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Climatic Factors Related to Low Rice (*Oryza sativa* L.) Yield in the Wet Season under Double Cropping in the Mekong Delta, Vietnam

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Abstract

This study aimed to determine the rice (*Oryza sativa* L.) yield under double cropping in the Mekong Delta, Vietnam, and identify which climatic factors cause a reduced yield in the wet season (WS) compared with the dry season (DS). A series of field experiments was conducted in the field from 2014 to 2017, along with a supplementary pot experiment, by using the rice variety OM 6976. The yield was 38% lower in WS than in DS, mainly due to a decrease in the spikelet number per panicle and percentage of ripening. This yield reduction observed in WS was most closely related to lower radiation at 51-80 days after transplanting, and was also related to higher temperature. These results suggest that low radiation and high temperature during the reproductive to grain-filling stages were mainly responsible for causing a low yield in WS. In addition, a need to further consider soil reduction was suggested based on more extensive root damage and sulfide levels on roots observed in WS as compared with DS.

Discipline: Crop Science
Additional key words: radiation, root damage, temperature

Introduction

Rice (*Oryza sativa* L.) cropping is widely practiced during both the wet season (WS) and dry season (DS) under a double-cropping system in the tropics, where water availability does not limit either cropping season. However, lower yield has been more frequently observed in WS rather than in DS due to abiotic and biotic factors, making yield improvement in WS crucial for increasing annual productivity.

In the Mekong Delta, a major rice-producing area in Vietnam, extremely low yield was reported in a field experiment (Watanabe et al. 2009). Low radiation is generally considered a major factor that limits rice yield in WS through reduced photosynthesis. Temperature is also considered a factor that affects the determination of yield. The precise effects of climatic factors on yield and yield components have yet to be assessed, however, despite such assessment being essential for implementing efficient measures to improve the yield in WS in this area. Moreover, root factors, particularly the root damage caused by soil reduction, must be considered in this area, as sublayers of the soil contain large amounts of jarosite, which is a potential source of toxic compounds such as Fe^{++} and sulfide compounds such as H_2S.

This study was undertaken to determine the effects of climatic factors on rice yield along with root observation in the Mekong Delta, by conducting a series of field experiments over a four-year period. At the same time, we conducted a pot experiment to evaluate the

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effects of climatic factors on yield, in order to exclude the effect of seasonal changes on soil conditions experienced in the field. We used the results from both field and pot experiments to discuss the cause of low rice yield in WS, as well as possible measures that could improve this situation.

Materials and methods

1. Field experiments

A series of field experiments was conducted from 2014 to 2017 in an experimental field of the Cuu Long Delta Rice Research Institute (CLRRI), Thoi Lai District, Can Tho city, Vietnam (10°08′N, 105°35′E), where nine crops were grown under double cropping in a year. The soil in this field was classified as Sulfic Endoaquepts (pH(H_2O) 5.3, T-C 35.1 (g kg^{-1}), total-N 3.3 (g kg^{-1})) (Watanabe et al. 2017), and fertilizer ($N:P_2O_5:K_2O$ kg ha^{-1}) was applied at rates of 100:40:40 and 80:40:40 in DS and WS, respectively. N was applied in three split applications at 3-5 days after transplanting (DAT), 20-25 DAT, and 30-35 DAT, whereas P was applied at 3-5 DAT and 20-25 DAT, and K was applied at 3-5 DAT and 30-35 DAT. Three water management treatments were employed in all seasons except the 2017 WS: continuous flooding during the crop season (W1; control), mid-season drainage at 40 DAT for two weeks (W2), and continuous flooding during the fallow period between DS and WS, and during the crop season (W3). Table 1 summarizes the transplanting and harvest dates, and the climatic conditions. During the 2017 WS, two crops with different transplanting dates were grown. The duration of sunshine (SH) during the entire crop season was 24.1% lower in WS than in DS on average, whereas the temperature and maximum wind speed were consistently higher in WS than in DS.

A popular indica rice variety (OM 6976) was used in the experiments. In each treatment, 13-day-old seedlings were transplanted at a spacing of 20 cm × 20 cm, with two seedlings on each hill. The plot size was 11 m × 6 m in a randomized complete block design with three replications. At maturity, the plants were harvested from 5 m^2 to measure the grain yield and from 0.5 m^2 to determine the yield components. The panicle number and spikelet number were counted for all plants, and filled and unfilled spikelets were separated manually to determine the percentage of ripening. The single grain weight for filled grain was expressed at 14% moisture.

2. Panicle structure analysis

To determine the spikelet number and percentage of ripening at different positions on a panicle, the three longest panicles were sampled from three hills with average panicle numbers in each plot. The spikelets were divided into those on the primary and secondary rachis branches, and then further divided into filled and unfilled grain. The number and weight of each grain type were then determined at 14% moisture.

3. Root observations

In order to observe root color, roots were sampled from a depth of approximately 12 cm over an area of about 20 cm × 20 cm on three hills with average tiller numbers during the late tillering to panicle initiation stages, and were carefully washed with tap water. Immediately after washing, the black root score (%) was determined using the method prescribed by Baba (1958), along with slight modifications. The proportion of black-colored roots with rot in the entire root system was visually scored to estimate the degree of root damage caused by soil reduction. Moreover, the presence of sulfide was assessed using the methylene blue colorimetric method (Takagi & Okajima 1953) in the 2013/2014 DS and 2014 WS. Briefly, p-aminodimethylaniline in 20% (v/v) sulfuric acid followed by 1% (w/v) $FeCl_3$ solution were added to the roots to visually assessed degree of blue color development caused by the formation of methylene blue using a color score (0: no coloration to 5: intense coloration).

4. Pot experiment

In parallel with the field experiments, a pot experiment was conducted in a screen house on the campus of CLRRI. Each pot (27 cm in diameter × 25 cm in depth) was filled with 5 kg of dry soil collected from the field used in the field experiments. N in the form of urea and diammonium phosphate (DAP), P in the form of DAP, and K in the form of KCl were then applied at rates of 1.0 g pot^{-1}, 0.5 g pot^{-1}, and 0.5 g pot^{-1}, respectively. Seedlings of OM 6976 (13-day old) were transplanted with three plants per pot. Plants were grown six times under submerged soil starting from May 23, 2016, with about two-month intervals between each group. At maturity, the dry weight of the aboveground parts and roots, and the grain yield were determined. In addition, the three longest panicles in each pot were used to determine the spikelet number, using the same procedure as in the field experiments. The root to shoot ratio was calculated as follows:

Root to shoot ratio (%) = root dry weight/dry weigh of aboveground parts × 100

5. Climatic data

Daily climatic data were obtained from the Can Tho meteorological station.

Table 1. Planting schedules and climatic conditions in dry season (DS) and wet season (WS) in the field experiments

Season	2013/2014 DS	2014WS	2014/2015 DS	2015WS	2015/2016 DS	2016WS	2016/2017 DS	2017WS T1	2017WS T2	DS Mean	WS Mean	WS/DS (%)
Transplanting	2013/12/5	2014/4/29	2014/11/26	2015/4/25	2015/11/29	2016/5/23	2016/11/28	2017/5/4	2017/6/1			
Harvest	2014/3/14	2014/8/7	2015/3/7	2015/8/3	2016/3/9	2016/8/30	2017/3/3	2017/8/8	2017/9/8			
Duration (d)	99	100	100	100	101	99	95	96	99	99	99	
SH (hr d^{-1})*	7.8	6.5	7.7	7.9	8.7	6.4	6.4	5.8	6.2	7.6	6.6	86
Mean temp (°C)*	25.5	28.2	26.1	28.6	27.5	27.7	26.7	27.7	27.7	26.5	28.0	106
Max. temp (°C)*	30.4	33.0	30.9	33.5	32.2	32.6	31.1	32.4	32.3	31.1	32.8	105
Min. temp (°C)*	22.2	25.3	23.0	25.8	24.5	25.1	24.0	25.5	25.4	23.4	25.4	108
Max. wind (m s^{-1})*	3.6	5.8	3.8	5.4	4.0	5.9	3.9	5.5	5.6	3.8	5.6	148
Rainfall (mm d^{-1})*	0.0	7.7	1.1	6.7	0.3	7.2	2.1	9.5	7.4	0.9	7.7	872

* Daily mean values during each crop season.
SH: duration of sunshine hours

6. Statistical analysis

The effect of water treatments in each season was analyzed by ANOVA using Statistix software (ver. 9, Analytical Software Co., USA). Average yield between WS and DS was compared by t-test (Excel 2013, Microsoft Co.).

Results

1. Yield and yield components

There were no significant differences in the yield or yield components among water treatments from the 2013/2014 DS to the 2016/2017 DS, partly due to imperfect water management. Therefore, said water treatments were pooled in subsequent analyses to represent a single season. Table 2 presents the grain yield and yield components in each season. Yield was constantly higher in DS than in WS throughout the experiments. Average yield over the years in WS was 38% lower than that in DS with a significant difference ($P < 0.05$), and was associated with a lower harvest index (HI) in WS than in DS. The total aboveground dry weight (TDW) was also lower in WS than in DS, but to a lesser extent than for yield and HI. The lower yield in WS was mainly attributed to a lower spikelet number per panicle and percentage of ripening.

2. Panicle structure

The spikelet number per panicle on the primary and secondary rachis were 9.9% and 23.7% lower, respectively, in WS than in DS (Fig. 1 (a)). There was large seasonal variability in the spikelet number per panicle on the secondary rachis in WS. The percentage of ripening was lower in WS than in DS on both the primary and secondary rachis (Fig. 1 (b)).

Table 2. Yield and yield components in field experiment

Season	Grain yield Mg ha^{-1}	Panicle no. no. m^{-2}	Spikelets /panicle	Percentage of ripening %	Single grain weight mg	TDW# g m^{-2}	HI
2013/2014DS	6.74	370	139	65.5	28.3	1,665	0.35
2014WS	2.83	355	100	53.9	27.6	1,344	0.18
2014/2015DS	5.86	420	153	68.0	26.8	2,245	0.23
2015WS	3.51	340	110	61.6	27.5	1,552	0.20
2015/2016DS	5.75	546	115	65.7	26.9	2,108	0.24
2016WS	4.96	436	125	63.5	27.2	1,928	0.22
2016/2017DS	5.20	296	146	62.9	28.2	1,483	0.30
2017WS T1	3.96	328	139	63.8	26.8	1,460	0.24
2017WS T2	2.86	381	120	38.8	27.0	1,367	0.18
DS mean	5.89a	408	138	65.5	27.6	1,875	0.28
WS mean	3.62b	368	119	56.3	27.2	1,530	0.20
WS/DS mean (%)	62	90	86	86	99	82	73

Total aboveground dry weight
DS: dry season, HI: harvest index, WS: wet season
Values with different letters indicate a significant difference by t-test ($P < 0.05$).

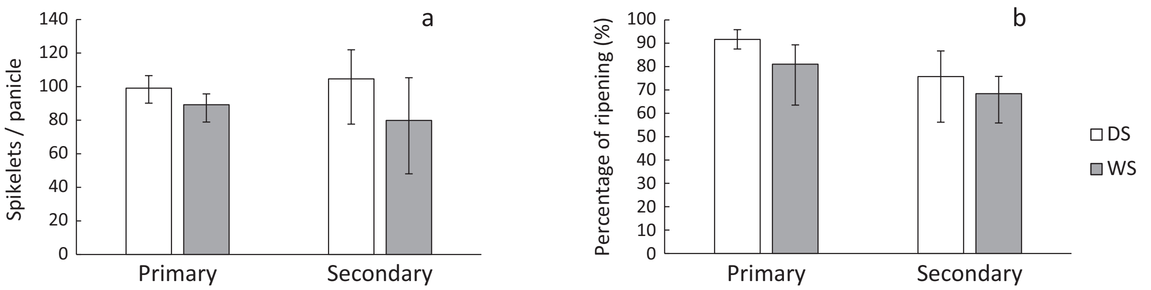

Fig. 1. Average spikelet numbers per panicle (a) and percentage of ripening in spikelets (b) on primary and secondary rachis branches in wet season (WS) and dry season (DS)
Bars indicate the minimum and maximum values.

3. Effects of climatic conditions on yield

Variations in yield were positively and most closely related with SH at 51-80 DAT, but were not related to SH at 21-50 DAT (Fig. 2 (a), (b)). In contrast, yield was negatively related with temperature at both 21-50 and 51-80 DAT (Fig. 2 (c), (d)). Similarly, the spikelet number per panicle and percentage of ripening tended to be positively related to SH and negatively related to temperature (Table 3). Because SH and temperature were correlated with each other (r = −0.79), the relationship between yield per cumulative SH and mean temperature at 51-80 DAT was examined to separate their effects (Fig. 3), based on the assumption that this index would independently reflect the yield response to temperature (Murata et al. 1964). This relationship was curvilinear, with a maximum yield per cumulative SH being observed at 25.9°C with relatively large variations against the regression line in WS.

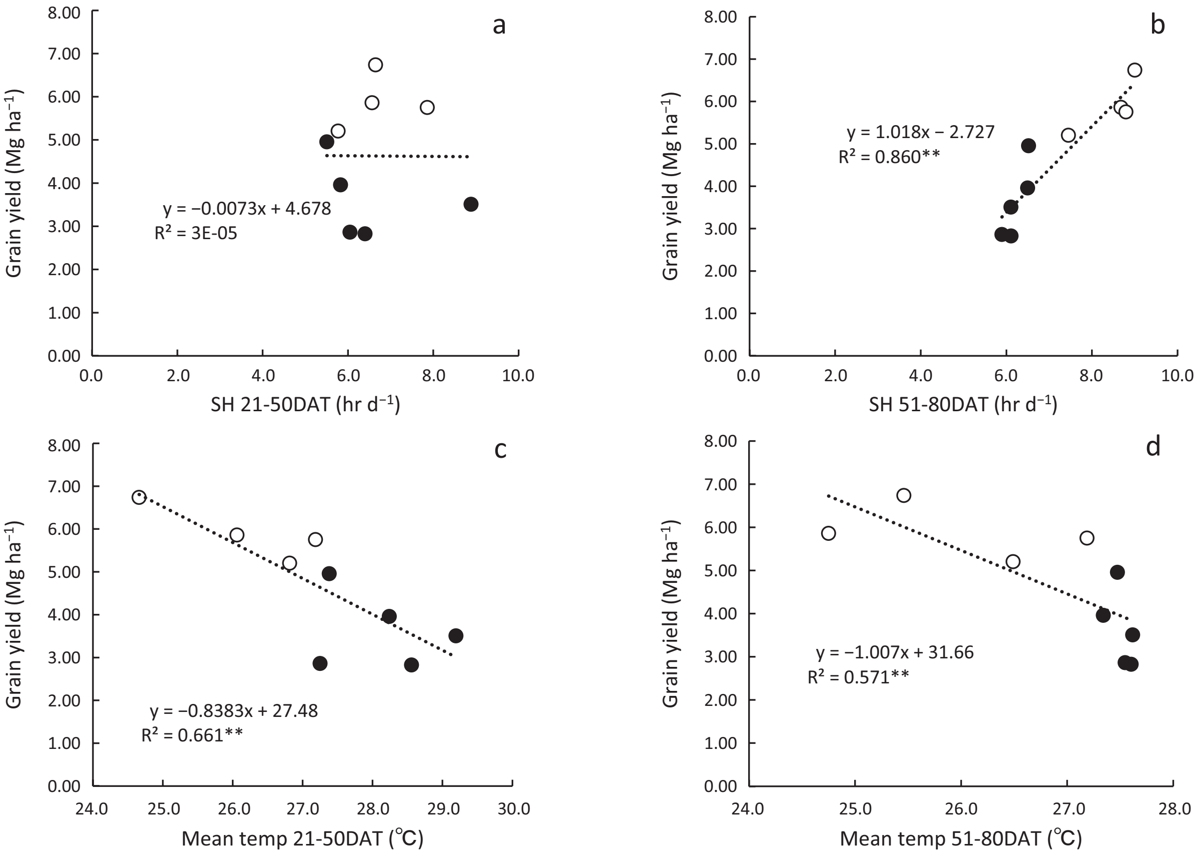

Fig. 2. Relationships between grain yield and duration of sunshine hours (SH) at 21-50 days after transplanting (DAT) (a) and 51-80 DAT (b), and between grain yield and mean temperature at 21-50 DAT (c) and 51-80 DAT (d)
Closed and open circles indicate the wet season (WS) and dry season (DS), respectively.
** indicates significance at $P < 0.01$.

Table 3. Correlation between yield components and duration of sunshine hours and temperatures 51-80 DAT

Climatic factor		Panicle no. no. m^{-2}	Spikelets /panicle	Percentage of ripening %	Single grain weight mg	TDW# g m^{-2}	HI
Duration of sunshine	51-80DAT	0.463	0.528	0.639	0.155	0.690*	0.686*
Mean temp	51-80DAT	−0.035	−0.770*	−0.495	−0.200	−0.528	−0.603
Max. temp	51-80DAT	0.021	−0.754*	−0.361	−0.166	−0.471	−0.475
Min. temp	51-80DAT	−0.152	−0.704*	−0.535	−0.237	−0.582	−0.648

Total aboveground dry weight
* indicates significance at $P < 0.05$.
DAT: days after transplanting, HI: harvest index

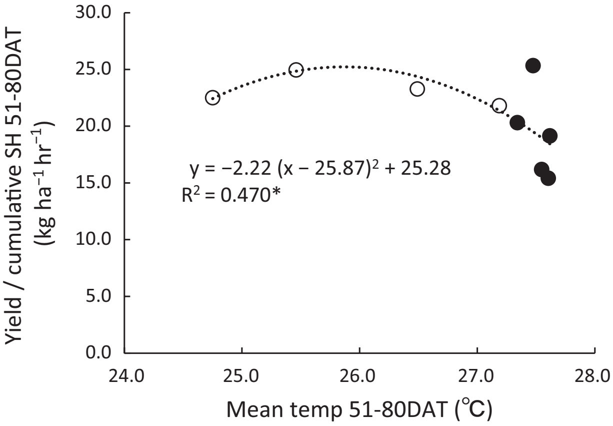

Fig. 3. Relationship between grain yield per cumulative duration of sunshine hours (SH) and mean temperature at 51-80 days after transplanting (DAT)
Closed and open circles indicate the wet season (WS) and dry season (DS), respectively.
* indicates significance at $P < 0.05$.

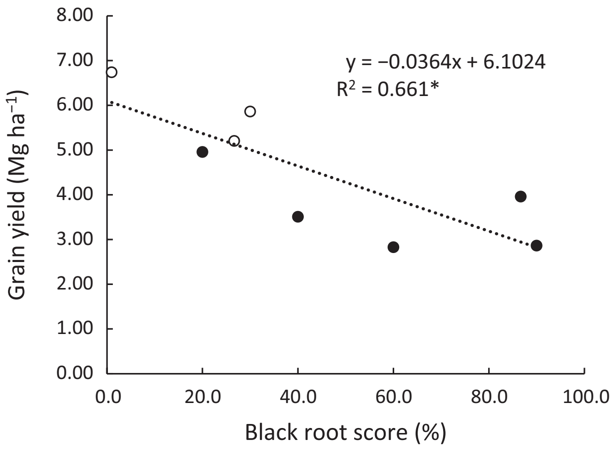

Fig. 4. Relationship between grain yield and black root score in the field experiments
Closed and open circles indicate the wet season (WS) and dry season (DS), respectively.
* indicates significance at $P < 0.05$.

4. Root observations

The presence of sulfide in the roots was visually recognized in both seasons, but was higher in WS than in DS in 2014 and 2015. Yield was negatively correlated with the black root score, with a tendency for higher values in WS (Fig. 4), thereby indicating a larger deposition of iron sulfide on the roots. A larger extent of sulfide formation was also indicated in the 2014 WS than in the 2013/2014 DS by using the methylene blue method (Fig. 5).

5. Pot experiment

Yield varied by 36.9% among the six crop periods examined in the pot experiment, and tended to be positively related with SH at 51-80 DAT ($R^2 = 0.840$* with the exception of one crop period), thus matching the field observations (Fig. 6 (a)). The slope of this relationship was smaller in the pot experiment than in the field experiments, indicating a reduced sensitivity to radiation under the pot conditions. The spikelet number was more variable on the secondary rachis branch than on the primary rachis branch at 51-80 DAT (Fig. 6 (b)). The root to shoot ratio tended to increase with SH at 51-80 DAT (Fig. 6 (c)).

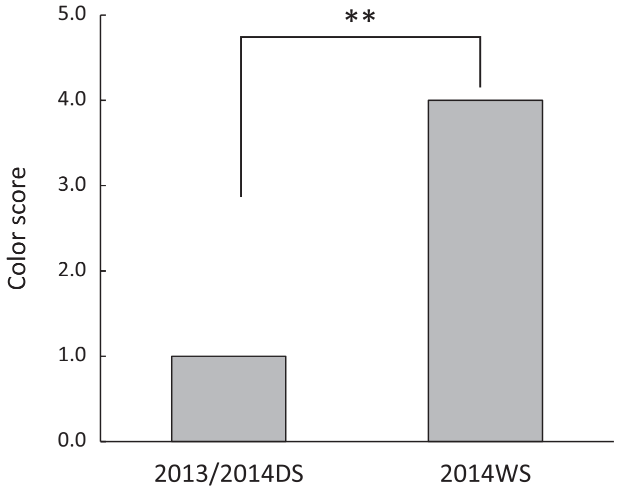

Fig. 5. Comparison between 2013/2014 DS and 2014 WS in color score by methylene blue method to indicate presence of sulfide
** indicates significant difference at $P < 0.01$.

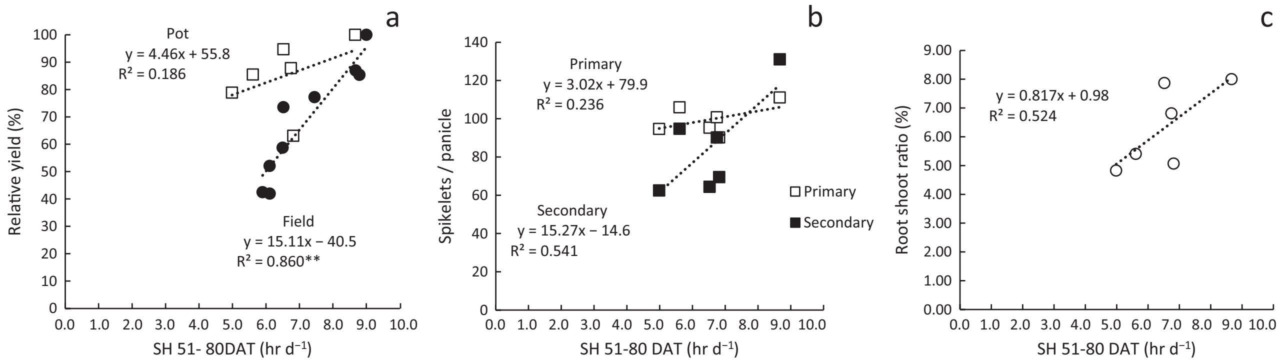

Fig. 6. Relationships between relative yield (% maximum yield) and duration of sunshine hours (SH) (a), spikelet number per panicle and SH (b), and root to shoot ratio and SH at 51-80 DAT (c) in the pot experiment
Data from the field experiment are also shown in (a).

Discussion

1. Yield characteristics of rice in WS and DS

Rice yield was substantially lower in WS than in DS, which is consistent with the findings of a previous study at the same site in different years (Watanabe et al. 2009). Yield was more closely related to HI (r = 0.80**) than to TDW (r = 0.69*), thus indicating that the distribution of biomass to grain was strongly affected by the season. This was due to a low percentage of ripening and spikelet number per panicle rather than a low panicle number in WS, which could be primarily attributed to low radiation based on the close relationship with SH in the reproductive to early grain-filling stages. These results are consistent with those of Yang et al. (2008), who pointed out that the sink production efficiency per unit biomass at flowering and the amount of solar radiation and biomass accumulation during the grain-filling period are critical factors for explaining the yield gap between DS and WS. During this period, the amount of radiation is important for panicle formation and starch accumulation in the grains through photosynthesis (Yoshida 1981). The spikelet number per panicle on the secondary rachis branches was more variable in WS than in DS in both the pot and field experiments (Figs. 1 & 6 (b)), probably due to a larger influence of supplying carbohydrates to the developing panicle on the generation of inferior rather than superior spikelets.

The results also suggested that high temperature in WS may have a negative effect on yield. Increasing temperature threatens rice production mainly through a decreased spikelet number per panicle, percentage of ripening, and HI (Peng et al. 2004, Yoshida 1981). The optimum mean temperature estimated in this study was 25.9°C, which is higher than that (21°C-22°C) for japonica varieties (Murata 1964, Nagata et al. 2016) and similar to the 24°C-25°C for indica varieties in the Philippines (Yoshida 1981) and Japan (Nagata et al. 2016).

2. Improvement of rice yield in WS

Although radiation and temperature can mainly explain the variations in yield, there still may be other factors that affect yield in WS based on the larger residual against the regression line with yield per unit SH and temperature in WS (Fig. 3). The 38% yield reduction that occurred in association with a 27% reduction in SH at 51-80 DAT in WS appeared to be larger than the value previously reported by Yoshida (1981), who demonstrated that a 33% reduction in radiation during the reproductive stages led to a 22% yield reduction in a shading experiment using a different variety that gave similar yield levels to OM 6976 in the present study. Root observation showing a larger extent of apparent root damage and the formation of sulfide led us to speculate that root damage caused by soil reduction in the field may be partly involved in suppressing the yield. A larger decrease in yield with lower radiation in the field as compared with the pot experiment would also suggest a possible seasonal change in soil conditions. Root damage caused by such sulfides as H_2S under soil reduction is known to inhibit root physiological activities, such as respiration and nutrient uptake, and also disrupts young panicle development (Takagi & Okajima 1953, Takagi et al. 1955). Low radiation generally leads to a higher allocation of photosynthetic products to the aboveground parts rather than the roots, thereby allowing plants to capture more light as indicated in the pot experiment in this study. And enhanced soil reduction by high temperature has been observed in acid sulfate soils in the Mekong Delta (Quang et al. 1995). Transpirational demand as affected by humidity and wind may also interactively affect plant growth with root activity in water uptake. Therefore, the effect of soil conditions on yield limitation in WS should be examined by precisely elucidating the changes in soil reduction, such as the levels of H_2S, and also the interaction with climatic conditions.

Overall, the results of this study indicated that the low yield of rice in WS could be mainly attributed to the combined effects of low radiation and high temperature. It may be of value to mitigate these constraints through agronomic and genetic measures. Adjusting the cropping season to optimize radiation and temperature conditions would be valuable, provided that irrigation control is feasible. Among the varietal characteristics, a large panicle size has been shown to be advantageous for adapting to WS (Laza et al. 2004). A further precise analysis of soil reduction and its effect on root and yield would also be useful as similar soils containing jarosite are widely distributed in the Mekong Delta (Moormann & van Breemen 1978). The results of this study highlight the importance of developing technology that can cope with WS conditions in double-cropping rice, particularly given the fluctuations in radiation and increasing temperatures that are predicted under global warming (IPCC 2014).

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