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Estimation of Drought Tolerance Based on Leaf Temperature in Upland Rice Breeding

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The evaluation of drought tolerance based on the leaf temperature was examined in upland rice breeding. The relationships of the leaf temperature with the transpiration and photosynthetic rates were observed in upland and lowland rice varieties under upland cultivation in 1995, 1996 and 1997. The leaf temperature of the upland rice varieties was lower than that of the lowland rice varieties. Their transpiration and photosynthetic rates were highly correlated with the leaf temperature, measured using an infrared radiation thermometer or portable photosynthesis gas analyzing system in all the three years. The leaf temperature also showed a significant relationship with the grain yield tested in 1995. It is considered that rice varieties with a lower leaf temperature can maintain high transpiration and photosynthetic rates as well as produce a high yield under upland conditions. In addition, there was a significant positive correlation between the leaf temperature and root growth recorded by the trench method. Upland rice varieties with deep rooting showed lower leaf temperatures than those with a shallower root system. On the other hand, in the comparison of leaf temperature in varietal groups of breeding materials, the upland rice lines with medium-late maturity showed the lowest temperature, followed by the early maturing lines and lines for cultivation with sprinkler irrigation. This tendency was in agreement with the general degree of drought tolerance of individual varietal groups. To analyze the mode of inheritance of the leaf temperature, the parent-offspring correlation of leaf temperature measured using an infrared radiation thermometer was examined in breeding materials. Leaf temperature was compared between the progeny lines (F_4 generation) of the upland rice variety Kantomochi168 with a high drought tolerance and the upland rice variety Norinmochi4 with a medium drought tolerance. Kantomochi168 progeny showed a lower leaf temperature than Norinmochi4. A similar tendency was confirmed in the F_5 generation in the following year. Significant parental-offspring correlation ($r = 0.812^{**}$) was observed between F_4 and F_5. Since the leaf temperature of the upland rice progeny may display a relatively higher inheritance, the leaf temperature is, therefore, considered to be a useful indicator to estimate the drought tolerance for line selection in upland rice breeding.

Key Words: upland rice, drought tolerance, deep rooting, leaf temperature, transpiration.

Introduction

Drought tolerance is the most important characteristic in upland rice breeding. Various evaluation methods have been reported for the estimation of drought tolerance based on plant body symptoms caused by water deficit, such as plant wilting, leaf rolling and yield loss (Gupta and O'Toole 1986, Kon 1990). However, these evaluation methods based on visible plant damage are not always appropriate for varietal screening in breeding programs, because they are labor-intensive. Therefore, more convenient methods should be developed for breeding of drought tolerance.

When plants undergo moisture stress, the decrease in the internal water potential results in the closure of stomata, and the transpiration and photosynthetic rates remarkably decrease before macroscopical damage occurs (Ishihara and Saito 1983). Blume *et al.* (1978) observed a rise in the leaf temperature associated with the decrease of the transpiration rate, reflecting the degree of water stress in sorghum, and indicated the possibility of selecting for drought tolerance based on the leaf temperature. O'Toole *et al.* (1984) also indicated the effectiveness of remote sensing of the canopy temperature using an infrared thermometer to estimate water stress in rice plants. IRRI (1983, 1984) reported that lowland rice varieties with deep rooting showed a relatively lower seed sterility under high air temperature injury, because such varieties maintained a lower temperature due to their higher transpiration rate. Leaf temperature may become an indicator for the detection of tolerant inbred lines, which can maintain higher transpiration ability under drought conditions.

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The objectives of the present study were to confirm the validity of the evaluation of drought tolerance based on the leaf temperature in upland rice breeding. Subsequently, we also estimated the heritability of the leaf temperature of upland rice by the parent-offspring correlation of inbred lines, and attempted to perform varietal screening of breeding materials based on the leaf temperature.

Materials and Methods

Four experiments were conducted from 1994 to 1997. These experiments were carried out in the experimental field of Ibaraki Agricultural Center, Agricultural Research Institute, Mito, Ibaraki.

Experiment 1: Relationship of leaf temperature with transpiration and photosynthetic rates, and yield

1995; The relationship of the leaf temperature with the transpiration and photosynthetic rates, and yield was observed in upland and lowland rice varieties and lines cultivated under upland conditions. Two upland rice varieties, Kantomochi168 and Tsukubahatamochi, four lowland rice varieties, Otomemochi, Tatsumimochi, Urumamochi and Kudoumochi, and 16 upland rice lines were cultivated in an upland field. Kantomochi168 (abbr. KM168) was developed from an Indian variety JC81 by three successive backcrossings with Norinmochi4 (abbr. N4), and registered as "Yumenohatamochi" by the Ministry of Agriculture, Forestry and Fisheries in 1996 (Hirasawa *et al.* 1998). The tested upland rice lines were inbred lines with medium or late maturity in the performance test of yield ability. The names of individual lines were omitted. These lines were composed of 11 inbred lines derived from combinations of upland rice (U/U cross) and five lines derived from combinations between upland rice and lowland rice (U/L cross). Trials consisted of randomized blocks with two replications. The seeding rate was 50 kg/ha. Plots comprised four rows, 150 cm long with intervals of 60 cm between rows. Sixty, 120 and 90 kg/ha of N, P_2O_5 and K_2O were applied as basal dressing. Forty and 90 kg/ha of N were applied as top dressing on June 10 and July 15, respectively. A sprinkler around the heading period provided minimum irrigation. Other activities followed the standard practices implemented in Ibaraki prefecture (Ibaraki prefecture 1990).

The leaf temperature of the materials was measured using an infrared radiation thermometer (Type 505, Konica Minolta, Japan) on July 15 under fine and breezy weather conditions. The measurements were carried out between 13:00 and 15:00. The measurements were continuously replicated for ten readings of the top unfolded leaves of plants in individual plots. Air temperature was recorded at the time when the leaf temperature was measured. The leaf temperature of tested rice was represented by the leaf temperature (Tl) minus the air temperature (Ta). The transpiration and photosynthetic rates were recorded using a portable photosynthesis gas analyzing system (SPB-H2, Shimadzu, Japan) for the top unfolded leaves of five individual plants on August 22, under fine windless weather conditions. Measurements were carried out between 13:00 and 15:00. The yield of brown rice in each plot was investigated following the standard research method of upland rice breeding applied at the Ibaraki Agricultural Center, Plant Biotechnology Institute.

1996 and 1997; Two upland rice varieties, KM168 and Tsukubahatamochi, and one lowland rice variety, Urumamochi, were repeatedly tested by a similar method to that used in 1995. Seven replications in 1996, and ten to 42 replications in 1997 were recorded for individual varieties. Cultivation followed the method used in 1995. The leaf temperature, and transpiration and photosynthetic rates were measured using a portable photosynthesis gas analyzing system (SPB-H2) on August 20 under fair and calm weather conditions. Measurements were replicated for the top unfolded leaves of five plants individually between 13:00 and 15:00.

Experiment 2: Relationship between leaf temperature and root system

In 1994 and 1995, the root system of six upland rice varieties, i.e. KM168, Kantomochi172, Tsukubahatamochi, Toyohatamochi, Fukuhatamochi and IRAT109, and one lowland rice variety, Urumamochi, was observed using the trench method (Hirayama *et al.* 1995, Nemoto *et al.* 1998). Each variety was represented by ten plants sown in one row 300 cm long with intervals of 60 cm between rows. A ditch was dug at a depth of about 100 cm at the edge of the hill after harvest. The depth of the root tip was recorded by observation. Leaf temperature, and transpiration and photosynthetic rates were measured using a portable photosynthesis gas analyzing system (SPB-H2) for seven varieties cultivated in an upland field in 1997. Cultivation and measurements were similar to the method described in Experiment 1.

Experiment 3: Comparison of leaf temperature in the progeny lines of Kantomochi168 and Norinmochi4

Genetic resources were compared for leaf temperature between the upland rice varieties, KM168 and N4 based on the leaf temperature of their F_4 and F_5 lines.

F_4 lines from the combination of KM168 and N4 with the respective upland rice lines, Ishikei378, Ishikei395 and 3KGY21, were used in this experiment. These F_4 lines, which were inbred lines with their F_1 and F_2 generations progressing without selection, were selected individually at the level of F_3 populations by the same person in charge. Six to 15 lines were tested in each combination. The heading period of the tested F_4 lines was almost identical with that of KM168 and N4 within two days' difference. These lines were cultivated in 1995 without replication using a similar method to that described in Experiment 1. Leaf temperature was measured using an infrared radiation thermometer (Type 505) on August 22 under fine windless weather conditions by the same method as that described in Experiment 1.

Three randomly selected plants from individual F_4 lines from the combination of Ishikei395/KM168 (11 lines) and Ishikei395/N4 (5 lines) were cultivated in 1996 by a similar method to that used in 1995. The leaf temperature of the individual lines was recorded using an infrared radiation thermometer (Type 505) on August 28 by a similar method to that used in 1995. The leaf temperature of the F_5 line was represented by the average value of the three lines derived from the same F_4 line.

Experiment 4: Varietal screening of leaf temperature in the inbred lines of upland rice

The leaf temperature was measured using a radiation thermometer for the inbred upland rice lines, lowland and upland rice varieties, and their temperatures were compared in varietal and maturity groups in 1995. Twenty-nine upland rice varieties, ten lowland rice varieties, 79 inbred upland rice lines, including 49 early maturing lines and 30 medium-late maturing ones, and 29 lines for cultivation under sprinkler irrigation (referred to as "intermediate-type rice"), were cultivated using a similar method to that described in Experiment 1. The tested varieties and lines consisted of breeding materials or check varieties used in the performance test of yield ability in that year. The leaf temperature was recorded using an infrared radiation thermometer (Type 505) by a similar method to that described in Experiment 1 from July 15 to 17, from 13:00 to 15:00.

Results

Experiment 1: Relationship of leaf temperature with transpiration and photosynthetic rates, and yield

Figures 1 and 2 show the relationships of the leaf temperature with the transpiration and photosynthetic rates in 1995, 1996 and 1997, respectively. The leaf temperature (Tl-Ta) showed a significant negative correlation with the transpiration ($r = -0.733$**, −0.931***, −0.658**) and photosynthetic ($r = -0.494$**, −0.577**, −0.432**) rates in all the three years. This indicates that rice plants with a lower leaf temperature show high transpiration and photosynthetic rates under upland conditions. A significant positive correlation was also observed between the transpiration and photosynthetic rates in the three years ($r = 0.629$**, 0.639**, 0.638**). In 1995, a significant negative correlation ($r = -0.532$**) was observed between the leaf temperature and grain yield (Fig. 1C). These relationships indicated that rice plants with a lower leaf temperature could maintain a high transpiration rate as well as a high photosynthetic rate and productivity under upland conditions.

In Figure 1, the leaf temperature was compared in varietal groups, i.e. upland rice varieties, lowland rice varieties, upland rice lines from U/U crosses and those from U/L crosses. The upland rice varieties showed the lowest average leaf temperature (−2.55°C), followed by the inbred lines from the U/U crosses (−2.15°C), inbred lines from the U/L crosses (−1.41°C) and lowland rice varieties (−0.73°C). This indicated that the leaf temperature decreased with the predominance of the genetic background of the upland rice varieties. In Figure 2, the leaf temperatures of the upland rice variety, KM168 and Tsukubahatamochi, and lowland rice variety Urumamochi, were compared in 1996 and 1997. The varietal order of leaf temperature was identical in both years. KM168 and the lowland rice variety Urumamochi, showed

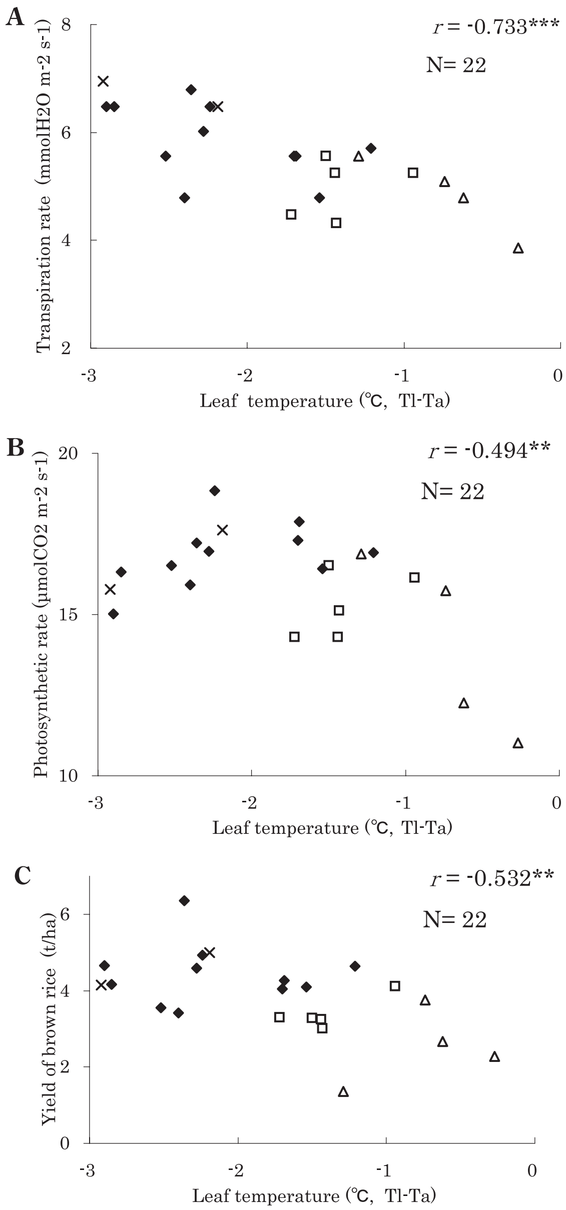

Fig. 1. Correlation coefficients of leaf temperature with transpiration rate, photosynthetic rate and yield in the materials tested in the performance yield trial in 1995. Tl-Ta: Difference between leaf and air temperatures. ◆ Upland rice lines from the crosses in upland rice. □ Upland rice lines from the crosses between upland rice and lowland rice. △ Lowland rice varieties. × Upland rice varieties. A. Relationship between transpiration rate and leaf temperature, B. Relationship between photosynthetic rate and leaf temperature, C. Relationship between yield and leaf temperature.

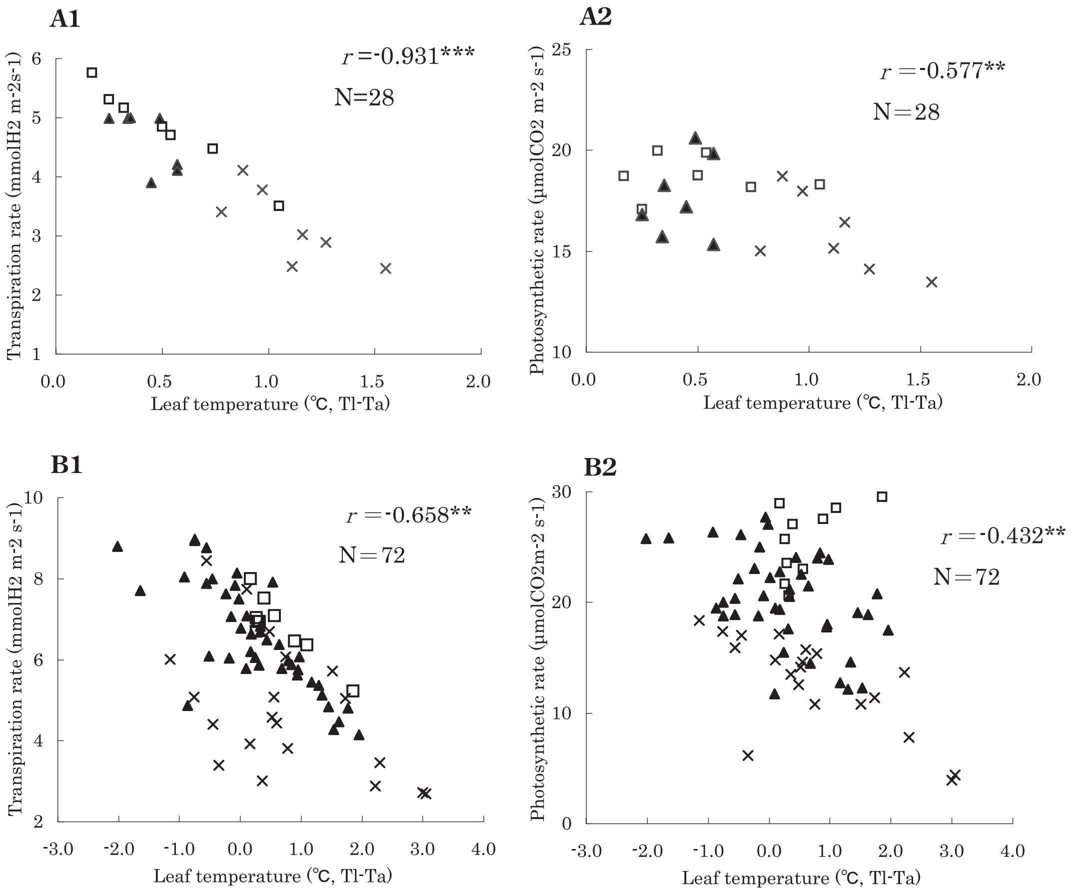

Fig. 2. Correlation coefficients of leaf temperature with transpiration rate and photosynthetic rate in upland and lowland rice varieties in 1996 (A) and 1997 (B). Tl-Ta: Difference between leaf and air temperatures. ▲ Kantomochi 168 (upland rice), □ Tsukubahatamochi (upland rice), × Urumamochi (lowland rice).

the lowest (0.43°C, 0.26°C) and highest (1.10°C, 0.74°C) temperatures in both years, respectively. The upland rice varieties and lines showed lower leaf temperatures than the lowland rice varieties, and displayed a high photosynthetic rate and yield under upland conditions.

Experiment 2: Relationship between leaf temperature and root system

Figure 3 shows the relationship of the root depth with the leaf temperature, transpiration and photosynthetic rates. The value of the root depth was indicated by the average depth of the root tips in 1994 and 1995. The average values of the root depth in both years showed a significant positive correlation coefficient with the leaf temperature (r=–0.580**), transpiration rate (r=–0.686**) and photosynthetic rate (r= –0.776**), recorded in 1997. This indicated that the leaf temperature of the deep-rooted rice varieties was low, and that they maintained higher transpiration and photosynthetic rates under drought conditions.

The trench method was employed in this experiment to observe root growth. This observation method is extremely laborious but more compatible with natural root growth. The roots in 1995 tended to grow into deeper soil layers compared with those in 1994. The highly drought-tolerant upland rice varieties IRAT109 (85, 112 cm), Kantomochi172 (84, 102 cm) and KM168 (81, 88 cm), showed a superior root growth in deeper soil layers in both 1994 and 1995. The root depth of the lowland rice variety Urumamochi stopped at 46 cm and 70 cm depths in 1994 and 1995.

Experiment 3: Comparison of leaf temperature in the progeny lines of Kantomochi168 and Norinmochi4

Figure 4 shows the frequency of the leaf temperature in the F_4 progeny lines from KM168 or N4. In the comparison of the parental varieties, the leaf temperature of the drought-tolerant variety KM168 was 1.05°C lower than that of N4. The average leaf temperatures of the KM168 progeny lines ranged from 0.60 to 1.47°C, values lower than those of N4 in all the three tested combinations. For example, the leaf temperature of the F_4 lines derived from the combination of Ishikei395/KM168 was –3.31°C on average, while that of Ishikei395/N4 was limited to –1.66°C. Furthermore, a similar tendency was confirmed in the F_5 generation. The leaf temperature of the F_5 lines of Ishikei395/KM168 was 0.96°C lower than that of Ishikei395/N4. Figure 5 shows the parent-offspring correlation between the F_4 and F_5 generations.

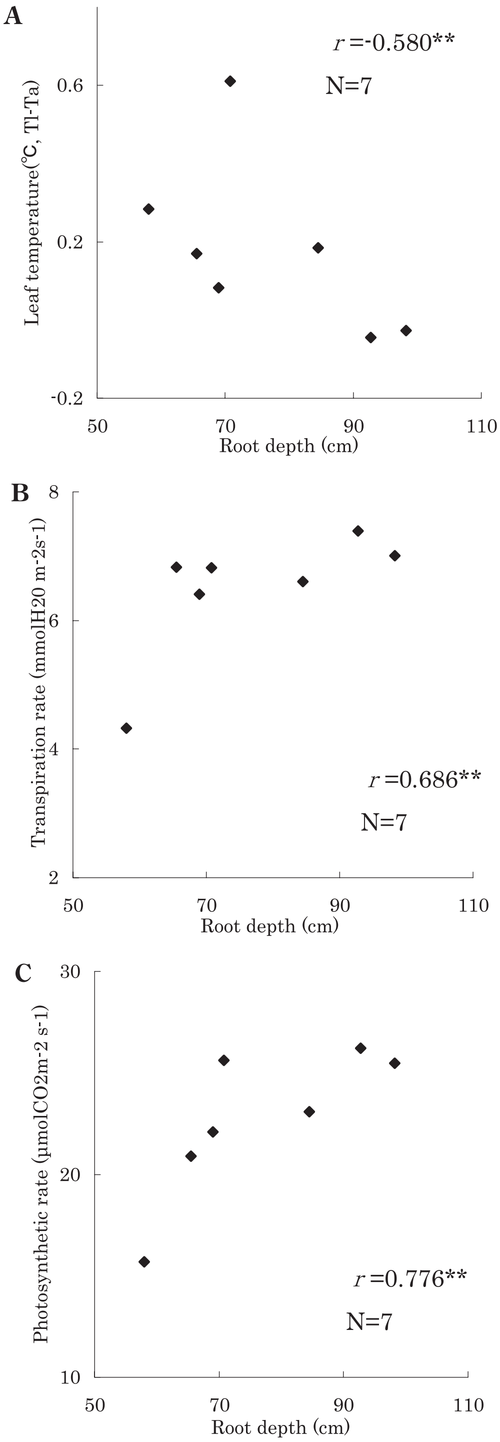

Fig. 3. Correlation coefficients of root depth with leaf temperature, transpiration rate and photosynthetic rate in upland and lowland rice varieties. A. Correlation between root depth and leaf temperature, B. Correlation between root depth and transpiration rate, C. Correlation between root depth and photosynthetic rate.

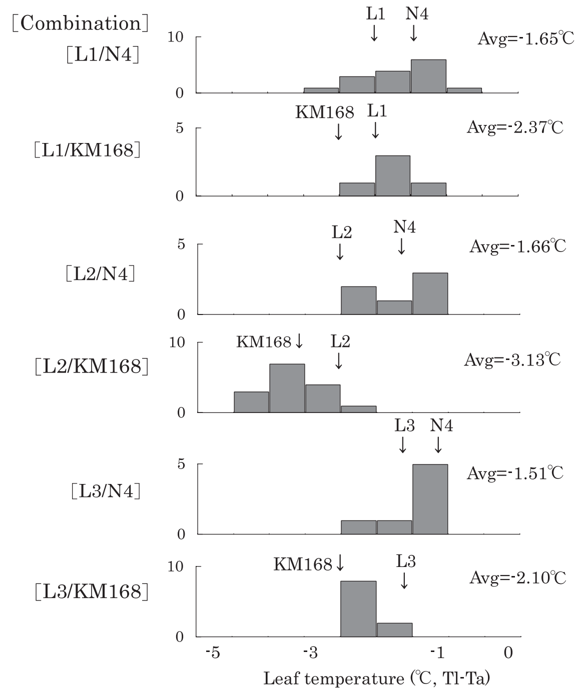

Fig. 4. Comparison of leaf temperature of F_4 progenies from the cross of Norinmochi4 (N4) or Kantomochi168 (KM168). Tl-Ta: Difference between air temperature (Ta) and leaf temperature (Tl). L1: Ishikei378, L2: Ishikei395, L3: 3KYG21.

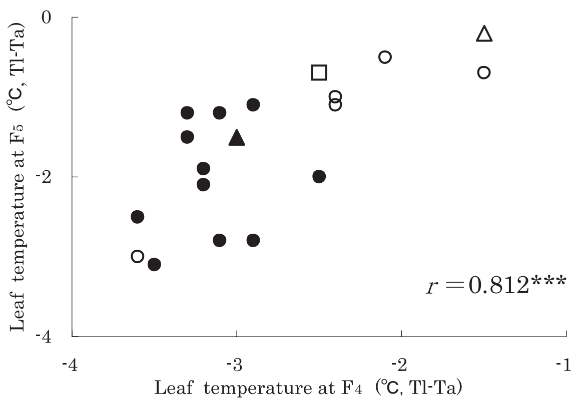

Fig. 5. Parent-offspring correlation of leaf temperature in the progenies from the crosses Ishikei395/Kantomochi 168 and Ishikei 395/Norinmochi 4. ● Ishikei395/Kantomochi 168, ○ Ishikei 395/Norinmochi 4, □ Ishikei 395, ▲ Kantomochi 168, △ Norinmochi 4

A significant positive correlation coefficient ($r = 0.812$**) between both generations indicated the high mode of inheritance of the leaf temperature.

Experiment 4: Varietal screening of leaf temperature in the inbred lines of upland rice

Japanese upland rice varieties were classified by the maturity period or cultivation type into three varietal groups, i.e. early maturing and medium-late maturing upland rice and intermediate-type rice (Nemoto 1995). Figure 6 shows the distribution of the leaf temperature in individual rice varietal groups. The average leaf temperature of the upland rice varieties (−1.58°C) was significantly lower than that of the lowland rice ones (−0.81°C). These varietal differences

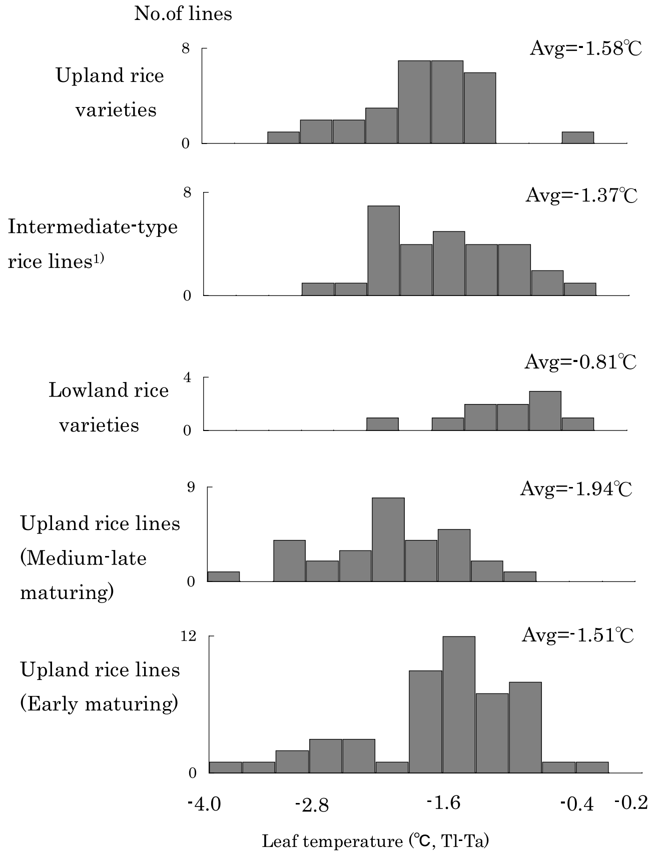

Fig. 6. Varietal differences in leaf temperature between upland and lowland rice. Tl-Ta: Difference between air temperature (Ta) and leaf temperature (Tl). [1] Intermediate-type rice lines: selected inbred lines for cultivation under sprinkler irrigation.

were similar to those shown in Figures 1 and 2. In particular, the upland rice varieties KM168 (–2.23°C), Kiyohatamochi (–2.07°C) and Tsukubahatamochi (–1.81°C) showed remarkably lower leaf temperatures. The average leaf temperature of the intermediate-type rice lines (–1.37°C) was intermediate between that of the upland and lowland rice varieties. Almost all the intermediate-type rice lines were bred from U/L crosses to improve the grain quality of upland rice. When the influence of maturity on the leaf temperature was compared, the leaf temperature of the upland rice lines with medium-late maturity (–1.94°C) was significantly lower than that of the lines with early maturity (–1.51°C). The drought tolerance of the upland rice varieties with medium-late maturity was generally higher than that of the early maturing varieties, because the medium-late maturing varieties with heading in mid-August are likely to withstand the intense heat of summer. The varietal differences in the leaf temperature were in agreement with the general degree of drought tolerance.

When the leaf temperature was compared in the combinations of the inbred lines shown in Figure 6, some specific combinations produced a larger number of inbred lines with a lower leaf temperature. For example, the inbred progeny lines of Tsukubahatamochi on the father (13 lines, –2.14°C) or mother side (9 lines, –1.81°C) showed relatively lower leaf temperatures. On the other hand, the leaf temperature of the progeny lines bred from the current leading variety Toyohatamochi stopped at –1.29°C on the father side (30 lines) and at –1.42°C on the mother side (9 lines). A significant correlation coefficient ($r = 0.661^{**}$) was observed between the cross combinations with the father and mother sides using the same varieties. Although, the influence of the parental varieties was observed in the leaf temperature of the progeny inbred lines, the direction of crossing did not affect the progeny.

Varietal variations in the leaf temperature were observed in individual varietal groups. Some intermediate-type rice lines and early maturing inbred lines were found to show low leaf temperatures comparable to those of the medium-late maturing varieties. In particular, the average leaf temperature of the early maturing lines (7 lines) induced from KM168 by mutation breeding under radiation was remarkably lower (–2.37°C), and these lines may inherit the high drought tolerance of KM168.

Discussion

It is generally recognized that upland rice cultivation forces rice to grow under moisture stress, because rice is essentially a hydrophyte, and upland rice is one of the most susceptible crops to water deficiency among upland crops. Drought is the most serious cause of instability in upland rice production. When rainfall decreases to less than 120 mm/month or when drought exceeds 15 days, drought damage is likely to occur in upland rice (O'Toole and Moya 1978). Drought damage in upland rice occurs every three years over large areas, and the local occurrence of drought is reported almost every year in Japan (Kon 1990). During the period of 1994 to 1997, when the current studies were performed, the summer seasons experienced drought conditions. Table 1 shows the precipitation at Mito and occurrence of drought in Ibaraki prefecture during the test period. Drought damage occurred in 82% (1994), 42% (1995), 76% (1996) and 33% (1997) of an upland rice cultivation area in Ibaraki prefecture (MAFF 1997). The materials in the present experiments were forced to grow under serious drought conditions.

Drought tolerance is the most important characteristic in upland rice breeding. Various evaluation methods have been proposed to estimate drought tolerance in upland rice breeding (Gupta and O'Toole 1986, Kon 1990). Recently, a remote-monitoring technique using an infrared radiation thermometer has been developed to estimate crop water stress. Inoue (1987, 1990 and 1991) examined the remote-monitoring technique to estimate the transpiration rate based on the plant temperature. The remote-monitoring technique may become a simple and convenient method to estimate the drought tolerance of breeding materials of upland rice.

Plants exposed to water stress closed their stomata to maintain their inner moisture content, and consequently,

Table 1. Precipitation and occurrence of drought in Ibaraki prefecture during the tested period[1)]

Year	Precipitation at Mito, Ibaraki every 5 days (mm)											
	April						May					
	1–5	6–10	11–15	16–20	21–25	26–30	1–5	6–10	11–15	16–20	21–25	26–31
1994	10	3	21	4	11	2	11	8	26	5	0	0
1995	1	16	24	15	14	22	38	0	124	21	15	12
1996	3	8	2	47	0	9	45	62	2	0	57	3
1997	6	40	0	6	6	17	11	16	11	26	149	33
Average year	19	20	21	21	20	20	21	24	26	25	22	24

Year	Precipitation at Mito, Ibaraki every 5 days (mm)											
	June						July					
	1–5	6–10	11–15	16–20	21–25	26–30	1–5	6–10	11–15	16–20	21–25	26–31
1994	0	6	19	26	8	26	3	3	0	24	0	9
1995	37	35	67	18	17	14	62	10	42	27	1	2
1996	0	4	4	3	29	11	10	99	2	2	51	15
1997	9	27	11	95	0	2	0	35	6	12	0	14
Average year	20	22	22	27	36	37	35	24	22	17	15	19

Year	Precipitation at Mito, Ibaraki every 5 days (mm)											
	August						September					
	1–5	6–10	11–15	16–20	21–25	26–31	1–5	6–10	11–15	16–20	21–25	26–30
1994	9	0	0	6	161	0	6	13	122	13	49	168
1995	0	18	8	25	13	3	0	1	32	160	2	1
1996	3	0	2	0	0	17	3	46	34	12	208	18
1997	0	10	28	4	0	14	1	21	13	66	14	18
Average year	17	19	18	21	23	29	24	24	26	29	30	28

Year	Cultivation area and drought occurrence of upland rice in Ibaraki pref.		
	Cultivation area (ha)	Damaged area by drought (ha)	Yield loss by drought (t)
1994	6,550	5,390	6,980
1995	6,110	2,560	2,480
1996	5,310	4,060	5,290
1997	5,190	1,710	1,280

[1)] Statistical Report on Agriculture, Forestry and Fisheries in Ibaraki prefecture for 1996–1997.

their transpiration and photosynthetic rates, and productivity decreased (Gollan *et al.* 1986, Termatt *et al.* 1985, Turner 1986). Figures 1 and 2 show the high correlation coefficient of leaf temperature with transpiration. It is considered that higher vaporization by transpiration took more heat from the plant body. The ability to maintain a lower leaf temperature may indicate high transpiration and photosynthetic rates, and productivity under drought. Similar results were reported by Idso *et al.* (1977) for wheat. They showed that the leaf temperature during the heading period was closely related to the grain yield, and may enable to estimate yield in wheat varieties. In addition, Fischer *et al.* (1998) reported that stomatal conductance, photosynthesis and canopy temperature were closely and positively correlated with yield in spring wheat. The evaluation and line selection of drought tolerance based on the leaf temperature could also be effective in upland rice to develop highly tolerant varieties to drought.

The maintenance of the inner moisture content under drought conditions requires a high water uptake. Root characteristics play an important role in the water uptake mechanism. Deep-rooted upland rice varieties, which are capable of utilizing soil moisture in deeper soil profiles, are more tolerant to drought than shallow-rooted varieties (Minabe 1951, Nemoto *et al.* 1998). IRRI reported that the leaf temperature of IR52 with deep rooting was 2°C lower than that of IR36 with ordinary roots (IRRI 1983). In the present study, the direct correlation between the degree of root growth and leaf temperature was confirmed as shown in Figure 3. Hirayama *et al.* (1995) compared the root system of Japanese upland rice varieties using the trench method. Medium-late maturing varieties with their reproductive stage in the height of summer, showed superior root growth into deeper soil layers, compared with the early maturing varieties. The difference in the leaf temperature between the medium-late maturing varieties and early maturing varieties corresponded to their general degree of drought tolerance and to the growth of the root system (Banba and Ohkubo 1981, Hirayama *et al.* 1995). In the present study, KM168 with deep rooting always showed a remarkably lower leaf temperature than N4. KM168 was developed from the deep-rooting Indian variety JC81 by successive backcrossings with N4 (Hirasawa *et al.* 1998). Almost all the characteristics of KM168 were similar to those of N4 except for the drought tolerance and deep rooting. The difference in the leaf temperature between both varieties was considered to be reflected in the root growth. It was concluded that the leaf temperature is a useful indicator to estimate the characteristics of water uptake and root growth into deep soil layers in upland rice.

The parental upland rice varieties Tsukubahatamochi, Kantomochi160 and Kantomochi166, produced a large number of progeny lines with lower leaf temperatures. Although, the progeny lines of KM168 were not included in the tested materials in the present experiment, a larger number of inbred lines with a lower leaf temperature was detected in the progenies of KM168 than in those of N4 (Fig. 4). A higher parent-offspring correlation was confirmed in the progenies of KM168 or N4. It is, therefore, concluded that the leaf temperature displays a higher heritability in the progeny of upland rice.

The measurement of the leaf temperature with an infrared thermometer could be effective in line selection for drought tolerance and root depth in upland rice breeding, before development of visual damage. The infrared radiation thermometer is convenient for line selection, because of its lightweight (ca. 800 g) and the short period of measurement (0.5 sec.). On the other hand, the Tl-Ta value of the difference between the leaf temperature and air temperature is affected by the weather conditions, for example, Tl-Ta of KM168 ranged from −2.23°C to 0.43°C in the three test years. The comparison of absolute Tl-Ta values may not be significant, and the Tl-Ta value should be used as a relative value in the measured materials under similar conditions. Leaf temperature measured with the infrared radiation thermometer may become a useful tool to select upland rice varieties with superior root growth and drought tolerance.

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