agriculture in rural regions, including conservation activities by volunteers, community programs that provide city–dwellers with the opportunity to experience farm work, and the direct sale of agricultural products. However, these measures obviously cannot motivate young people to stay and work in rural regions, given the low incomes earned through farming. Thus, it is essential to increase agriculture–related incomes by overcoming disadvantages inherent in hilly and mountainous farming conditions; to do so, the following conditions are necessary: determine reasonable prices for agricultural products, by taking into consideration disadvantageous farming conditions in hilly and mountainous areas; and produce safe and high–quality agricultural products, so that consumers will become convinced to pay a premium for their added value. Given the consideration discussed above, this study focuses on improvements to rice production in rice terraces–a unique form of land use in hilly and mountainous areas.

It is said that rice terraces provide a suitable environment for rice production, due to their large daily ranges of temperature and clean water resources. However, it was found through our field survey that while the daily range of temperature was locally large in the rice terrace region, some fields were at a disadvantage in terms of receiving solar radiation, due to the contoured topography. Also, it was indicated that rice quality in the paddy field where tea fields were located upstream was affected by high nitrogen concentration in irrigation water; in this way, the rice terrace environment is not necessarily advantageous for rice production. In addition, various cultivation practices by individual farmers have resulted in varying degrees of rice quality in the region; therefore, to improve rice production in the region, recommendations should be made on the bases of the various environmental conditions of each field and the cultivation practices of individual farmers.

In this study, rice production was studied in three paddy fields; each was cultivated by a different farmer, located at a different altitude, and served by a different water system in Hoshino village, Fukuoka prefecture,

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Japan. We did so, to assess the effects of air temperature, nitrogen concentration in irrigation water, and cultivation practices, with the endpoint of making recommendations for producing high–quality rice.

MATERIALS AND METHODS

Sites of field survey and data collection of cultivation practices

The field survey was conducted in three paddy fields during the rice–growth season of 2008; fields were located at different altitudes and served by different water systems in Hoshino village, Fukuoka prefecture, Japan. The fields ranged from 33.21°N to 33.27°N in latitude and 130.72°E to 130.80°E in longitude. The altitude of each field is listed in Table 1. Yumetsukushi cultivar was grown in each of the fields, by different farmers. Yumetsukushi cultivar is mainly grown at high altitudes in Hoshino village, owing to its extremely early crop year. Cultivation practices were recorded in the printed form gathered by authors, and distributed to the farmers in advance of their cultivation. An accurate heading date was determined, based on field monitoring for rice growth. The harvesting date was defined as the date on which rice samples were harvested from each field, for the purpose of measuring the yield components and physicochemical properties of the brown rice.

Table 1. Altitudes of the paddy fields surveyed, cultivation practices, yield components and physicochemical properties of brown rice

Field	1	2	3
Altitude (m)	481	463	399
Transplanting	6/6	6/2	6/15
Heading	8/16	8/9	8/19
Harvesting	9/27	9/20	10/2
Straw application	Half	All	All
Tillage in winter	–	12/2	–
Tillage in spring	5/6	3/26	4/30
Compost application	11/17	11/30	–
N amount (kg ha^{-1})	70	87	–
Basal fertilization	6/3	5/11	6/10
N amount (kg ha^{-1})	30	32	42
Topdressing 1	7/4	7/30	–
N amount (kg ha^{-1})	5	11*	–
Topdressing 2	7/26	–	–
N amount (kg ha^{-1})	16*	–	–
Total N (kg ha^{-1})	50	43	42
Panicle length (cm)	16.1 (2.1)	15.9 (2.0)	15.3 (2.4)
Panicles per hill	24.0 (1.3)	18.4 (3.3)	24.7 (2.6)
Hills (m^{-2})	17.3	16.2	17.9
Spikelets per panicle	78 (24)	86 (29)	76 (26)
Panicles (m^{-2})	415	298	441
Spikelets (10^2 m^{-2})	326	256	336
PPT (%)	50(4)	48(10)	46(9)
PRG (%)	84	95	85
1000–GW (g)	23.1	23.4	21.4
Yield (g m^{-2})	632	570	613
Protein content (%)	6.8	6.0	6.7
Amylose content (%)	17.3	16.6	16.7

"All" ("Half") in the line of straw application indicates that all (half) rice straw was incorporated in a field. "N" represents Nitrogen. The amounts of nitrogen were calculated based on the nitrogen content of compost or fertilizer applied by each farmer. "*" indicates that rapeseed oil cake was applied. Figures in parentheses represent standard deviation.

Air temperature

Meteorological information including air temperature, relative humidity, and solar radiation, was measured using 7 meteorology–monitoring apparatuses, which included 3 apparatuses manufactured by Onset Computer Corporation (Bourne, MA, USA) and 4 apparatuses manufactured by the authors (Hirai and Beppu, 2007), at seven locations in Hoshino village during the rice–growth season. The daily average air temperature at each paddy field was calculated by correcting the air temperatures measured by the closest meteorological equipment to each field, using the lapse rate in the mountainous area (i.e., 0.55 °C per 100 m) (Yoshino, 1961). Based on the daily average air temperature, the average temperatures were calculated for each growth stage. Each growth stage–rooting, tillering, panicle development, and early ripening–was defined as the first 10 growing days, the duration from the 10th day after transplanting to the maximum tillering period, the 30–d period before heading, and the 20–d period after heading, respectively. The maximum tillering period was defined as the date when the maximum number of tillers was exhibited in the field survey. Matsuo (1990) has reported that the accumulation of starch and protein into endosperm cells reaches a maximum approximately 20 d after flowering after which the contents remain almost constant. Therefore, the 20–d period after heading is especially important in assessing the effect of air temperature on rice quality.

Inorganic nitrogen concentration in irrigation water

Irrigation water was sampled at each paddy field, on June 20, July 10, July 31, August 17, and September 6; it was then analyzed by ion chromatography (ICS–90, DIONEX). In this study, only inorganic nitrogen forms–such as nitrite–nitrogen (NO_2–N), nitrate–nitrogen (NO_3–N), and ammonium–nitrogen (NH_4–N)–were measured, since our former study (Tomita *et al.*, 2008) showed that the concentration of organic nitrogen was negligible in the water systems of the field survey sites, and rice plants mainly absorb inorganic nitrogen to sustain their growth.

Rice growth

Growth indicators–such as the number of tillers, plant length, and SPAD value–were monitored for 5 hills, each at two separate locations in each paddy field (i.e., 10 hills in total) at about two–week intervals during the rice–growth season. The SPAD value was measured five times for the uppermost fully expanded leaf blade in the longest tiller of a hill, and an average value was calculated. The percentage of productive tiller (PPT) was calculated for each hill as a ratio of the number of panicles to the maximum tiller number.

Yield components and physicochemical properties of brown rice

Five standard rice hills were manually harvested, each at two separate locations in each paddy field (i.e., 10 hills in total). Here, the 10 hills harvested in each field were different from ones whose growth indicators were monitored during the rice–growth season. After harvesting, row and hill spacings were measured at six locations, and the average values were calculated. The rice hills' harvests were air–dried, and the numbers of panicles and spikelets and the panicle lengths were measured for the 10 hills in each field. The rough rice was then husked, and samples of brown rice were analyzed for their physicochemical properties. Each sample from the three paddy fields was first sorted by a 1.85–mm sieve, whereupon the number of sorted grains was counted. The 1000–grain weight (1000–GW) was measured three times for each sample by the single–grain rice inspector (RG120A, Satake Corporation, Hiroshima, Japan) and the average value was calculated. Protein and amylose contents were measured by the grain analyzer (Infratec 1241, FOSS, Hilleroed, Denmark). In this analyzer, a sample injected into the instrument is automatically divided into small volumes, and the average value is calculated from the measurement results of 10 small volumes. Moisture content was measured 3 times for each sample by oven–drying at 135 °C for 24 hours, and the average value was calculated. Each value of 1000–GW, protein content and amylose content was converted into the value at 14.5% w.b. In general, it has been reported that the accuracy in predicting amylose content by near infrared spectroscopy (NIR) is insufficient (Kobayashi *et al.*, 1994). On the other hand, Shimizu *et al.* (2003) assessed the accuracy of amylose determination in milled rice, using the same spectrometer as that used in this study; the validation results for the two calibration models showed high determination coefficients of 0.77 and 0.86, regarding the correlation between the predicted values by NIR and the values chemically analyzed. Thus, we established that amylose content values, as determined by NIR, could be used for the examinations in this study.

RESULTS

Cultivation practices

Information regarding cultivation practices is presented in Table 1. All rice straw was left in fields 2 and 3, after the rice grain was harvested by a combine harvester. On the other hand, rice plants were harvested by a binder in field 1, and approximately half of the rice straw was used as a covering material for tea and vegetable production. The remainder of the rice straw was chopped and scattered in the field. Fields 1 and 3 were tilled once in the spring, while field 2 was tilled twice (i.e., in winter and spring). The transplantation dates ranged from the beginning of June to the middle of June; as a result, the heading and harvesting dates varied among the three fields. Compost was applied to fields 1 and 2, and the amounts of nitrogen therein were 70 kg ha^{-1} and 87 kg ha^{-1}, respectively. The amounts of total nitrogen fertilization were smaller in all paddy fields than the standard in Fukuoka prefecture for the Yumetsukushi cultivar (i.e., 60 kg ha^{-1}). Basal fertilization in field 2 was applied 21 d before transplantation, which is somewhat earlier than the conventional timing. For field 1, topdressing was applied 43 d before heading and 21 d before heading, whereas in field 2, topdressing was applied 9 d before heading. Rapeseed oil cake was applied to both fields for topdressing, while chemical fertilizer was applied as basal fertilization and the first topdressing in field 1. No topdressing was applied to field 3.

Air temperature during each growth stage

According to the meteorological data of Kurume city, as provided by the Fukuoka District Meteorological Observatory, the daily average air temperatures in June, July, and August 2008 were approximately 2 °C lower, 2 °C higher, and 1 °C lower, respectively, than the average values of the five years between 2003 to 2007. The daily average air temperature in September was about the same as that in an average year. The average air temperature during each growth stage is presented in Table 2. The air temperatures during the rooting stage were 3 °C different between field 2 (17.9 °C) and field 3 (20.9 °C), because the transplantation date of field 2 was about half a month earlier than in field 3, and field 2 was located 82 m higher in altitude. Also, the average air temperature during the tillering stage was the lowest in

Table 2. Average air temperature during each growth stage

Growth stage	Rooting		Tillering		Panicle development		Early ripening	
	Period	˚C	Period	˚C	Period	˚C	Period	˚C
Field1	6/6–6/15	18.6	6/16–7/31	23.3	7/17–8/15	25.5	8/16–9/4	22.4
Field2	6/2–6/11	17.9	6/12–7/25	22.5	7/10–8/8	25.1	8/9–8/28	23.3
Field3	6/15–6/24	20.9	6/25–7/31	24.7	7/20–8/18	25.9	8/19–9/7	23.0

field 2 (22.5 °C). Among the three fields, the temperatures during the panicle development stage were at approximately the same level; on the other hand, the average temperature in the early ripening period of field 2 was the highest, in spite of it being located at a higher altitude than field 3.

Inorganic nitrogen concentration in irrigation water and estimation of nitrogen supply and absorption

The inorganic nitrogen concentrations during each growth stage are presented in Table 3. In all water systems, NO_3–N accounted for about 90% of inorganic nitrogen in most of the growth stages. NO_2–N concentrations were negligible. The concentration of inorganic nitrogen was noticeably high in field 1, owing to tea production in upstream fields; the standard of nitrogen fertilizer for green tea in Fukuoka prefecture (Fukuoka Prefectural Government Department of Agricultural Agricultural Technologies Support Division, 2000) is 530 kg ha^{-1}–almost nine times the standard amount of nitrogen fertilization for the Yumetsukushi cultivar in the area (60 kg ha^{-1}). In addition, high nitrogen concentrations resulted from the small water volume, since field 1 was located in the uppermost area of its water system. The nitrogen concentration of field 3 was relatively high, due to intensive tea production in surrounding fields; field 3 was located around the midstream area of its water system, and the water collected in the area diluted the nitrogen concentration within. The nitrogen concentration was low in field 2, because there was no upstream tea production. The nitrogen concentrations during each growth

Table 3. Inorganic nitrogen concentration in irrigation water and estimation of nitrogen supply and absorption

Growth stage	Tillering	Panicle development	Booting	Ripening
Irrigation requirement (t ha^{-1})	3660	4360	2220	2920
Absorption rate (NH_4–N)	0.08	0.21	0.23	0.15
Absorption rate (NO_3–N)	0.31	0.37	0.56	0.46
Field1				
NH_4–N concentration (mg L^{-1})	1.02	0.37	0.14	0.28
NO_3–N concentration (mg L^{-1})	12.65	4.62	6.60	12.89
Inorganic nitrogen supplied (kg ha^{-1})	50.4	21.72	14.95	38.44
Inorganic nitrogen supplied after B. S. and in total (kg ha^{-1})	After B. S.	53.40	Total	125.15
Inorganic nitrogen absorbed (kg ha^{-1})	14.49	7.82	8.28	17.54
Inorganic nitrogen absorbed after B. S. and in total (kg ha^{-1})	After B. S.	25.82	Total	48.13
Field2				
NH_4–N concentration (mg L^{-1})	0.05	0.16	0.63	0.41
NO_3–N concentration (mg L^{-1})	0.72	0.66	0.55	0.80
Inorganic nitrogen supplied (kg ha^{-1})	2.80	3.58	2.61	3.53
Inorganic nitrogen supplied after B. S. and in total (kg ha^{-1})	After B. S.	6.15	Total	12.52
Inorganic nitrogen absorbed (kg ha^{-1})	0.82	1.21	1.00	1.26
Inorganic nitrogen absorbed after B. S. and in total (kg ha^{-1})	After B. S.	2.25	Total	4.29
Field3				
NH_4–N concentration (mg L^{-1})	0.30	1.08	0.45	0.19
NO_3–N concentration (mg L^{-1})	6.38	4.83	6.07	3.57
Inorganic nitrogen supplied (kg ha^{-1})	24.43	25.75	14.48	11.00
Inorganic nitrogen supplied after B. S. and in total (kg ha^{-1})	After B. S.	25.49	Total	75.67
Inorganic nitrogen absorbed (kg ha^{-1})	7.24	8.81	7.79	4.91
Inorganic nitrogen absorbed after B. S. and in total (kg ha^{-1})	After B. S.	12.7	Total	28.76

"B. S." represents Booting Stage. Data reported by Jinnouchi and Iwabuchi (2000) and Hidaka (1990) were cited for Irrigation requirements and the absorption rates of NH_4–N and NO_3–N, respectively.

stage varied, depending on fertilization in the tea fields and rainfall. Table 3 also includes the amounts of nitrogen supplied from irrigation water and nitrogen absorbed by the rice plants, as estimated via NH_4–N and NO_3–N concentrations; data regarding irrigation water required at each growth stage, as reported by Jinnouchi and Iwabuchi (2000); and the absorption rates of NH_4–N and NO_3–N, as reported by Hidaka (1990). The amount of nitrogen supplied throughout the growth season in field 1 reached 125.15 kg ha^{-1}; this amount corresponds to approximately twice the standard amount of nitrogen fertilization. Also, the total amount of nitrogen absorbed by rice plants reached 48.13 kg ha^{-1}; this amount corresponds to approximately 40% of the nitrogen uptake at the harvest stage; Araki *et al.* (2002) reported 12.5 kg ha^{-1} as the ideal amount of nitrogen uptake in terms of yield.

Rice growth

Each indicator of rice growth (Fig. 1) is the average value of measurements for 10 hills. Throughout the season, the number of tillers was the smallest in field 2. PPT was the largest in field 1 (Table 1). Plant length was the smallest in field 1 by the middle of the tillering period, while it rapidly increased during the internode elongation period. At one point, the plant length of field 1 reached the same level as that in field 2, but the former eventually became the shortest. Throughout the season, plant length in field 3 was the largest. The SPAD values of field 1 were the highest throughout the growth season and in excess of 40 by approximately the heading date. The SPAD values decreased over the panicle development period in fields 2 and 3 and then slightly increased over the early ripening period.

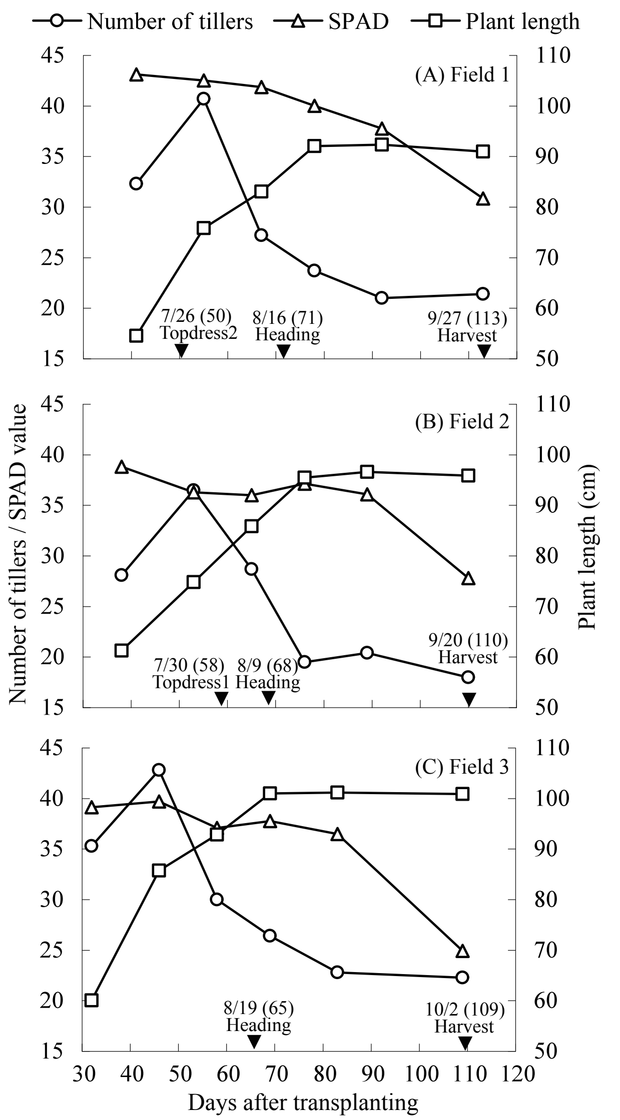

Fig. 1. The number of tillers, plant length and SPAD value. Figures in parentheses represent days after transplanting.

Yield components and physicochemical properties of brown rice

The panicle length and the number of hills were at approximately the same level among the three fields. In field 2, the numbers of panicles per hill, panicles and spikelets were the smallest, while spikelets per panicle, percentage of ripened grains (PRG), and 1000–GW were the largest. The yield was 62 g m^{-2} smaller than that in field 1, whose yield was the largest. The spikelets per panicle and PRG were about the same between fields 1 and 3. Although the number of panicles in field 1 was slightly smaller than that in field 3, its yield was the largest, due to the large 1000–GW. The protein content was the lowest in field 2, and relatively high in fields 1 and 3. Finally, the amylose content was the highest in field 1 and at approximately the same level in fields 2 and 3.

DISCUSSIONS

Effects of cultivation practices and production environment on yield components and physicochemical properties of brown rice

The largest SPAD value, as found in field 1 (Fig. 1), was thought to be prompted by an abundant nitrogen supply from irrigation water, since the amount of total nitrogen fertilization was approximately the same level among the three fields. The number of tillers in field 1 was smaller than that in field 3, probably due to the smaller amount of basal fertilization and lower temperature in the former, during the tillering period. The number of tillers is affected by the nitrogen content in a stem (Matsuo, 1990), which depends upon nitrogen uptake as controlled by temperature and nitrogen supply. On the other hand, PPT was larger in field 1; consequently, the number of panicles there was approximately the same as in field 3. The larger PPT in field 1 was thought to have been caused by the large amounts of nitrogen supply from irrigation water, following the maximum tillering period. Other yield components were almost identical between fields 1 and 3, except 1000–GW, which was 1.7 g larger in field 1. Carbohydrate assimilation was found to have been promoted by vigorous photosynthesis, due to the high leaf–blade nitrogen content; however, the abundant nitrogen supply resulted in the largest protein content. Amylose content was the highest in field 1 because of its lowest temperature during the early ripening period. Amylose content generally increases as air temperature decreases during the ripening period (Inatsu, 1988).

The number of tillers was the smallest in field 2. This was thought to have been caused by the reduced nitrogen uptake, due to the low temperature during the tillering period and the possible nitrogen loss caused by early basal fertilization. As a result, field 2 had the smallest number of panicles and spikelets. On the other hand, it was judged from the large PRG and 1000–GW that the accumulation of starch into each grain had been promoted by the increased production of dry matter per tiller, which was made possible by favorable light–receiving conditions under the small number of tillers. Thus, the yield of field 2 remained at 62 g m^{-2} lower than that of field 1. Although the SPAD values of field 2 were approximately the same as those of field 3 during the early ripening period, the protein content in the former was the lowest; the reasons were thought to be a lower amount of nitrogen distributed in each grain, due to the large number of spikelets per panicle, as well as an increased accumulation of starch. The plant length was relatively high in field 2, about 40 d after transplantation; however, the elongation rate of plant length was moderate during the internode elongation period, probably due to the small amount of nitrogen supply. Finally, the plant length in field 2 became larger than that of field 1, because solar radiation was more plentiful in the former during the two–week period prior to heading. It was hypothesized that the low PPT of field 2 (48%) was caused by a shortage of nitrogen supply, due to late topdressing. The highest average temperature during the early ripening period, which was achieved by early transplanting, resulted in the lowest amylose content in field 2.

The initial growth (i.e., the number of tillers, plant length) was vigorous in field 3, due to high temperatures during the tillering period and a relatively large amount of basal fertilization. The elongation rate of plant length during the internode elongation period in field 3 was as high as that in field 1 and resulted in the largest plant length. The maximum number of tillers in field 3 was the largest, while its number of panicles was about the same as that in field 1, due to the large number of non–productive tillers. The SPAD values of field 3 were a little high compared to field 2 during the period of initial growth, while the values stayed at the same level as field 2 during the early ripening period, in spite of there being no topdressing on field 3; the nitrogen supply from the irrigation water is thought to be the main reason for this. Also, it was found that the mineralization of organic nitrogen in rice straw incorporated in the spring could have been a possible reason for the SPAD values. According to a study into the effect of applying rice straw, as conducted in the Yamaguchi prefecture by Marumoto *et al.* (1982), the highest yield was produced by broadcasting rice straw in the autumn and incorporating it in the spring. In the current study, from the small 1000–GW (21.5 g), it is believed that the accumulation of starch into each grain was insufficient, owing to the small amount of dry–matter production per tiller. Hoshikawa (1985) explains that the net production of dry matter decreases under excessive growth, due to increased respiration and reduced efficiency of photosynthesis, as caused by deteriorating light–receiving conditions. Also, it is believed that the small number of spikelets per panicle and the small accumulation of starch increased the protein content of field 3. The amylose content was low in field 3, due to relatively high temperatures during the early ripening period.

Recommendations for improving rice production

Inatsu (1998) reported that approximately 40% of nitrogen absorbed by rice plants is supplied from fertilization. For field 1, the estimated nitrogen absorbed from irrigation water (48 kg ha^{-1}) accounted for approximately 40% of the nitrogen uptake at the harvest stage; Araki *et al.* (2002) reported 12.5 kg ha^{-1} as the ideal amount of nitrogen uptake in terms of yield. This indicates that the nitrogen fertilization was not required in this field.

The number of tillers was restricted in field 2, due to early transplantation; it resulted in small numbers of panicles and spikelets. The small number of tillers was advantageous in terms of the production of dry matter per tiller; it led to large 1000–GW and high PRG, without increasing protein content. The restriction of initial growth could be recommended for improving rice quality, in terms of lowering protein content and increasing 1000–GW; however, PPT was low (48%) in field 2, indicating that both a reduction in basal fertilization and an appropriate measured and timed application of topdressing are needed to ensure productive tillers. Hashikawa (1985) encourages both a reduction in basal fertilization and heavy topdressing during the differentiation period of neck of spike (i.e., 35 d before heading). To execute this fertilization practice, further work is needed to determine the amounts of basal fertilization and topdressing for fields in the region.

Additionally, it was found that early transplantation increased temperature during the early ripening period and led to low amylose content. In mountainous areas, temperatures during the early ripening period tend to be low; thus, early transplanting is advantageous in terms of both restricting initial growth and lowering amylose content. Morita (2005) reported that for the Koshihikari cultivar, the number of white immature grains dramatically increases at daily average temperatures greater than 27 °C during the early ripening period. Also, Iwabuchi *et al.* (2003) reported for the Yumetsukushi cultivar, the inspection grade was significantly lowered on account of increased rates of milky–white and white–backed kernels, when the mean air temperature was higher than 28 °C during the early ripening period. Thus, it is possible to take measures to ensure that the air temperature during the early ripening period is increased by about 3 °C, which in turn lowers amylose content. The transplantation date must be carefully determined, considering not only air temperature in an average year but also the risks incurred by variations in air temperature each year and suitable air temperature for each growth stage.

In comparing SPAD and 1000–GW values between fields 1 and 3, it is thought that a high leaf–blade nitrogen content is required to increase 1000–GW, when there are a large number of spikelets. On the other hand, when leaf–blade nitrogen content increases, the protein content of brown rice also increases, as seen in field 1. Therefore, it is difficult to achieve low protein content via nitrogen fertilization adjustments, when there are a large number of spikelets. Therefore, it is important to restrict initial growth, to avoid an excessive number of spikelets.

From the aforementioned examinations, the following recommendations are made, to improve rice production in the rice terrace region. Earlier transplantation dates are recommended, as they led to increased air temperature during the early ripening period and restrictions of initial growth. The amount of basal nitrogen fertilization should be reduced, also to restrict initial growth. Finally, nitrogen fertilizer should not be applied to fields where sufficient nitrogen is already supplied from irrigation water.

ACKNOWLEDGEMENTS

The authors would like to thank you Prof. Emeritus Susumu Uchida in Saga University for his helpful support in analyzing physicochemical properties of our rice samples. Also, the authors would like to express their heartfelt gratitude to Mr. Beppu, Mr. Kawai, Mr. Yokoyama, Mr. Shuto, and Ms. Mouri, for their dedication to the field survey.

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