Multi-site monitoring network of canopy micrometeorology and environmental stresses of rice under the climate change（Abstract of the Final Report）

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1. Introduction

The abnormal weather with heat and drought is likely to occur more frequently by the progress of the global warming, which is concerned as threatening the crops production 1). Rice is highly adaptive to a range of environments, but previous chamber experiments have shown that rice is also highly susceptible to heat 2,3). These studies revealed that flowering is the most sensitive stage and that heat-induced spikelet sterility (HISS) is the major reason for yield losses. The yield loss due to HISS, however, has not been well documented in the rice production. One reason of this is the shortage of dataset of thermal environment in rice paddy field. Furthermore, the plant body (panicle) temperature, which is directly related to the reproduction process of rice, can be different from the air temperature. For a proper assessment of the vulnerability of rice production to any environmental change, we need micrometeorological data in the open paddy field under variable climatic and management.

2. Research Objective

The objective of this project is to construct the monitoring network of canopy micrometeorology of rice paddy and heat stress in the 'hot spots' rice cultivation areas in the world, to determine the relationship between the proper explanatory variables and heat stress based on heat balance of canopy, and to evaluate the global distribution of vulnerability of heat stress under climate change. In order to achieve this, we conducted below in three years.

1) Multi-site monitoring of heat and drought stresses in hot spots of rice cultivation area in the world

2) To identify the interactive effect of variety and Si application on rice canopy temperature and productivity under drought- and flood- prone rainfed fields in West Africa

3. Results and Discussion

1) Multi-site monitoring of heat and drought stresses in hot spots of rice cultivation area in the world

① Establishment of multi-site monitoring network of micrometeorology and heat stresses in paddy field of 11 hot rice cultivation areas (MINCERnet)

MINCER (Micrometeorological Instrument for the Near-Canopy Environment of Rice) developed by NIAES in 2009 is a stand-alone, solar-powered, force-ventilated radiation shield system 4), which has been used as a common instrument in MINCERnet. However, supplying the solar fan part was discontinued recently which would cause difficulties for its multiplying and repairing. In order to solve the problem, the new generation MINCER (2G) was developed by re-designing of solar fan part. The 2G has advantages for long-lived fan motors and its convenience as CRU (Customer Replaceable Unit). The 2G solar fan has a backward compatibility, which enables us to continue the monitoring seamlessly in the MINCERnet from now on.

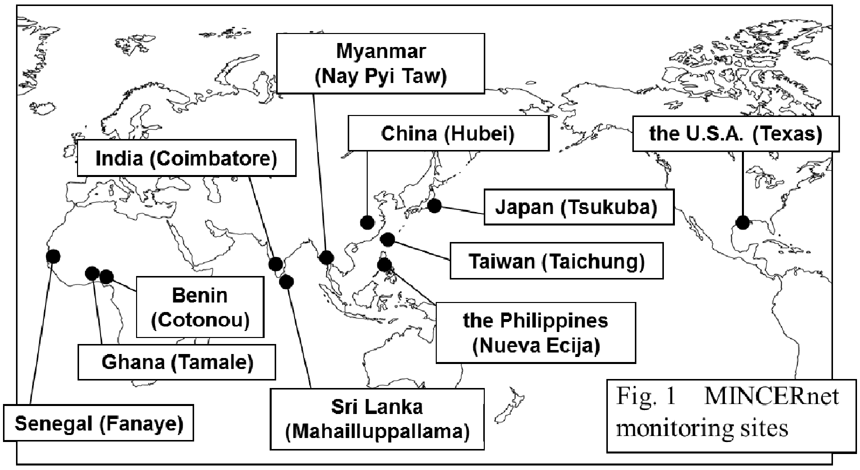

Fig. 1 MINCERnet monitoring sites

We established the monitoring network of canopy micrometeorology and rice crop information at 11 monitoring sites in 'hot spots' rice cultivation areas in the world (MINCERnet, Fig. 1). The air temperature and relative humidity above the canopy (at twice of canopy height from the ground) and inside the canopy (at flowering panicle's position) were monitored by MINCER from heading to harvesting, which were summarized as a dataset with other crop information like heading date, flowering time, spikelet sterility.

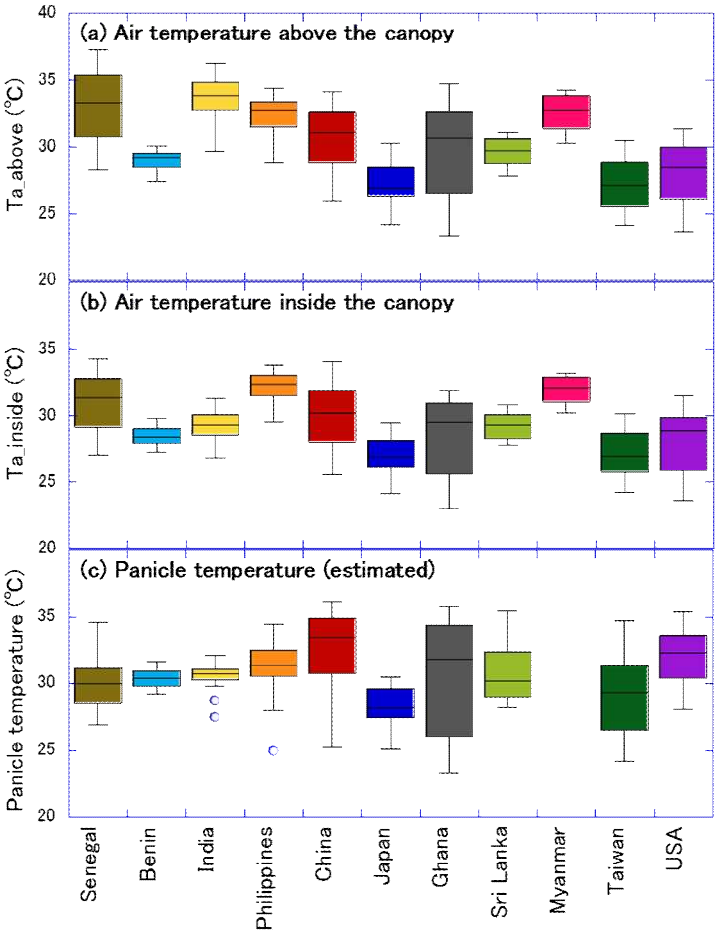

Fig. 2 Temperature ranges of T_a above the canopy(a), T_a inside the canopy(b) and the estimated panicle temperature T_p(c) at flowering time in heading period.

Based on the kick-off meeting in 2015, two types of experiment, varieties response experiment, heat and drought experiment are conducted. The participants are India, Philippines, China, Japan, Benin and Senegal for the varieties response experiment, and Ghana, Sri Lanka, Myanmar, Taiwan and the US for the heat and drought experiment. The standard variety among all sites is IR64, which is the moderate variety against HISS. In the varieties response experiment, the heat-tolerant variety (N22) and the heat-susceptible variety (IR52) were also cultivated.

② Micrometeorology gap between above- and inside-canopy and sterility ratio of common

varieties

The dataset of air temperature (T_a) and relative humidity (RH) at flowering time in heading period (6 days) at each site showed that T_a was lower and RH was higher inside the canopy than above the canopy, because of the transpiration-cooling by plants and evaporative cooling by water surface. Their cooling effect was the strongest at Senegal with the driest climate, where the air temperature inside the canopy was lower by 7.0 ℃ than nearby weather station. While at Benin, China, Taiwan, Japan and the US sites, the T_a difference between above- and inside-canopy was small, because the evaporative cooling was small under the humid climate (Fig. 2(a)(b)). The range of RH inside the canopy was differed among climates, whose median was 56% in Senegal with the driest climate but about 90% in humid climate sites.

The panicle temperature (T_p) was estimated by the existing heat balance model, IM^{2}PACT $^{5)}$ (Fig. 2(c)). The T_p was higher than the T_a inside the canopy in humid climate sites (Benin, China, Taiwan, Japan and US) and lower in the driest climate sites (Senegal). When comparing the thermal environment among sites by T_p, the hottest site was China, followed by Philippines, US and Ghana, which was different order from that with comparing by T_a above the canopy.

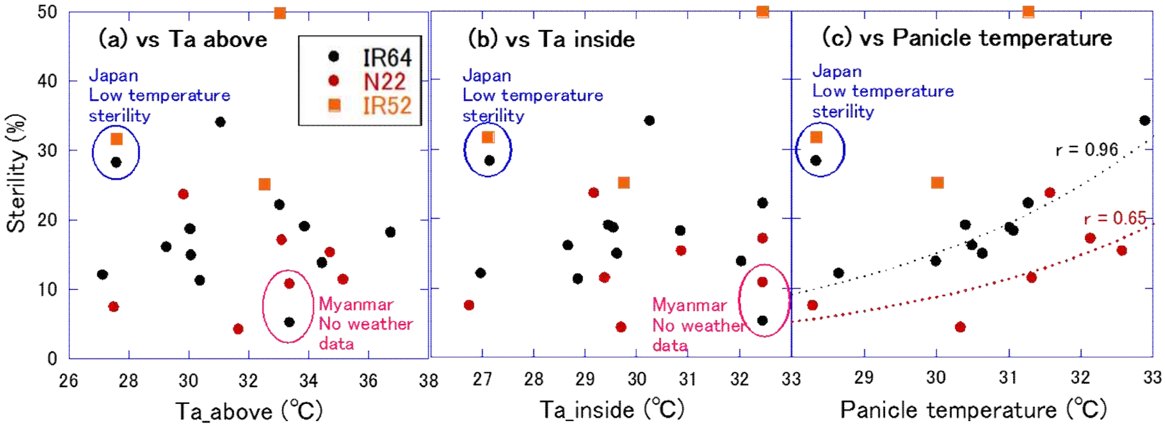

Fig. 3 The relationship of sterility of 3 varieties (IR64, N22, IR52) and the T_a above the canopy(a), the T_a inside the canopy(b), and the estimated T_p(c)

Fig. 3 shows the relationship between sterility of common varieties (IR64, N22, IR52) and the temperatures in Fig. 2. Previous studies often used the air temperature at nearby weather station as an explanatory variable of HISS because of lack of environmental data in paddy fields. However, Fig. 3 shows that the correlation with the T_a inside the canopy (Fig. 3(b)) was slightly higher than that with the T_a above the canopy (Fig. 3(a)), and the correlation with the T_p was the highest (IR64, r = 0.96) (Fig. 3(c)). It was ascertained that referring of

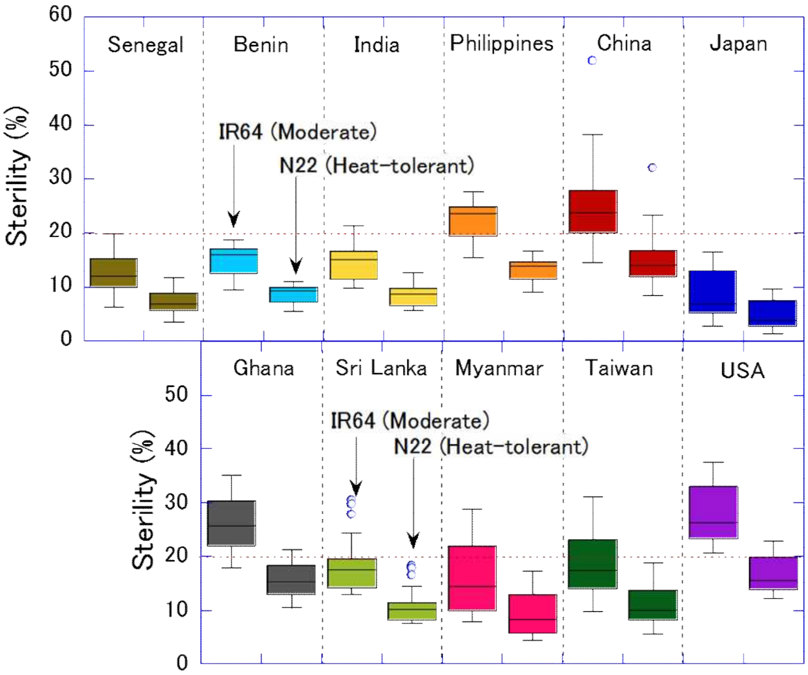

Fig. 4 The heat-induced spikelet sterility risk estimated by panicle temperature

panicle temperature is essential for clarifying the mechanism of HISS. The threshold T_p of HISS was suggested around 30～31℃, which was lower than previous studies by closed chamber experiments, 34～35℃. The effect of introducing heat-tolerant variety (N22) instead of moderate variety (IR64) was clear if the T_p was used as explanatory variable of HISS.

The T_p was calculated for 30 days of heading and maturing periods in all sites, and the HISS risk was estimated (Fig. 4) using the T_p and the relationship of Fig. 3(c). The highest risk of HISS was found in China, where the median of sterility range was 23% for IR64, and 14% for N22. The HISS risk map in the world could be greatly changed and improved by using the relationship of panicle temperature and sterility.

③ The interactive effect of drought on HISS by heat and drought stress experiment

The protocol for heat and drought stress experiment was completed. In drought stress plot, it was drained around one week before flowering, while the control plot was kept flooded. The drainage treatment led the micrometeorology inside the canopy warmer by 1.15℃ in dry climate (Sri Lanka site) and 0.23℃ in humid climate (Taiwan site), and the panicle temperature higher by 2.5℃ in Sri Lanka and 0.8℃ in Taiwan. The panicle temperature was possible to increase because of the decrease in panicle transpiration due to drought stress as well as the elevation of T_a inside the canopy.

The drought stress increased the sterility rate from 15.0 to 40.8 % in Sri Lanka site, and from 12.1 to 17.6 % in Taiwan site. The estimated sterility from T_p in drought stress plot using Fig. 3(c) was 33.8 % in Sri Lanka site and 13.3 % in Taiwan site, suggesting that about 80% of the sterility at drought stress plot could be explained by the T_p elevation by drought stress.

2) The interactive effect of variety and Si application on rice canopy temperature and productivity under drought- and flood- prone rainfed fields in West Africa

A series of field experiments in northern Ghana revealed the effect of water stress, variety and silica fertilizer management on the canopy temperature and productivity of rice. The daily maximum temperatures during the flowering stage were consistently high ranging 34.5 and 35.0 °C on average in dry season, whereas apparent heat stress damages indicated by the grain sterility rate were relatively small for both local variety, Jasmine85, and the check variety, IR64. This low sterility rate despite significantly high air temperature was attributable to the fact that the canopy temperature ranged only at 28.4 and 30.6 °C during the flowering time because of earlier start of flowering by 36 minutes and greater transpiration-cooling effect in the dry season relative to the wet season. A mild water stress at pre-heading stage reduced the grain yields by 10-15%. Continuous observation of canopy temperature by MINCER and sterility measurements implied that this yield reduction induced by mild water stress could be related not to the direct heat stress damages to the flowering but to the increased canopy temperatures from later afternoon to night time (stomatal closure and increased respiration). In addition, the Si application consistently increased the grain yield of Jasmine85 by 25-26% (no effect on IR64), but this yield increase was not related to the decrease in sterility.

In conclusion, we revealed that (1) heat stress can be avoided by earlier flowering time and greater transpiration cooling even under very high temperature condition in dry season of northern Ghana, (2) the effect of mild water stress at pre-heading stage on canopy temperature and grain sterility is relatively small, (3) sensitiveness to heat stress is not different between local variety and IR64, and (4) positive effect of Si application is variety specific. These obtained results were presented at two international symposiums held in Tsukuba in Nov 2015 and in Jan 2018.

Quantitative evaluation for the effect of water stress and variety on the canopy temperature and grain yield has been little studied for rice production areas that are vulnerable to climate change in West Africa. Our findings should provide key information to assess the impact of climate change on the rice production in the region by showing relatively small heat stresses under very high air temperatures in dry season, canopy temperature increases not at flowering time in the morning but at later afternoon to night time induced by mild water stress at pre-heading stage, and sensitivity level of local variety to heat stress. In addition, our leadership for the worldwide monitoring of heat stress on rice production was strengthened and extended to West Africa by transferring necessary techniques and equipment to the counterpart institutes through the project.

Reference

1) IPCC, 2014: Climate Change 2014: Impacts, adaptation and vulnerability. Part A: Global and sectoral aspects. Chapter 7 Food security and food production system. 485-534.
2) Satake, T., and Yoshida, S., 1978: High temperature-induced sterility in indica rices at flowering. Jpn. J. Crop Sci., 47, 6-17.
3) Kim, H. Y., Horie, T., Nakagawa, H., and Wada, K., 1996: Effect of elevated CO_2 and high temperature on growth and yield of rice. II. The effect on yield and its components of Akihikari rice. Jpn. J. Crop Sci., 65, 644-651 (in Japanese with English summary)
4) Fukuoka, M., Yoshimoto, M., and Hasegawa, T., 2012: MINCER: A novel instrument for monitoring the micrometeorology of rice canopies. J. Agric. Meteorol., 68, 135-147.
5) Yoshimoto, M., Fukuoka, M., Hasegawa, T., Utsumi, M., Ishigooka, Y., Kuwagata, T. (2011) Integrated micrometeorology model for panicle and canopy temperature (IM^{2}PACT) for rice heat stress studies under climate change, J. Agric. Meteorol., 67(4), 233-247