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Varietal Differences in Tillering and Yield Responses of Rice Plants to Nitrogen-Free Basal Dressing Accompanied with Sparse Planting Density in the Tohoku Region of Japan

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Abstracts : At present, the main challenge in rice production is to achieve a high and stable yield with low input. In this study, the growth of tillers and yield of 12 rice cultivars and lines in the practice of nitrogen-free basal dressing with sparse planting density (BNo) was examined and compared with those in the conventional cultivation (CONT). The results in 1999, 2000 and 2001 showed that the numbers of both primary and secondary tillers m^{-2} were smaller in BNo than in CONT for all cultivars. However, a large number of tillers in CONT, especially the secondary tillers, were nonproductive, and most of those in BNo were productive. The difference between BNo and CONT in the number of panicles m^{-2} was larger for the cultivars of the panicle-number type than for those of the panicle-weight type. Grain yield was often lower in BNo than in CONT, and the yield averaged over years and cultivars was 748 g m^{-2} in BNo and 772 g m^{-2} in CONT (the ratio of value in BNo to that in CONT was 97 %). The difference between BNo and CONT in grain yield varied with the cultivar and the year. Under favorable weather conditions in 2000 and 2001, grain yield was high in both CONT and BNo, and was higher in CONT than in BNo for most cultivars. Nevertheless, under the unfavorable weather condition in 1999, grain yield was low in both CONT and BNo, and was similar or higher in BNo than in CONT. In all 3 years, the grain yield of Akitakomachi and Fukuhibiki was lower, and that of Ouu316 and Hitomebore tended to be higher in BNo than in CONT. The practice of BNo was found to be effective for achieving a stable and high yield of Ouu316 and Hitomebore in the Tohoku region.

Key words : Nitrogen-free basal dressing, Rice cultivars, Sparse planting density, Weather conditions, Yield.

In the conventional rice cultivation practice in Japan, a large amount of nitrogen fertilizer is usually applied as a basal fertilizer to promote the growth of rice at the early vegetative stage (Wada et al., 1990; Matsushima, 1995). Rice plants grown by this method produce a large number of tillers and spikelets per unit area, and give a high grain yield under favorable weather conditions (Matsushima, 1995; Hirano et al., 1997). The application of heavy nitrogen fertilizer at the early growth stage, however, sometimes causes over-luxuriant growth at the middle growth stage resulting in lodging and low percentage of ripened grains, subsequently leading to a reduction in grain quantity and inferior quality (Yoshida, 1981; Tanaka, 1983; Hashikawa, 2001). Rice grown with a large amount of nitrogen applied at the early growth stage is also subject to physical disorders caused by pests, diseases and environmental stresses, such as flood, drought, heat and cold damages at the reproductive stage (Yoshida, 1981; Satake et al., 1987).

In Japan, rice production was severely affected by cool weather in 1993, and the crop situation index was 74 for the nation, 56 for the Tohoku district and 40 for the Hokkaido district (Nishiyama, 1996). The main part of damage was sterility due to cool weather around the young microspore stage, and the rest was damage by blast disease and others (Oyamada, 1995; Nishiyama, 1996). Although most farmers in the Tohoku district suffered from heavy yield loss due to cool weather, interestingly, some of them obtained grain yields comparable to the amount in normal years (Murata et al., 1994; Hirano et al., 1997). These farmers practiced a specific cultivation, in which the early growth of rice plants was controlled by the omission of nitrogen fertilizer at transplanting time and by sparse planting density (13 to 17 hills per m^2), and later growth was promoted by nitrogen top-dressing after the 8^{th} leaf age stage (BNo). By this method, the total amount of nitrogen fertilizer applied was smaller, the planting density was lower, and grain yield was 5-10% lower than that in the conventional cultivation (CONT) in normal years (Hirano et al., 1997).

Until now, the characteristics of rice plants grown under BNo have been studied for improving grain yield and bringing this cultivation technique into use.

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Table 1. Planting density, time and rate of fertilizers applied.

Plots	Planting density hills m^{-2}	Nitrogen application (g m^{-2})					Total fertilizers (g m^{-2})		
		Basal dressing 5/8[1)]	8th-leaf age 6/6-6/8	NNI 6/26-7/6	Panicle initiation[2)] 7/8-7/18	Heading stage 7/28-8/8	N	P_2O_5	K_2O
CONT	22.2	6.5	—	—	2.5	2.0	11.0	14.0	12.8
BNo	16.7	—	3.0	2.0	2.0	2.0	9.0	14.0	12.8

1): Dates of nitrogen application. NNI: Neck node initiation stage (33~35 days before heading).
2): When a young panicle had grown about 1.5~2.0 mm long. P2O5 and K2O were applied as basal fertilizers.

Previous studies (Hirano et al., 1997) indicated that a smaller number of tillers m^{-2} resulting in a smaller number of panicles m^{-2} was one of the main reasons for the lower yield in BNo. In the study on the effect of planting density and nitrogen top-dressing on the growth and yield of rice plants in BNo, Truong et al. (1998) suggested that increased planting density could not improve yield, but that the top-dressing of nitrogen fertilizer at the neck node initiation stage (33 to 35 days before heading) could increase grain yield up to 95-100% of that in CONT through increasing the number of panicles on the secondary tillers and the number of spikelets per panicle.

It has been well known that the growth and yield of rice plants are not only affected by weather conditions of a particular cultivation season (Yoshida, 1981; Samui, 1999; Sasaki et al., 2001), but also vary with the cultivar (Kuroda et al., 1999; Peng et al., 2000). Previous studies, nevertheless, have been carried out only in some limited normal weather years, and with only Akitakomachi and Hitomebore, the two cultivars widely cultivated in the Tohoku region. In order to bring a new cultivation technique into use, we need to examine the usefulness of this technique for many years and with various cultivars. Therefore, we carried out this study to examine the effects of BNo on tillering characteristics and grain yield of different rice cultivars for three years. Furthermore, the effects of temperature and solar radiation in different weather years on the rice yield under BNo and CONT are also discussed.

Materials and Methods

Experiments were conducted in the paddy field with Wet Aldosols at the Faculty of Agriculture, Iwate University in 1999, 2000 and 2001. The materials used were seven cultivars and five lines. The names, earliness and plant types of these cultivars and lines are shown in Fig. 2 and 3. The seven cultivars were chosen because they are widely cultivated in the Tohoku region. The five promising lines were used because of their high yield performance in previous yield tests at the field of Iwate University (Kuroda et al., 1999).

The experiments were laid in a split-random block design with two replications. Growth conditions (CONT and BNo) were arranged as main-plots, and cultivars as sub-plots. The sub-plot size of about 20 m^2 was used. Table 1 shows the planting density, the total amount of fertilizers applied and fertilizer application times. In CONT, rice plants were transplanted at the standard planting density of 22.2 hills m^{-2}, with 15 cm in row and 30 cm between rows (15 × 30 cm), and with a nitrogen fertilizer application regime following the standard practice in Iwate prefecture. In BNo, nitrogen fertilizer was not applied as basal dressing, but was top-dressed at the 8th leaf age stage, and seedlings were transplanted with the planting density of 16.7 hills m^{-2} (20 cm in row and 30 cm between rows). The sparse planting density of 16.7 hills m^{-2} and top-dressing of 2.0 g N m^{-2} at the neck node initiation stage were used in BNo because these produced the

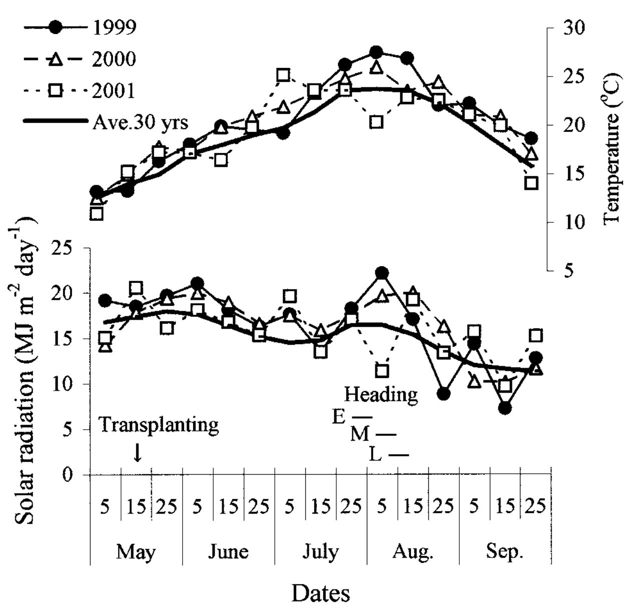

Fig. 1. Air temperature (above) and solar radiation (below) during the growing season of rice plants in 1999, 2000 and 2001.
Data were collected from Morioka Meteorological Station. Ave.30 yrs is the mean value of recent 30 years. E, M and L indicate the heading times of the early, medium and late maturing cultivars, respectively.

highest yield for Akitakomachi and Hitomebore in previous experiments (Truong et al., 1998). Seedlings at around the 4th leaf age stage were transplanted with three seedlings per hill in the middle of May. Standard cultural management was applied during all growth stages. At the maximum tiller number stage, midseason drainage was carried out in CONT, but a water level at 5-8 cm was kept in BNo to prevent excessive loss of nitrogen.

For investigating the number of tillers and panicles, we randomly sampled 5 hills and 15 hills, respectively, from each replication at the maximum tiller number and full heading stages. The numbers of tillers and panicles on the main stems, primary and secondary tillers were then counted. For determining grain yield, 54 hills from each plot were hand-harvested at maturity, and then were air-dried. After threshing and hulling, grains were screened with a quadrat sampling rice separator (strings width, 1.8 mm) and weighed. Brown rice yield was adjusted to the moisture content of 14.5%. Daily weather records were obtained from Morioka Meteorological Station, situated near the experimental site.

Results

1. Weather conditions

Fig. 1 shows the changes in temperature and solar radiation during the growing season of rice plants. The patterns of temperature and solar radiation were quite different in the three years. The temperature in all three years was often higher than the average value during the period from mid-May to mid-July (from transplanting to panicle formation stages). From the end of July to the middle of August (from heading to milk ripening stages), temperature was abnormally high in 1999 (4-5 ℃ higher than the average value), 2-3 ℃ higher in 2000, but 1-3 ℃ lower than the average value in 2001. From the end of August to the middle of September (middle ripening to full ripening stages), the average temperature in 1999 and 2000 was slightly higher than, and that in 2001 was similar to the average value.

In 1999, solar radiation was high from mid-May to mid-August (from transplanting to the milk ripening stage). However, solar radiation during the last ten days of August and during the middle ten days of September was very low (9 and 7 MJ m^{-2} day^{-1}, respectively), and was only 65% and 63% of the average value, respectively. Solar radiation in 2000 was high and often higher than the average value from the middle of May until the end of August (from transplanting to yellow ripening stage), but slightly lower than the average value thereafter. In 2001, solar radiation was markedly low during the first ten days of August (heading time). It was then similar to or even higher than the average value during the period from mid-August to mid-September.

The heading date of rice plants in BNo was the same as that in CONT. The heading date of the early maturing cultivars was 4 to 5 days, and 8 to

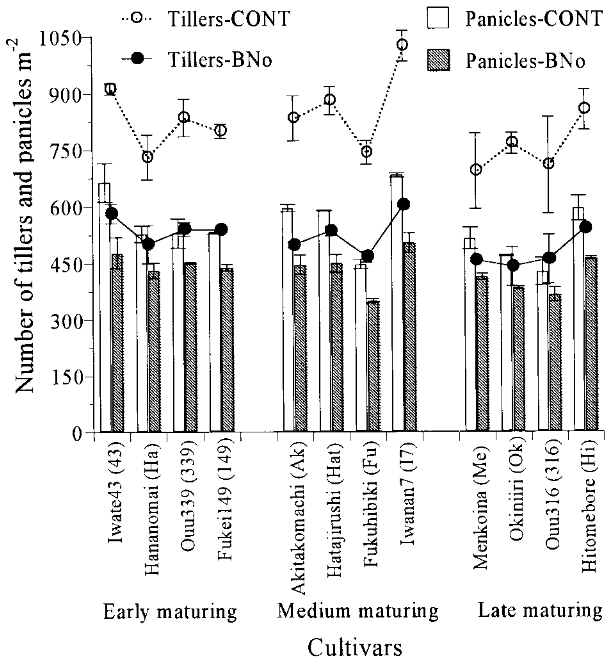

Fig. 2. The total number of tillers and panicles of different rice cultivars under CONT and BNo in 2001.
Error bars indicate standard errors. Letters and numerals in ( ) indicate the abbreviated cultivar names.

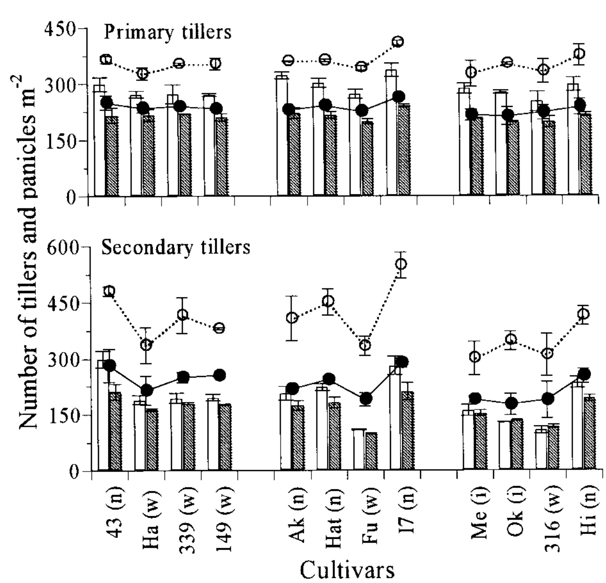

Fig. 3. The number of tillers and panicles on the primary tillers (above) and secondary tillers (below) under CONT and BNo in 2001.
Error bars indicate standard errors. Symbols are the same as Fig. 2.
Letters in ( ) indicate the plant type of cultivars: n = the panicle number type, i = the intermediate type and w = the panicle weight type.

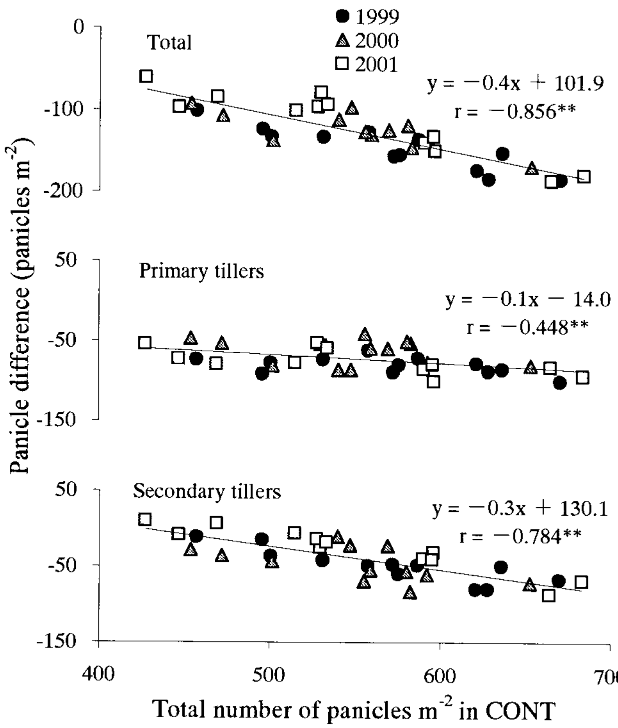

Fig. 4. Correlation of the difference in panicle number between BNo and CONT with the total number of panicles in CONT.
**: significant at 0.01 probability level.

10 days earlier than that of the medium and late maturing cultivars, respectively. As affected by higher temperature from transplanting to heading, the heading date in 1999 and 2000 was about 3 days earlier than that in 2001, and about one week earlier than that in normal years.

2. Tillering characteristics

Since the tillering pattern was similar in all three years, only the data for 2001 are presented here (Fig. 2 and 3). The total number of tillers m^{-2} as well as the number of primary and secondary tillers m^{-2} was greater in CONT than in BNo for all cultivars. The degree of difference between BNo and CONT in the total number of tillers m^{-2} and in the number of primary and secondary tillers m^{-2} did not obviously vary with the cultivar. A large number of tillers in CONT, particularly the secondary tillers, were nonproductive whereas most tillers were productive in BNo. Although the total number of panicle m^{-2} was smaller in BNo, the degree of difference between BNo and CONT in panicle number was much smaller than that in tiller numbers for all cultivars. In some cultivars and lines belonging to the panicle-weight type (Hananomai, Ouu339, Fukei149, Fukuhibiki and Ouu316) and the intermediate type (Menkoina and Okiniiri), the number of panicles m^{-2} on the secondary tillers was not significantly different between BNo and CONT (Fig. 3).

Fig. 4 shows the correlation of the difference in panicle number between BNo and CONT (PD) with the total number of panicles m^{-2} in CONT. The correlation of PD on the main stems with the total number of panicles m^{-2} in CONT is not presented here because PD was similar for all cultivars in all 3 years.

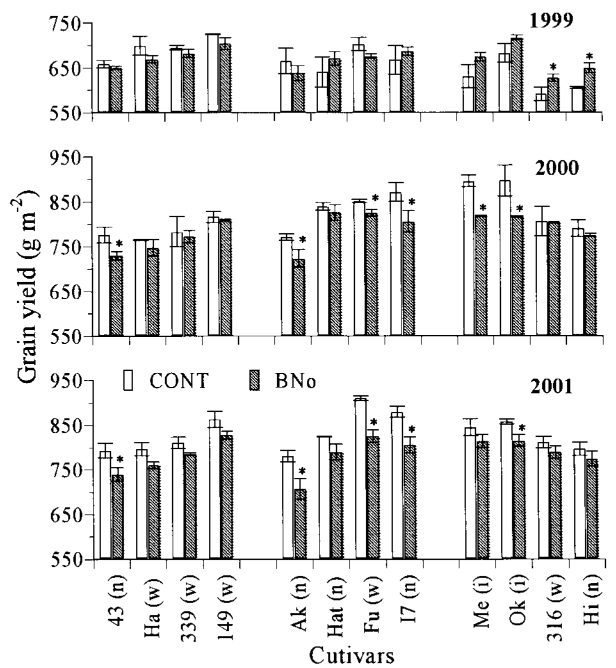

Fig. 5. Grain yield of different rice cultivars under CONT and B No in 1999, 2000 and 2001.
Error bars indicate standard errors. *: significant difference between BNo and CONT at 0.05 probability level.
Letters in ( ) are the same as Fig. 3.

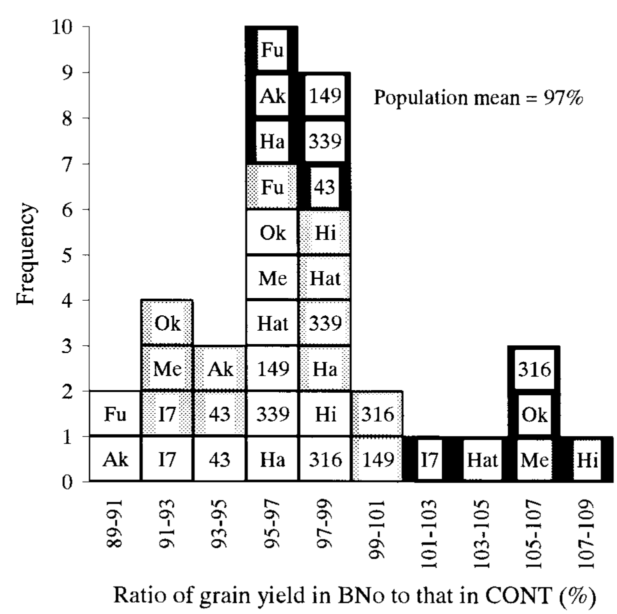

Fig. 6. Frequency distibution of the ratio of grain yield in BNo to that in CONT (%). Solid bars: in 1999, dotted bars: in 2000, and open bars: in 2001.

The regression line and correlation coefficient in each year are also not shown since they were nearly the same in all 3 years. Overall, PD for the total number of panicles as well as for the number of panicles on the primary and secondary tillers significantly correlated with the total number of panicles m^{-2} in CONT. Slope coefficients were -0.4, -0.1 and -0.3 for the total panicles, the panicles on the primary and secondary tillers, respectively, indicating that PD varied with the total number of panicles m^{-2}. These slope coefficient values suggested that the variation in PD for the total panicles was mainly attributed to that in the number of panicles on the secondary tillers.

3. Differences in grain yield

Fig. 5 and 6 show the grain yields under BNo and CONT for all cultivars in 1999, 2000 and 2001. Grain yield was often lower in BNo than in CONT. The yield averaged over the years and cultivars was 748 g m^{-2} in BNo and 772 g m^{-2} in CONT (the ratio of value in BNo to that in CONT was 97 %). In 1999, grain yield was low in both CONT and BNo. It ranged from 590 to 724 g m^{-2} in CONT, and from 627 to 717 g m^{-2} in BNo. The yield averaged over 12 cultivars and lines was 663 and 670 g m^{-2} in the former and in the latter, respectively. In comparison with CONT, grain yield in BNo was slightly lower for Iwate43, Hananomai, Ouu339, Fukei149, Akitakomachi and Fukuhibiki, slightly higher for Hatajirushi and Iwanan7, and clearly higher for Menkoina, Okiniiri, Ouu316 and Hitomebore (the late maturing cultivars). In 2000 and in 2001, grain yield was high in both CONT and BNo. The average yield of 12 cultivars and lines was 822 g m^{-2} in CONT and 778 g m^{-2} in BNo in 2000. It was 830 and 776 g m^{-2} in the former and in the latter, respectively, in 2001. In these two years, grain yield was lower in BNo than in CONT for most cultivars. Over the three years, the difference between BNo and CONT in grain yield did not relate to the plant type of cultivars, and cultivars that produced lower or higher yield in BNo, as compared with CONT, could belong to any plant type. Grain yield in BNo, however, was often clearly lower for Akitakomachi and Fukuhibiki, and slightly lower for Ouu339, Hananomai, Fukei149 and Hatajirushi, but was higher than or similar to that in CONT for Ouu316 and Hitomebore (Fig. 5 and 6).

Fig. 7 shows the correlation of yield difference between BNo and CONT (YD) with the grain yield in CONT. YD varied widely from +44 g m^{-2} for Hitomebore in 1999 to -86 g m^{-2} for Fukuhibiki in 2001, and overall, YD significantly correlated with grain yield in CONT (r = − 0.794**). YD was smaller in the low yield year (1999), and larger in the high yield years (2000 and 2001). In the same year, YD was often larger in high yielding cultivars.

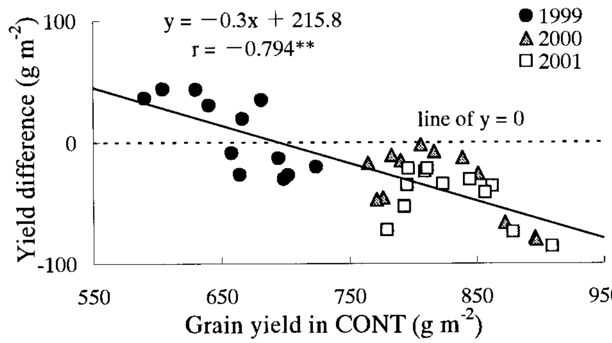

Fig. 7. Correlation of yield difference between BNo and CONT (BNo-CONT) with grain yield in CONT.
**: significant at 0.01 probability level.

Discussion

1. Low tiller and panicle number in BNo and differences among cultivars in the degree of difference between the panicle number under BNo and CONT

In previous studies, Hirano et al. (1997) and Truong et al. (1998) reported that two cultivars Akitakomachi and Hitomebore, produced a greater number of tillers m^{-2} in CONT than in BNo. The present study showed that the numbers of total, primary and secondary tillers m^{-2} were also much smaller in BNo than in CONT for all 12 cultivars and lines (Fig. 2 and 3). Generally, the number of tillers m^{-2} is determined during the vegetative growth period, and is mainly governed by tillering capacity of cultivars, planting density and the availability of mineral nutrition, particularly nitrogen (Yoshida, 1981). A large amount of nitrogen fertilizer applied as basal dressing in CONT could promote the emergence of tillers from lower node orders and subsequently bring about a large tiller number for all cultivars. The shortage of nitrogen at the early growth stage of rice plants in BNo, on the other hand, retarded the emergence of lower node tillers (Hirano et al., 1997). Sparse planting density, furthermore, reduced the number of the main stems, on which the primary tillers emerged. The combination of nitrogen-free basal dressing and sparse planting density, consequently, decreased the number of tiller m^{-2} for all cultivars in BNo.

The number of panicles m^{-2} varies not only with the number of tillers (Shnier et al., 1990; Hanada, 1993; Wu et al., 1998), but also with the morphological and physiological characteristics of tillers (Hoshikawa, 1989). A large number of tillers, particularly those emerged from lower nodes, could produce a larger number of panicles in CONT (Hirano et al., 1997). A large number of tillers and a large leaf area index of rice plants in CONT, however, caused mutual shading, resulting in the shortage of photosynthates and subsequent reduction in the number of tillers surviving (Tanaka et al., 1966; Hanada, 1993; Hirano et al., 1997). In CONT, the omission of nitrogen top-dressing at the neck node initiation stage and a high competition among tillers for assimilates and nutrients in dense plant community might also lower the percentage of productive tillers, especially for the secondary tillers and for the cultivars belonging to the panicle-weight type. The application of nitrogen fertilizer at the neck node initiation stage and sparse planting density in BNo, on the other hand, could overcome the problems caused by the shortage of nitrogen and by mutual shading. Each tiller, especially the secondary one, of rice plants in BNo received more sunlight and nutrients, produced more carbohydrates and became more productive than in CONT (Hirano et al., 1997). The higher rate of productive tillers suggested that BNo was an effective rice cultivation technique with little waste.

The negative and significant correlations of the degree of difference in panicle number between BNo and CONT (PD) with the total number of panicles m^{-2} in CONT (Fig. 4), especially for the total panicles and the panicles on the secondary tillers, indicated that PD varied with the total number of panicles m^{-2} in CONT, and was large in the cultivars with a large number of panicles in CONT (cultivars of the panicle-number type). In other words, PD was small in the cultivars with a small number of panicles (cultivars of the panicle-weight type). The small PD in the cultivars of the panicle-weight type suggested that the practice of BNo may be more suitable for cultivation of these cultivars than for the cultivars of the panicle-number type in the Tohoku region.

2. Effects of weather conditions on yield and varietal differences in yield responses to cultivation methods

Hirano et al. (1997) and Truong et al. (1998) demonstrated that grain yield in BNo was about 90-100% of that in CONT in the normal years. In the present study, the ratio of grain yield in BNo to that in CONT was 95-108% in 1999, when yield was low in BNo and CONT, and was about 90-100% in 2000 and 2001, when most rice cultivars produced more than 750 g m^{-2} of brown rice in both BNo and CONT (Fig 5 and 6). The efficiency of nitrogen fertilizer, calculated from kilograms of brown rice produced per kilogram of nitrogen applied, was higher in BNo than in CONT (data not shown). In 1999, the average efficiency was 74.4 in BNo compared with 60.3 in CONT (the ratio of value in BNo to that in CONT was 123%). It was also 17 and 16% higher in the former than in the latter in 2000 and 2001, respectively. These proved that BNo practice could bring about a high yield with a low input. The great change in grain yield among years as well as the large variation in the ratio of grain yield in BNo to that in CONT, furthermore, indicated that grain yield was highly influenced by weather conditions, cultivars and cultivation practices.

After heading, solar radiation and temperature were confirmed to be the two main environmental factors affecting grain yield (Murata, 1964; Suzuki and Nakamura, 1978; Yoshida, 1981). Low solar radiation during the ripening period could have adverse effects on grain filling and subsequently on grain yield and quality (Yoshida and Parao, 1976; Kobata et al., 2000). The optimal temperature for grain filling of Japonica rice in Japan was reported to be in the range from 20 to 22 °C (Matsushima and Manaka, 1957; Murata, 1964; Yoshida, 1981). High temperature increases respiration rate, affects the translocation of photosynthates to grains, resulting in a decrease in grain weight, an increase in the number of sterility and partially filled grains, and consequently the decrease in grain quantity and quality (Matsushima and Wada, 1958; Morita, 2000; Zakaria et al., 2002). According to Terashima et al. (2001), the percentage of the first grade rice in Iwate prefecture in 1999 was significantly lower than that in normal years because of the high temperature during the early ripening stage. In our experiments, during the first 20 days of August 1999, the average temperature was higher than 27 °C, but during the following 10 days and 30 days, solar radiation was 8.8 and 10.1 MJ m^{-2} day^{-1}, respectively, (65% and 82% of that in normal years, respectively) (Fig. 1). As a result, all cultivars in this year were affected by the high temperature during the early ripening period, and by low solar radiation from the milk ripening stage onwards. During the whole grain filling period (40 days after full heading), the late maturing cultivars were more affected by low solar radiation (11.5 MJ m^{-2} day^{-1}) than the early and medium ones (14.3 and 13.0 MJ m^{-2} day^{-1}, respectively). Under such unfavorable weather conditions, grain yield of all cultivars, especially of late-maturing ones, was very low and much lower than that in normal years. The grain yield of Ouu316 and Hitomebore in CONT, for example, was 590 and 605 g m^{-2}, respectively. These values were significantly lower than the values of 815 and 772 g m^{-2}, respectively, in a previous experiment carried out in 1996, when these two cultivars were cultivated at the same site under the same cultivation condition (Kuroda et al., 1999).

In 1999, grain yield in BNo was similar to that in CONT for the early and medium maturing cultivars, and was higher for the late-maturing ones (Fig 5 and 6). Under a low solar radiation and a high temperature condition, a large number of stems, large leaf area index and large biomass often result in a high respiration rate that reduces photosynthates for grain filling (Murata and Iyama, 1958; Suzuki and Nakamura, 1978). Rice plants in CONT with such characteristics (Hirano et al., 1997; Truong et al.,

1998) might have been affected by low solar radiation and high temperature. The extremely low solar radiation during the whole grain filling period of the late maturing cultivars, as compared with that of the early and medium cultivars, thus, may have a stronger effect on grain filling of the former cultivars in CONT in 1999. On the other hand, rice plants in BNo characterized by a smaller number of stems, a smaller leaf area index and a better light intercepting canopy (Hirano et al., 1997) might be less affected by low radiation, and consequently produced the similar or higher grain yield than those in CONT. More study on ecological and physiological characteristics relating to the grain filling process of rice plants, particularly the canopy structure and dry matter production process, is necessary to further understand the reason for higher grain yield in BNo under unfavorable weather conditions.

In contrast to the weather condition in 1999, temperature was warm and solar radiation was high in 2000, throughout the growth period of rice plants. In 2001, the average temperature at the heading stage was lower (20.4℃) than in normal years (23.8℃), but it was higher than the critical low temperature of 20°C (Yoshida, 1981), and thus is considered to have had no adverse effect on grain yield. After heading, rice plants in 2001 also experienced a long period of mild temperature and high solar radiation (Fig. 1). Under such favorable weather conditions of 2000 and 2001, grain yield was much higher than that in 1999 in both BNo and CONT (Fig. 5). In CONT, the large leaf area index might bring about more photosynthates for grain filling, and subsequently raise grain yield, especially for high yielding potential cultivars with a large number of spikelets m^{-2}. On the other hand, the smaller number of spikelets m^{-2} of rice plants in BNo, which was caused by the omission of basal nitrogen dressing and sparse planting density (Hirano et al., 1997; Truong et al., 1998), could be the main reason for the lower grain yield in BNo.

The degree of yield difference between BNo and CONT varied not only with the year, but also with the cultivar. The grain yield of Akitakomachi and Fukuhibiki was always lower in BNo than in CONT in all 3 years, but that of Ouu316 and Hitomebore in BNo was higher than or similar to that in CONT (Fig. 5 and 6). The reason for the same or higher yield of Ouu316 and Hitomebore in BNo as compared with that in CONT was not clear, but it would be worth noting that these two cultivars belong to the late-maturing group, and the sink size was less affected by the shortage of nitrogen at the early growth stage (Wada and Cruz, 1990). Further research on yield components would be helpful to explain the high and stable yield of these cultivars grown by the practice of BNo in the Tohoku region.

Hirano et al. (1997) compared the yield components and grain yield of Akitakomachi and Hitomebore in BNo with those in CONT, and stated that the smaller number of panicles m^{-2} was the main reason for the lower grain yield of rice plants in BNo. The present study also showed that the number of panicles m^{-2} was smaller in BNo than in CONT for all cultivars and in all 3 years (Fig. 4). Thus, the smaller number of panicles m^{-2} in BNo may have caused the lower yield in BNo in 2000 and 2001. However, in 1999, the grain yield in BNo was similar to or higher than that in CONT despite the smaller number of panicle m^{-2}, suggesting that the smaller number of panicles m^{-2} does not always cause the lower yield in BNo, and that other yield components could compensate for the small number of panicles m^{-2} in this condition. Furthermore, although the difference in panicle number m^{-2} between BNo and CONT (PD) was smaller in the cultivars of the intermediate type and the panicle-weight type than in the cultivars of the panicle-number type (Fig. 2, 3 and 4), yield difference (YD) was not always smaller in the former cultivars (Fig. 5). This also indicated that the variations in YD among cultivars did not closely relate with the variations in PD. Therefore, the effect of other yield components on YD is worth investigating.

As mentioned above, the yield difference between BNo and CONT varied with the production year and the cultivar, and varied from +44 g m^{-2} for Hitomebore in 1999 to -86 g m^{-2} for Fukuhibiki in 2001. Generally, there was a tendency that YD was greater in the high yielding years and cultivars (Fig. 7). Grain yield was higher in CONT than in BNo in 2000 and 2001, especially for high-yielding-potential cultivars, indicating that the conventional cultivation technique with heavy nitrogen basal dressing and high planting density could be suitable for rice cultivation under favorable weather conditions. On the other hand, the higher grain yield of rice plants in BNo than in CONT for the late maturing cultivars in 1999 proved that the practice of nitrogen-free basal dressing with sparse planting density might be more effective for rice cultivation under unfavorable weather conditions, particularly when the weather conditions during the grain filling period are unfavorable. The stable and high yield of Ouu316 and Hitomebore in BNo, furthermore, suggested that this practice may be more suitable for cultivation of these two cultivars in the Tohoku region. For further elucidation of the above trend of variation in grain yield of different rice cultivars under BNo and CONT conditions, some physiological characteristics related to grain yield, especially the dry matter production process and yield components, will be examined in future studies.

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* In Japanese with English abstract or summary.

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