JARQ 53 (4), 229-239 (2019) https://www.jircas.go.jp

REVIEW

Influence of Daily Temperature Range on Seedling Emergence and Establishment and Estimation of Early Sowing Limits in Directly Seeded Rice under Submerged Conditions in a Cold-climate Area (Hokuriku Region, Japan)

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Abstract

Although direct seeding in rice cultivation has potential for labor- and cost-saving benefits in comparison with transplanting, the latter remains the predominant method in Japan because the former shows some weaknesses in seedling emergence and establishment, and in lodging resistance. We therefore set out to compare seedling emergence and establishment in direct seeding culture under different daily temperature ranges. We compared a windbreak-shielded and control plot using pot-grown plants under outdoor conditions. In the windbreak plot, which was subject to a high maximum temperature and wide daily temperature range, seedling emergence and establishment rates were higher than in the control plot. Additionally, detailed laboratory tests revealed that the influence of post-seeding daily temperature ranges on seedling emergence was greater under low-temperature than high-temperature conditions. Moreover, changes with time in the measured values for seedling emergence rates and those estimated using the Arrhenius equation were approximately the same. We also used maximum and minimum temperatures to calculate early sowing limits for direct seeding of paddy rice at different locations in the Hokuriku region; previously, daily mean temperature has been used as the basis of early sowing limit calculations. The two calculation methods showed different early sowing limits. Moreover, early sowing limits based on daily temperature ranges were observed to occur earlier in the inland and later in the coastal area when compared with early sowing limits based on daily mean temperature.

Discipline: Crop Science
Additional key words: AMeDAS weather data, Arrhenius equation, wind

Introduction

Rice cultivation in Japan currently relies predominantly on the use of transplanting machines. The total working time dedicated to transplanting cultivation is about 250 h per ha (MAFF 2018a), of which, however, 25% is represented by raising rice seedlings and their subsequent transplanting. In this context, it is expected that the introduction of direct seeding methods, which do not require seedlings to be raised before transplanting, would be both labor-saving and more cost-effective. The area over which direct seeding of paddy rice is used increased between 2006 and 2016, from 5,331 to 9,362 ha in dry-seeded fields and from 10,549 to 22,672 ha in flooded paddy fields (MAFF 2018b). However, the area in which direct seeding is used comprises only 2.2% of the whole rice cultivation area. It is thought that this is because of instability in seedling emergence and establishment and because the lodging resistance associated with directly seeded rice is weaker than for transplanted paddy rice. The Hokuriku region is the area of the country where growth in the use of direct seeding methods in flooded paddy fields is the most advanced; this tendency is particularly apparent in Fukui Prefecture, where direct seeding cultivation comprises 12% of the whole rice cultivation area (Hokuriku Regional Agricultural Administration

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Received 19 September 2018; accepted 12 February 2019.

Office 2010).

Even in Fukui, however, the degree to which the use of direct seeding culture has increased varies by location because seedling establishment is more successful in inland compared with coastal areas. Meteorology reports indicate that sea breezes associated with the coast have the effect of depressing increases in daily temperature. In Niigata Prefecture, which is also in the Hokuriku region, the daily mean temperatures of Takada, which is inland, and Itoigawa in the coastal area are very similar. However, the daily temperature range of the latter is narrower than the former, as Itoigawa has a lower daily maximum temperature and higher daily minimum temperature than Takada (Fig. 1). In other words, even if the same daily mean temperature is recorded at each location, it is possible that wind-facilitated decreases in the coastal daily temperature range influence seedling emergence and establishment in flooded paddy fields. Our first objective was, therefore, to elucidate the influences of different daily temperature ranges on seedling emergence and establishment in pot and laboratory tests; we applied the Arrhenius equation to seedling emergence rates in the laboratory test.

Flooded paddy fields in the Tohoku and Hokuriku regions account for 67% of the national area (MAFF 2018b). The early sowing limit temperature is considered to be 15°C and 12°C-14°C in the Hokuriku and Tohoku regions, respectively. To date, early sowing limit temperatures have been estimated using daily mean temperature. However, more detailed early sowing limits responding to local climatic conditions will be required in the future. Our second objective was therefore to determine a new estimate of early sowing limits in flooded paddy fields in the Hokuriku region, using the Arrhenius equation and weather data from the Automated Meteorological Data Acquisition System (AMeDAS) of the Japan Meteorological Agency.

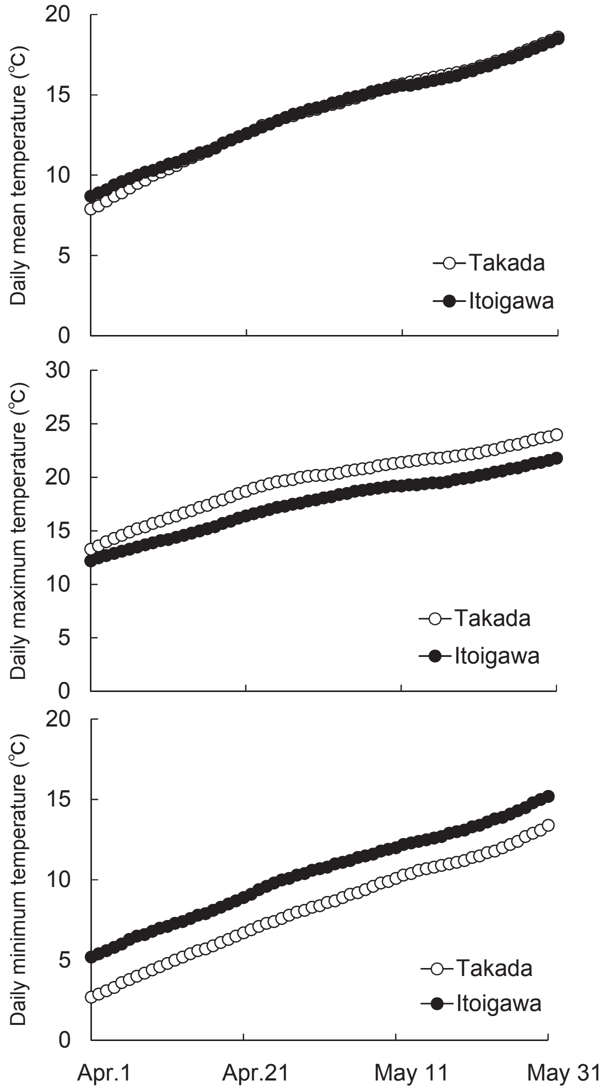

Fig. 1. Meteorological comparison between Takada (inland area) and Itoigawa (coastal area) from April to May
Daily mean temperature, daily maximum temperature, and daily minimum temperature were shown by the average year value (average from 1971 to 2000).

Materials and methods

1. Pot experiment

The location of the pot experiment was the Hokuriku research station, Central Region Agricultural Research Center, NARO (Inada, Joetsu, Niigata). We prepared calcium peroxide-coated seeds of rice (*Oryza sativa* L., cv. Koshihikari). The paddy soil at the research station was finely crushed beforehand and then used to fill Wagner pots (1/2000 a). In the field site (Shimomasuda, Joetsu, Niigata) with stronger wind conditions than the Hokuriku research station site, paddy soil in pots was puddled with 1.3 g·pot^{-1} of nitrogen (basal dressing, coated urea, LP100; JCAM AGRI. Co., Ltd.) on the day before seeding. On the following day, calcium peroxide-coated seeds were sown, 50 seeds per pot, at a depth of 1 cm. After seeding, we hammered iron pipes into the ground at four corners around each pot to create a 2 m × 2 m square frame, around which we wrapped clear agricultural vinyl (thickness, 0.1 mm) at an approximate height of 1.5 m, forming a windbreak. We did not place any covering over the structure, which therefore remained open on top. In this paper, we refer to this plot as the windbreak plot; the plot with no windbreak treatment is referred to as the control plot. The water management treatment was flooding (approximately 2 cm depth), applied after seeding. We counted the number of emerged seedlings, emerged first leaves (incomplete leaf), and established seedlings (emerged second leaves) every day for 14 days. We also calculated the number of days required for seedling emergence, and the days required for first leaf emergence and seedling establishment, according to the method of Furuhata et al. (2005). The plant length, leaf age, and dry weight of the shoots of all seeds, collected from the soil at 14 days after seeding, were determined using three replicate pots. We considered coleoptile emergence to define individual plants having achieved seedling emergence and second leaf emergence as the definition of seedling establishment. The air temperature of the test section was measured hourly with a data logger (TR-52S; T&D Corporation, Matsumoto, Japan) at a height of approximately 30 cm in a small weather instrument shelter.

2. Laboratory test

We prepared pre-germinated seeds (the proportion of germinated seeds was approximately 50%) of "Koshihikari." Paddy soil at the Hokuriku research station was finely crushed beforehand. The paddy soil was puddled on the day before seeding, used to fill disposable cups (PP resin, 500 ml), and left for 1 day. On the following day, pre-germinated seeds were seeded, 10 seeds per disposable cup, at a depth of 1 cm. The seeded cups were placed in an incubator under the following conditions: light conditions, 12 h dark period and 12 h photoperiod; daily mean temperature of either 15°C, 20°C, or 25°C; and a daily temperature range (the difference in air temperature between the photoperiod and dark period) of 5°C, 10°C, or 15°C (Table 1). Water management comprised drainage of residual water after seeding; from the third day post-seeding, we then added water at a level appropriate for avoiding extreme drying of the soil. Each day for 14 days, we counted the number of emerged seedlings, emerged first leaves, and established seedlings (emerged second leaves). The coleoptile length and dry weight of the shoots of all individuals, which were collected from the soil on days 3, 5, 7, 10, and 14 post-seeding, were measured. Then, the number of emerged seedlings, emerged first leaves, and established seedlings and the dry weight of the shoots were obtained from the average values of six replicates (average of six disposable cups). Coleoptile length was obtained from the average values of six replicates (average of six disposable cups), each based on an average of 10 individuals per cup. Furthermore, the number of days required for seedling emergence, first leaf emergence, and seedling establishment was calculated according to the same methodology as the pot experiment. Seedling emergence rate was estimated using the following procedures. According to the method of Hara (2010), the number of days transformed to standard temperature (DTS) was calculated using the following equation:

$$\mathrm{DTS} = \exp\left(\left(1 / (273.15 + 25) - 1 / (273.15 + \mathrm{TL})\right) \times E/R\right) / 2 + \exp\left(\left(1 / (273.15 + 25) - 1 / (273.15 + \mathrm{TD})\right) \times E/R\right) / 2 \quad \text{(Eq. 1)}$$

where TL and TD are the air temperatures in the photoperiod and dark period, respectively, R is the gas constant (8.31 J K^{-1} mol^{-1}), and E is the activation energy. The value of E (88000 J mol^{-1}) was obtained from the following calculation method. The estimated values of the seedling emergence rate were calculated by a logistic function based on DTS. The value of E was calculated using Solver, a tool in Excel software used to determine optimal solutions to decision problems, in order to minimize the differences between estimated and measured values.

Table 1. Setting of daily mean temperature and daily temperature range (laboratory test)

Daily temperature range (℃)	Daily mean temperature (℃)		
	15	20	25
5	17.5/12.5	22.5/17.5	27.5/22.5
10	20.0/10.0	25.0/15.0	30.0/20.0
15	22.5/ 7.5	27.5/12.5	32.5/17.5

5°C indicates the average of temperature ± 2.5°C, 10°C indicates the average of temperature ± 5°C, and 15°C indicates the average of temperature ±7.5°C. The temperature was set in the temperature of photoperiod/temperature of dark period.

3. Estimation of early sowing limits for directly seeded rice in the Hokuriku region

Using yearly average values (based on the period from 1971 until 2000) of daily mean temperature, and the maximum and minimum air temperature, obtained from AMeDAS weather data for the Hokuriku region from April to May, we calculated the following: the first day on which the mean of the daily mean temperature for 20 consecutive days exceeded 15°C (hereinafter referred to as the early sowing limit by daily mean temperature) and the first day when the accumulated DTS for 20 days exceeded 7.573 (the value of 7.573 is calculated with a 15°C ± 5°C condition using Eq. 2). DTS was calculated using Eq. 2 (hereinafter referred to as the early sowing limit by daily temperature range):

$$\mathrm{DTS} = \exp\left(\left(1 / (273.15 + 25) - 1 / (273.15 + \mathrm{TH})\right) \times E/R\right) / 2 + \exp\left(\left(1 / (273.15 + 25) - 1 / (273.15 + \mathrm{TM})\right) \times E/R\right) / 2 \quad \text{(Eq. 2)}$$

where TH and TM are the maximum and minimum air temperatures, respectively, R is the gas constant (8.31 J K^{-1} mol^{-1}), and E is the activation energy (80000 J mol^{-1}).

Results and discussion

1. Pot experiment

The seedling emergence rate was higher in the windbreak plot than in the control plot; a similar trend was observed for the rates of first leaf emergence and seedling establishment (Fig. 2).

The number of days required for seedling emergence was lower in the windbreak compared with the control plot; a similar trend was observed for first leaf emergence and seedling establishment. Plant length was greater, leaf age was more advanced, and shoot dry weight was greater in the windbreak compared with the control plot (Table 2).

The daily mean temperature was 0.4°C higher in the windbreak than in the control plot. There was no difference in the minimum temperature between plots, but the maximum temperature of the windbreak plot was significantly higher than the control plot (Table 3).

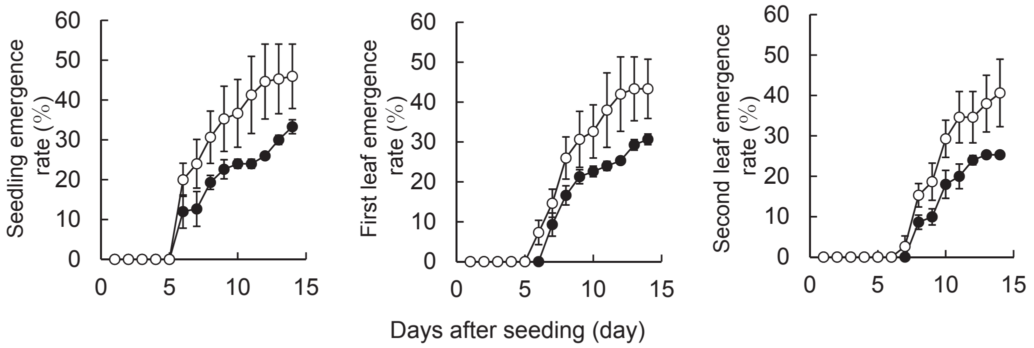

Fig. 2. Influences of windbreak treatment on seedling emergence, first leaf emergence, and seedling establishment (pot experiment)
●: Control plot, ○: Windbreak plot. Bars indicate the standard error (n = 3). Second leaf emergence rate indicates seedling establishment rate.

Table 2. Influences of windbreak treatment on the early growth of directly seeded rice in flooded paddy field (pot experiment)

Windbreak	Days required for seedling emergence	Days required for first leaf emergence	Days required for seedling establishment	Plant length (cm)	Leaf age	Dry weight of the upper part (mg/plant)
Control	8.9	9.1	9.8	1.2	0.6	1.0
Windbreak	8.1	8.6	9.7	2.2	1.2	2.1
T-test	ns	ns	ns	ns	ns	ns

Plant length, leaf age, and dry weight of the upper part was shown by average value of the 14th day after seeding (n = 3). ns indicates no significant differences at 5% level by t-test.

Table 3. Influences of windbreak treatment on air temperature during the experiment period (pot experiment)

Windbreak	Average of daily mean temperature (℃)	Average of maximum temperature A (℃)	Average of minimum temperature B (℃)	Daily temperature range A-B (℃)
Control	18.3	25.8	14.1	11.7
Windbreak	18.7	27.2	14.2	13.0
Differences	0.4	1.4	0.1	1.3
T-test	**	*	ns	**

Each average of the daily mean temperature, maximum temperature, minimum temperature, and daily temperature range was shown by the average value at 14 days after seeding. **,*: Indicates significant differences at 1%, 5% level by t-test. ns indicates no significant differences at 5% level by t-test.

The pot experiment results showed that the growth of directly seeded rice in the windbreak plot was promoted more than in the control plot (Fig. 2, Table 2), and daily temperature ranges in the windbreak plot were larger than in the control plot (Table 3). This indicated that daily temperature ranges directly influenced the growth of directly seeded rice. There are some reports of the influence of daily temperature ranges on paddy rice growth. The number of tillers has been found to be larger under conditions of a wider daily temperature range around the culm base than under narrower daily temperature range conditions (Matsushima et al. 1965). Similarly, the number of tillers has been reported to be larger under wider daily water temperature range conditions (Tanaka et al. 1968). Under low temperature conditions, sterility at the booting stage decreases when daily temperatures show a wider range (Shibata et al. 1970). A significantly positive correlation between translocation rate at the ripening stage and daily temperature range has been found (Yang et al. 2005). These studies suggest that paddy rice growth is further promoted when there is a wider daily temperature range.

In conclusion, the windbreak treatment under outdoor conditions increased the daily temperature range, and seedling emergence and the establishment of directly seeded rice were promoted under wider daily temperature range conditions.

2. Laboratory test

There was only a small difference in seedling emergence rates among different daily temperature ranges exposed to the 20°C and 25°C daily mean temperature conditions, but the difference was large under the 15°C daily mean temperature condition. For the 15°C daily mean temperature condition, seedling emergence was the fastest and slowest on the 15°C and 5°C daily temperature range plots, respectively. Differences in first leaf emergence and seedling establishment rates among the different daily temperature ranges were small under the 20°C and 25°C daily mean temperature conditions, whereas they were apparent only in the 15°C daily temperature range plot under the 15°C daily mean temperature condition (Fig. 3).

Differences by daily temperature range in the

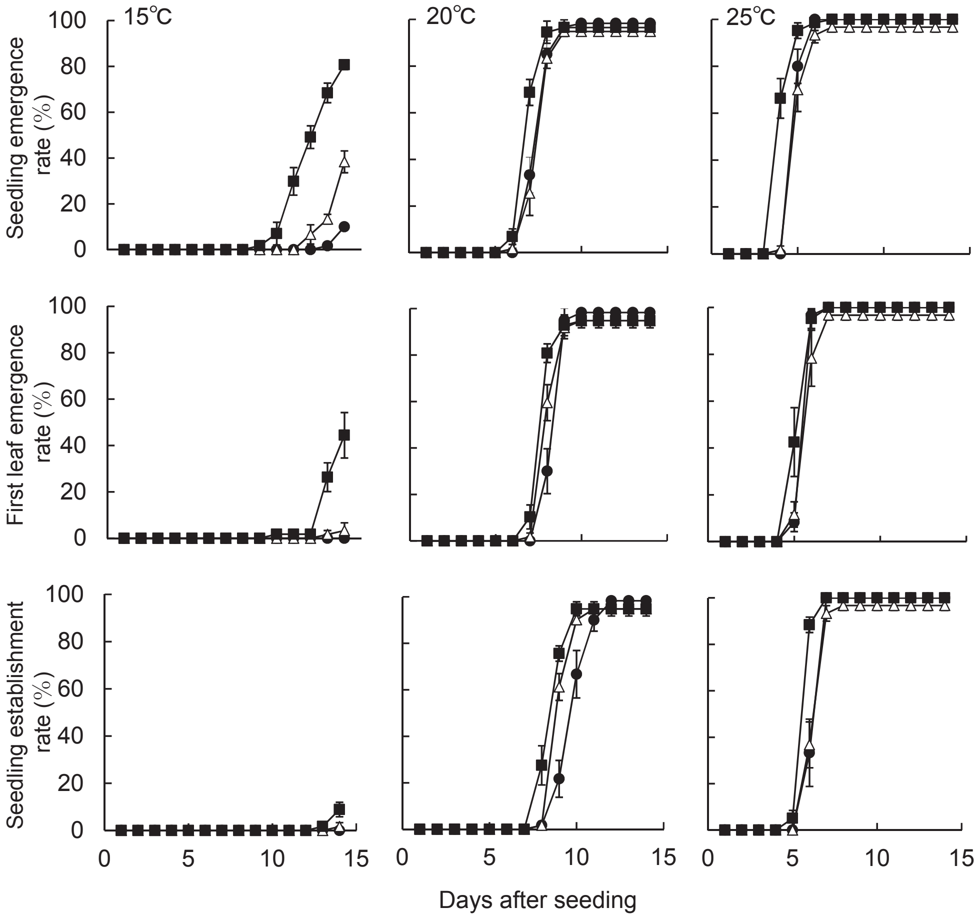

Fig. 3. Influences of daily mean temperature and daily temperature range on seedling emergence, first leaf emergence, and seedling establishment (laboratory test)
●: Daily temperature range 5°C, △: Daily temperature range 10°C, ■: Daily temperature range 15°C. Bars indicate the standard error (n = 6).

number of days required for seedling emergence were the smallest and largest under the 25°C and 15°C daily mean temperature conditions, respectively. In each of the three daily mean temperature plots, the 15°C and 5°C daily temperature range plots showed the shortest and longest periods required for seedling emergence, respectively, with the 10°C daily temperature range plot lying in between these values. Furthermore, a similar trend was observed for the number of days required for first leaf emergence and seedling establishment (Table 4).

Differences in coleoptile length among the daily temperature ranges were small under the 20°C and 25°C daily mean temperature conditions and the largest under the 15°C condition. Coleoptile length was the longest and shortest in the 15°C and 5°C range plot, respectively (Fig. 4).

The differences in shoot dry weight among daily temperature ranges were the smallest and largest under the 25°C and 15°C daily mean temperature conditions, respectively. Under the 15°C daily mean temperature condition, dry weight was the highest and lowest in the 15°C and 5°C daily temperature range plots, respectively (Fig. 5).

The estimated seedling emergence rate by daily temperature range and measured values indicated a similar trend. The differences in values estimated using daily temperature range were small under the 20°C and 25°C conditions and large under the 15°C daily mean temperature condition (Fig. 6).

The laboratory test results showed that the influence of post-seeding daily temperature range was greater under low temperature conditions (Figs. 3, 4, 5). Furthermore, growth under low temperature conditions was promoted under a wider daily temperature range (Figs. 3, 4, 5, Table 4; Furuhata & Hara 2014a). There are some reports

Table 4. Influences of the daily mean temperature and daily temperature range on the days required for seedling emergence, first leaf emergence, and seedling establishment (laboratory test)

Growth stage	Daily temperature range (℃)	Daily mean temperature (℃) 15	20	25
Seedling emergence	5	13.8^{a}	7.9^{a}	5.2^{a}
	10	13.5^{a}	7.8^{a}	5.2^{a}
	15	12.1^{b}	7.1^{b}	4.5^{b}
First leaf emergence	5	−	8.7^{a}	6.0^{a}
	10	−	8.4^{ab}	5.9^{a}
	15	−	8.1^{b}	5.6^{a}
Seedling establishment	5	−	10.2^{a}	6.8^{a}
	10	−	9.4^{b}	6.7^{a}
	15	−	8.9^{b}	6.1^{b}

In each growth stage of the same daily mean temperature, means followed by same letters do not differ significantly at the 5% level by Tukey's test (n = 6).

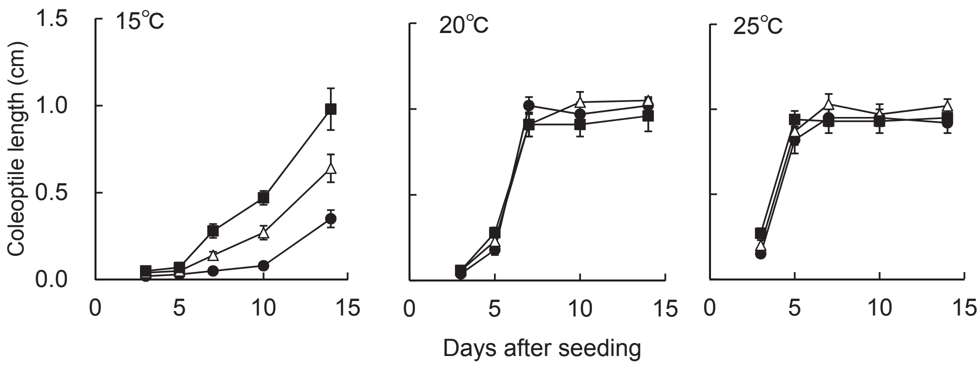

Fig. 4. Influences of the daily mean temperature and daily temperature range on coleoptile length (laboratory test)
●: Daily temperature range 5°C, △: Daily temperature range 10°C, ■: Daily temperature range 15°C. Bars indicate the standard error (n = 6).

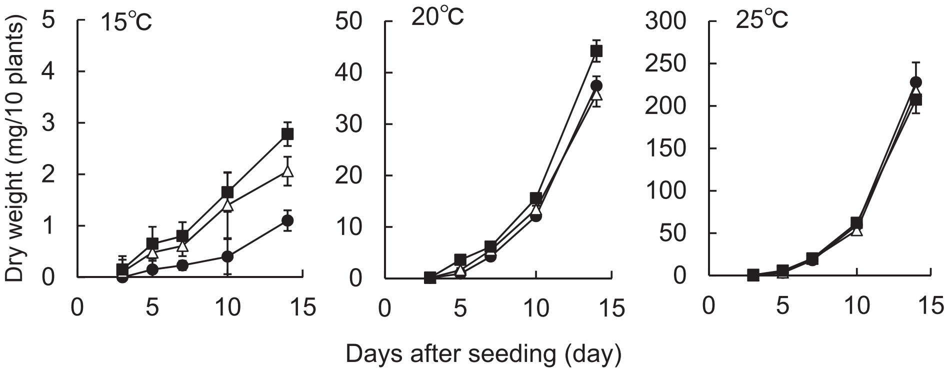

Fig. 5. Influences of the daily mean temperature and daily temperature range on the dry weight of shoots (laboratory test)
●: Daily temperature range 5°C, △: Daily temperature range 10°C, ■: Daily temperature range 15°C. Bars indicate the standard error (n = 6).

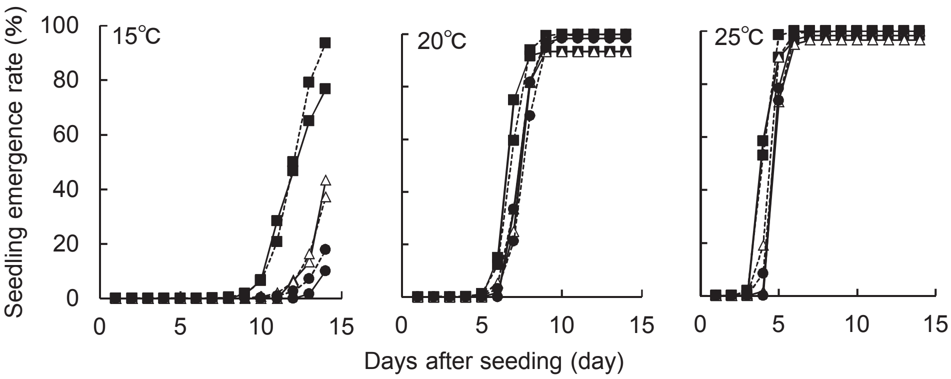

Fig. 6. Seedling emargence rate and estimation by Arrhenius equation in different daily mean temperatures and daily temperature range conditions (laboratory test)
●: Daily temperature range 5°C, △: Daily temperature range 10°C, ■: Daily temperature range 15°C. Solid lines indicate the measured values, and dashed lines indicate the estimated values.

of the influence of daily temperature range on the early growth of paddy rice under low temperature conditions. Germination after seeding is improved under conditions of wider daily temperature ranges (Yabuki & Miyagawa 1957). Variations in the early growth of rice seeded in nursery boxes under low temperature conditions are larger under narrower daily temperature range conditions (Matsumura 2007). Moreover, we investigated seedling emergence and establishment of directly seeded rice grown in low temperature conditions under different daily temperature ranges using calcium peroxide-coated, iron-coated, and non-coated seeds in an incubator (Furuhata & Hara 2014b). For all these seed types, growth under low temperature conditions was improved under conditions of wider daily temperature ranges (Furuhata & Hara 2014b). Furthermore, seedling emergence rates estimated by the Arrhenius equation provide a good simulation of the measured values (Furuhata & Hara 2014b). Therefore, this suggests that it is possible to use the Arrhenius equation to estimate the early sowing limit for direct seeding.

In conclusion, the influence of the post-seeding daily temperature range was enhanced under low temperature conditions, and seedling emergence and the establishment of directly seeded rice were promoted under wider daily temperature range conditions. Furthermore, the measured values for seedling emergence rates and those estimated using the Arrhenius equation were approximately the same.

3. Estimation of early sowing limits for directly seeded rice in the Hokuriku region

Estimation of early sowing limits for directly seeded rice in Niigata Prefecture is shown in Figure 7. In inland areas, the early sowing limits for the localities of Niitsu, Tsugawa, Irihirose, Koide, Nagaoka, Tokamachi, Yuzawa, Yasuzuka, and Takada were earlier when assessed based on the daily temperature range than when based on daily mean temperature. The early sowing limits for

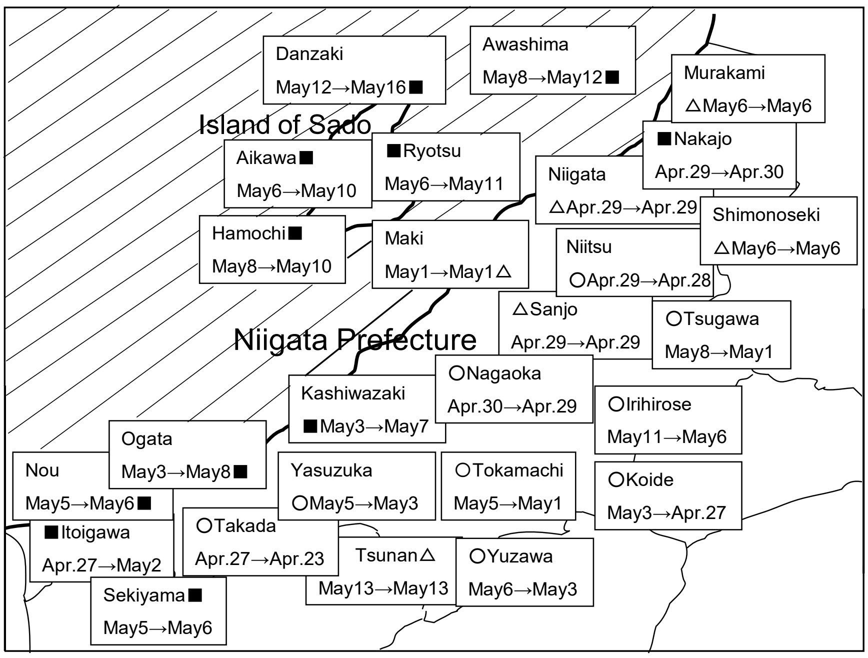

Fig. 7. Estimation of early sowing limits of directly seeded rice in Niigata Prefecture
Symbols indicate the position of AMeDAS stations. ○: The points where early sowing limit by daily temperature range is earlier than the early sowing limit by daily mean temperature, △: The points where early sowing limit by daily temperature range is the same day as early sowing limit by daily mean temperature, ■: The points where early sowing limit by daily temperature range is later than early sowing limit by daily mean temperature. The dates in the boxes show that early sowing limit by daily mean temperature → early sowing limit by daily temperature range.

Shimonoseki and Sanjo were the same whether using daily temperature range or mean temperature, but those for the high-altitude stations of Tsunan and Sekiyama were either the same or 1 day late based on daily temperature range, when compared with daily mean temperature. In coastal areas, the early sowing limits for Murakami, Nakajo, Niigata, and Maki, which are stations in the Kaetsu district, were the same or 1 day late when using daily temperature range compared with daily mean temperature, but those for Kashiwazaki, Ogata, Nou, and Itoigawa, which are stations in either Joetsu or Chuetsu district, were later when based on daily temperature range compared with daily mean temperature. Furthermore, the early sowing limits by daily temperature range for Awashima, Danzaki, Ryotsu, Aikawa, and Hamochi, which are island stations, were clearly later than those estimated by daily mean temperature. Moreover, the early sowing limit by daily mean temperature was April 27 for both Takada (inland area) and Itoigawa (coastal area). However, the early sowing limit in Takada was April 23 when based on daily temperature range, 4 days earlier than when using daily mean temperature. In contrast, the early sowing limit by daily temperature range for Itoigawa was May 2, 5 days later than when using daily mean temperature.

Estimation of early sowing limits for directly seeded rice in Toyama Prefecture is shown in Figure 8. Early sowing limits for Yao (inland area) and Toyama and Fushiki (coastal area of Toyama bay) were earlier for those estimated by daily temperature range than by daily mean temperature, whereas early sowing limits were the same for Tonami and Nantotakamiya (both inland), whichever basis was used. Early sowing limits for Tomari, Uozu, and Himi (stations in the northern coastal areas) were later when based on the daily temperature range, compared with daily mean temperature. Furthermore, the early sowing limit for Kamiiti, a high-altitude station, was 1 day later when based on the daily temperature range, compared with daily mean temperature.

Estimation of early sowing limits for directly seeded rice in Ishikawa Prefecture is shown in Figure 9. The early sowing limits according to the daily temperature range for Hakusanyoshino and Kayano (inland area) were earlier than when using daily mean temperature, but later for Kusu, Wajima, Shiga, Nanao, Hakui, and Kahoku on the Noto Peninsula and Kanazawa and Komatsu in the coastal area.

Estimation of early sowing limits for directly seeded rice in Fukui Prefecture is shown in Figure 10. Early

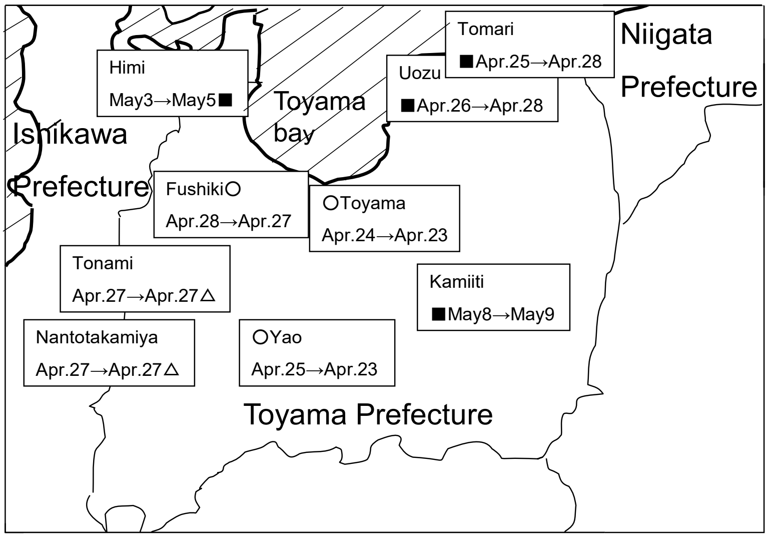

Fig. 8. Estimation of early sowing limits of directly seeded rice in Toyama Prefecture

Symbols indicate the position of AMeDAS stations. ○: The points where early sowing limit by daily temperature range is earlier than early sowing limit by daily mean temperature, △: The points where early sowing limit by daily temperature range is the same day as early sowing limit by daily mean temperature, ■: The points where early sowing limit by daily temperature range is later than early sowing limit by daily mean temperature. The dates in the boxes show that early sowing limit by daily mean temperature → early sowing limit by daily temperature range.

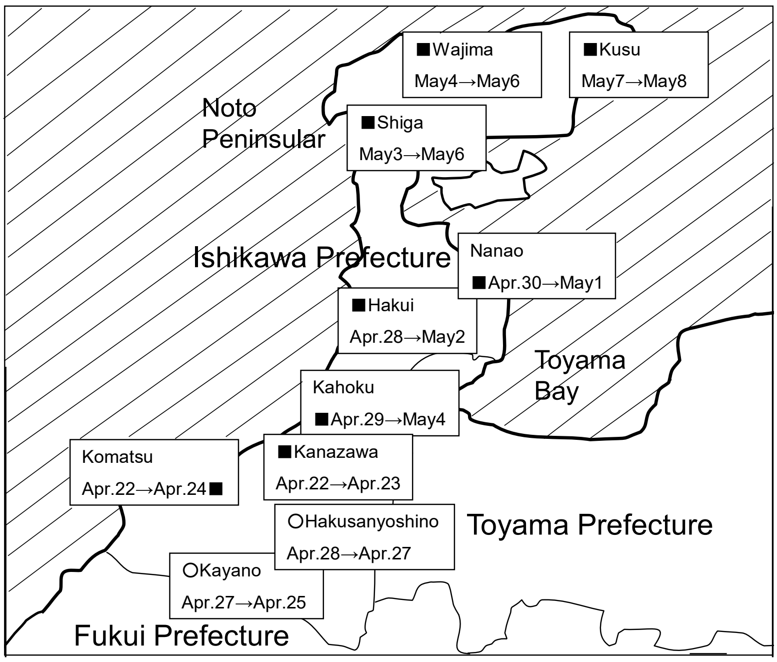

Fig. 9. Estimation of early sowing limits of directly seeded rice in Ishikawa Prefecture

Symbols indicate the position of AMeDAS stations. ○: The points where early sowing limit by daily temperature range is earlier than early sowing limit by daily mean temperature, △: The points where early sowing limit by daily temperature range is the same day as early sowing limit by daily mean temperature, ■: The points where early sowing limit by daily temperature range is later than early sowing limit by daily mean temperature. The dates in the boxes show that early sowing limit by daily mean temperature → early sowing limit by daily temperature range.

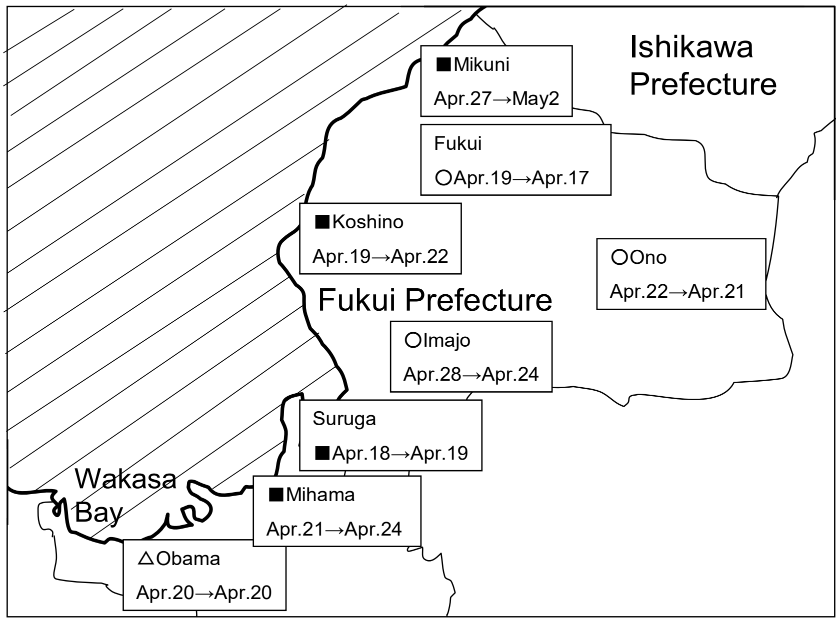

Fig. 10. Estimation of early sowing limits of directly seeded rice in Fukui Prefecture
Symbols indicate the position of AMeDAS stations. ○: The points where early sowing limit by daily temperature range is earlier than early sowing limit by daily mean temperature, △: The points where early sowing limit by daily temperature range is the same day as early sowing limit by daily mean temperature, ■: The points where early sowing limit by daily temperature range is later than early sowing limit by daily mean temperature. The dates in the boxes show that early sowing limit by daily mean temperature → early sowing limit by daily temperature range.

sowing limits estimated using daily temperature range for Fukui, Ohno, and Imajyo (inland area) were earlier than when using daily mean temperature, but later for coastal areas, except for Obama.

We calculated the early sowing limits for direct seeding of paddy rice at different locations in the Hokuriku region using AMeDAS weather data and the Arrhenius equation. The results indicated that the early sowing limits calculated using daily mean temperature differed from those calculated using daily temperature range. Moreover, early sowing limits tended to be earlier in inland areas, except at high altitudes, than in coastal areas (Furuhata & Hara 2013). This tendency differed in some locations: the island of Sado in the western coastal area of Kaetsu district in Niigata; Toyama and Fushiki in the coastal areas of Toyama bay; and Obama to the rear of Wakasa bay. In these locations, topography was thought to influence the strength of sea breezes, causing them to show differing results to other coastal areas. Therefore, this suggests that the early sowing limit for direct seeding cultivation is affected not only by whether an area is coastal or inland but also by its altitude and topography.

Estimated early sowing limits based on daily temperature range at each location are believed to correspond to local climatic conditions, such as those pertaining to inland or coastal areas. In the future, a comparison between estimated and measured values at multiple points will be essential to improve the accuracy with which early sowing limits are determined.

In conclusion, this review determined new early sowing limits for directly seeded rice when based on daily temperature range, compared with daily mean temperature. Furthermore, estimated early sowing limits using daily temperature range at each location were found to correspond to local climatic conditions, such as those relevant to inland and coastal areas. A collective approach, aggregating data of measured values from different studies conducted in local areas, is required to further explore these findings.

Acknowledgments

We thank T. Kurisaki and U. Watanabe for technical assistance in conducting these experiments.

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