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Temperature Responses of Rice Canopy to Temperature Impacts

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ABSTRACT

Effects of short-term temperature impacts on canopy temperatures of rice plants (*Oryza sativa* L. cv. Tainung 67) were evaluated in this study. Pot-grown post-heading plants were moved from outdoors to growth chambers with temperature setpoints from 10 to 45 ℃ for 6 hr. The performance was observed up to 72 hr for extensive effect comparisons at 10 and 45 ℃ treatments. Short-term temperature impacts for rice resulted in varied response rates of acclimation prior to equilibrating to chamber temperatures. Before the equilibrium, canopy temperature was greater than chamber temperature when placed under suboptimum temperatures (25 ℃ and below), but was lower than the surroundings under superoptimum temperatures (30 ℃ and above). Results suggest that canopy temperature of rice plants responds rapidly to temperature fluctuation of growth habitat, and the sensitivity depends on the magnitude of temperature alteration. In the range of 10-45 ℃ short-term temperature impacts, rice is able to maintain its canopy temperature through heat-dissipating function if soil moisture is not limited. This ability of temperature adjustment enables rice plants tolerating to less favorable conditions which is often the case in the real natural world.

Key Words: Rice (*Oryza sativa*), Canopy temperature, Temperature shock, Radiometric temperature, Thermal infrared imaging radiometer.

水稻植冠溫度對周遭溫度衝擊之反應

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摘要：本項研究旨在探討水稻 (*Oryza sativa* L. cv. Tainung 67) 植冠輻射溫度對短期周遭溫度衝擊之反應。將已抽穗盆栽稻株自田間移入10 至45 ℃範圍之不同溫度設定植物生長箱中6 小時，觀察稻株植冠溫度之改變，並將10 及45 ℃處理者延長觀察至72 小時。根據試驗結果，稻株置於短期周遭溫度衝擊環境下，其達到溫度平衡之變化速率端視周遭溫度改變幅度而異，植冠溫度在適應植物生長箱內溫度之前，若周遭溫度在25 ℃或以下時，植冠溫度迅由高而低下降；若周遭溫度在30 ℃或以上時，植冠溫度則由低而高快速攀升。試驗結果顯示，稻株植冠溫度對環境溫度之衝擊反應十分靈敏，其反應程度隨周遭溫度轉變幅度表現有別。在本研究之10~45 ℃範圍內，稻株受到短期溫度衝擊時，在

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無土壤缺水限制下可藉由調節植體散熱功能維持與環境溫度相當之植冠溫度，此一快速迅速之體溫調節能力，乃水稻能夠容忍溫度變化難料的自然環境主因。

關鍵詞：稻 (*Oryza sativa*)、植冠溫度、溫度衝擊、輻射溫度、熱紅外線影像輻射表

Introduction

In many plant species growth is thermoperiodic, generally plant grows faster in warmer day temperature than cooler night temperature. Plant characteristics such as plant height (Went, 1944; Viglierhio and Went, 1957) and leaf size and orientation (Erwin and Heins, 1985; Fischer, 1954) are known to respond to diurnal changes in temperature. Many growth processes are also found to be affected by temperature impacts and can be modified by other environmental factors (Berry and Raison, 1981; Ellis *et al.*, 1992; Hodges, 1991; Johnson and Thornley, 1985; Robertson, 1968). Seedling growth and leaf initiation and elongation of corn were shown curvilinear responses to temperature (Bollero *et al.*, 1996; Miedema and Groot, 1987; Tollenaar *et al.*, 1979; Watts, 1971) and dry matter production was suggested linking more closely with leaf growth than with net photosynthesis in response to temperature effects (Duncan and Hesketh, 1968; Hanson, 1971; Pollock, 1990). Symptoms include flower opening, seed number and size, and pod formation of soybean were proved temperature sensitive (Hume and Jackson, 1981; Musser *et al.*, 1983; Thomas and Raper, 1978; Thomas *et al.*, 1981). In rice plant, crop development is temperature dependent (Ellis *et al.*, 1993; Yang and Heilman, 1990, 1993) and a nonlinear model has been proposed successfully for describing the response to temperature of several developmental processes (Yin *et al.*, 1995).

On the other hand, a common symptom of stressed plants is the change of body temperature upon environmental impacts. High daytime temperature coupled with low humidity in the moisture-limited soil causes an elevation of canopy temperature, while chill nighttime temperature in the field during cooler seasons results in a decrease of canopy temperature. Plants from well-watered soil receive sufficient water through roots and have cooler leaves than those from arid environments (Clarke, 1997). Therefore, temperature fluctuation of a plant canopy signify whether or not plant is under stress conditions. Monitoring of canopy temperature can not only detects the transition from no stress to an economically harmful level but also provides useful data for plant water management practices (Hatfield *et al.*, 1984; Hatfield, 1990; Jackson *et al.*, 1977; Throssell *et al.*, 1987; Thunnissen and Nieuwenhuis, 1990).

Surface temperature of plant canopy (vegetation) is also a key factor for assessing heat fluxes at the canopy-atmosphere interface. Proper estimation of surface temperature is of great importance in accurately estimating water and energy balance at the interface (Kustas, 1990; Seguin and Itier, 1983). Remote measurements of this parameter are widely applied and are currently practiced, either from the field scale or the regional scale, using a thermal infrared radiometer (thermometer) nowadays. By this technique, it is radiometric (radiative) rather than dynamic temperature to be determined, and is strongly dependent on both the meteorological conditions and the water status of the surface. With radiometric temperature measurements, the vertical distribution of plant canopy may be modeled and the correlations between environmental factors and morphological-physiological processes may be evaluated. Measurement of infrared surface temperatures, together with meteorological data, can also be applied to

estimation of the surface energy balance and the water regulation of plant transpiration through the stomata (Taconet *et al.*, 1995).

This paper describes a controlled-environment experiment designated to investigate the radiometric temperature responses of rice canopy over a wide range of short-term temperature impacts using the thermal infrared imagery technique. Canopy temperatures were monitored continually with the aim of, firstly, evaluating the response behavior to temperature impacts and, secondly, determining the sensitivity of rice plant to sub- and superoptimum temperature environments.

Materials and Methods

Three-week-old seedlings of rice cultivar Tainung 67 were transplanted onto opaque plastic pots (0.30 m in diameter and 0.60 m in height) filled with loam soil of pH 5.7. Three plants were arranged in even space per pot and several groups of pots were placed in the experimental field of Taiwan Agricultural Research Institute (Wufeng, Taichung Hsien) until heading stage. The plants were watered in excess daily to keep soil saturated and were flushed every week. They were fertilized with Tai-Fei 39 (granule, N:P_2O_5:K_2O= 12%: 18%: 12%, Taiwan Fertilizer Company, Kaohsiung) as basal dose at one week after transplanting and ammonium sulphate (21% granule, TFC) as additional dose at 4 weeks after transplanting, at a rate of 400 kg ha^{-1}. One week before heading, urea (46% granule, TFC) at a rate of 400 kg ha^{-1} was applied. Handweeding was practiced weekly to avoid weed interference.

Post-heading plants, 3 pots of 9 plants, were moved into growth chambers with different temperature setpoints of 10, 15, 20, 25, 30, 35, 40, or 45 $\pm$ 0.5 ℃. Actual temperature inside chamber during the measurements did not vary by more than 1 ℃ from the desired temperature setpoints. The photoperiod of growth chambers were set at 12 hr (06:00-18:00, local standard time) with irradiance of 250 Wm^{-2} and the plants were moved in at ca. 10:00. Plants were acclimated in room temperature for 5 min (designated as time 0) before placed into chambers, and canopy temperatures were monitored for 6 hr by a portable thermal infrared imaging radiometer. Treatments at 10 and 45 ℃ were further monitored up to 72 hr.

Thermograms (thermal infrared images) of rice canopy were remotely taken from the border of growth chamber using Inframetrics model-760 imaging radiometer (Inframetrics Inc., Massachusetts, USA). The distance to the image center from the instrument was ca. 0.80 m in a viewing angle of ca. 30 °. The measuring system includes a scanner with 1X standard lens, a fiber-optic cable connecting to a main controller, and a 12-V rechargeable battery. The scanner has a 15 ° vertical field-of-view and 20 ° horizontal FOV. The emissivity of rice canopy was set at 0.98 and the external optics transmission was fixed at 1. The measuring temperature span was limited to 10 ℃, and the background temperature was measured and set at the time of measurements. The radiometer was calibrated from −20 to 400 ℃ in Normal Range mode at the laboratory of Inframetrics with reference blackbodies.

Thermograms were analyzed and transformed to radiometric temperatures by the ThermaGRAM software (Thermoteknix System Ltd., Cambridge, England) designed specific for Inframetrics model-760. The software has the statistics functions and the capability of point, line, and area temperatures analyses. Canopy temperature is calculated from the radiometric temperatures of every pixel viewed in the image window of plant canopy. Ambient and chamber temperatures were measured by covered and natural wind-aspirated hygrometers (model A2, Rotronic Ag Inc., Swiss) and wet-and-dry bulb hygrometers.

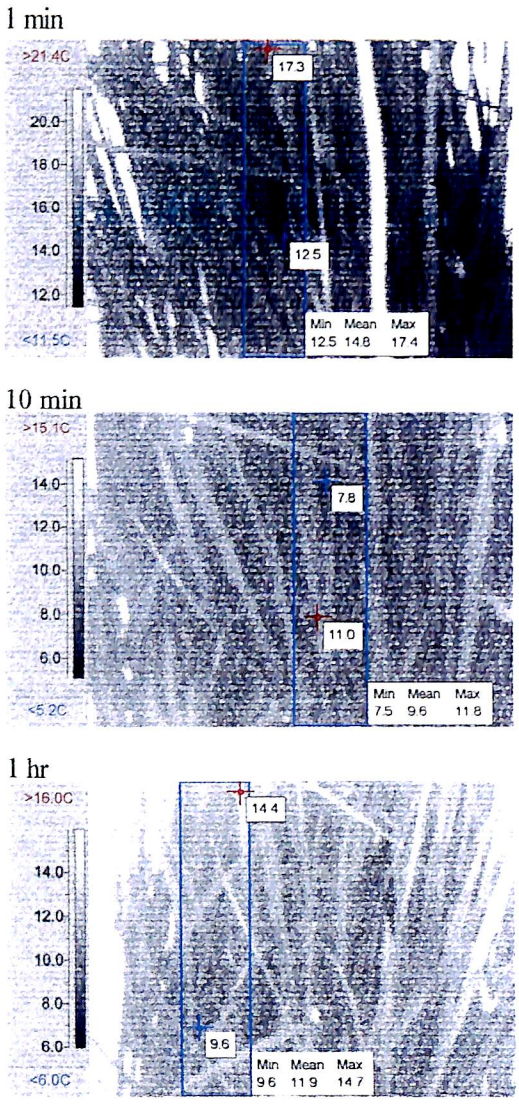


Fig. 1A. Thermograms of rice (*Oryza sativa* L. cv. Tainung 67) plants placed at 10 ℃ chamber taken at 1 min, 10 min , and 1 hr after treatment. Point temperatures and the minimum, mean, and maximum temperatures in the block area are listed.

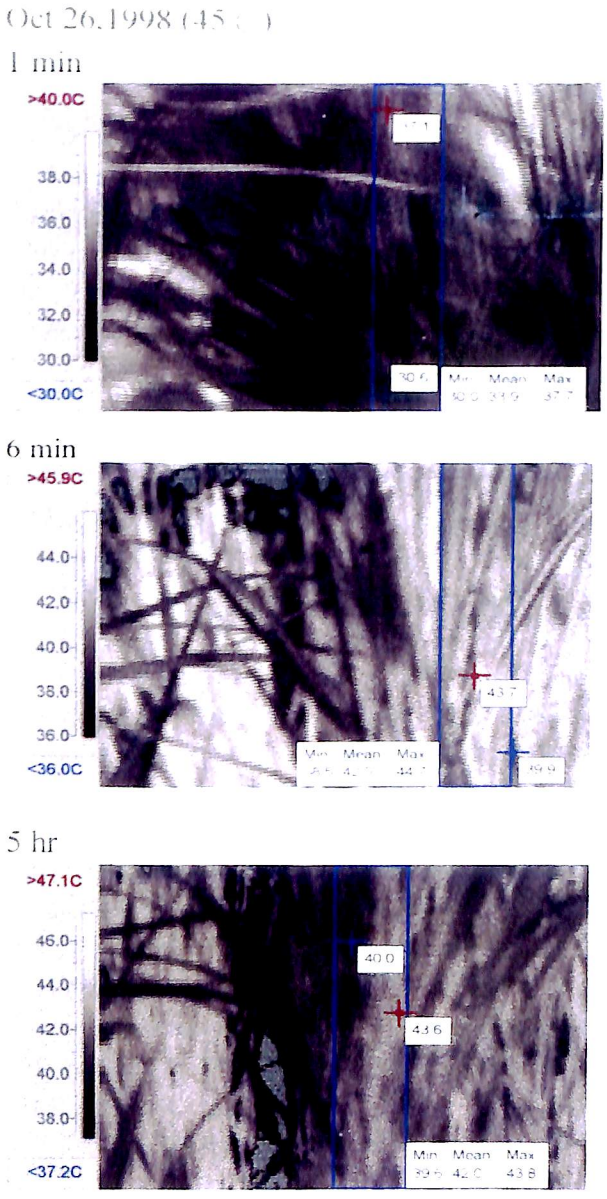


Fig. 1B. Thermograms of rice (*Oryza sativa* L. cv. Tainung 67) plants placed at 10 ℃ chamber taken at 1 min, 10 min , and 1 hr after treatment. Point temperatures and the minimum, mean, and maximum temperatures in the block area are listed.

Results and Discussion

Potted plants of rice were subjected to short-term temperature impacts by removing them from ambient conditions into growth chambers of different temperature settings. Thermograms of rice plants placed at 10 (1 min, 10 min , and 1 hr) and 45 ℃ (1 min, 6 min, and 5 hr) treatments are shown in Figs. 1A and 1B, respectively. As an example of function illustration, radiometric temperatures at any point of canopy can be revealed by the cursor, and the minimum, mean, and maximum

temperatures of canopy can be calculated and displayed when an area was selected. After moved into the growth chamber of 10 °C from ambient temperature of ca. 28 °C, the mean canopy temperature decreased rapidly to 14.8 °C at 1 min and further down to near 10 °C in less than 10 min (Figs. 1A and 2). For 45 °C treatment, the mean canopy temperature increased drastically to 33.8 °C at 1 min and moved up to 42.0 °C no later than 6 min (Figs. 1B and 2).

Changes of canopy temperatures in 6 hr after moved from outdoors to growth chambers with temperature setpoints from 10 to 45 °C were graphed in Fig. 2. As indicated short-term temperature impacts for rice plants resulted in varied response rates of acclimation prior to equilibrating to chamber temperatures. Before the equilibrium, canopy temperature was greater than chamber temperature when placed under suboptimum temperatures (25 °C and below), but was lower than the surroundings under superoptimum temperatures (30 °C and above). Generally canopy temperatures reached the 'steady-state' with chamber temperatures within 10 min after treatments (Figs. 2 and 4). The performance maintained at least up to 72 hr, as illustrated in Fig. 3 at 10 and 45 °C treatments.

It further shows that time period required for canopy temperature to reach a state of equilibrium with environment depends on the extent of temperature difference (impact). In the range of 20 to 40 °C, it took less than 3 min to equilibrate to the surrounding temperatures (Fig. 4). The time period increased for treatments below or above this range. The mean canopy temperature was maintained in the same amplitude as chamber temperature below 40 °C, and kept 3 °C lower at 45 °C up to 72 hr after treatment (Fig. 4). Results suggest that rice is able to uphold its canopy temperature within 10-45 °C range of short-term temperature impacts through heat- dissipating function if soil moisture is not limited. In the report of Su and Yang (1998),

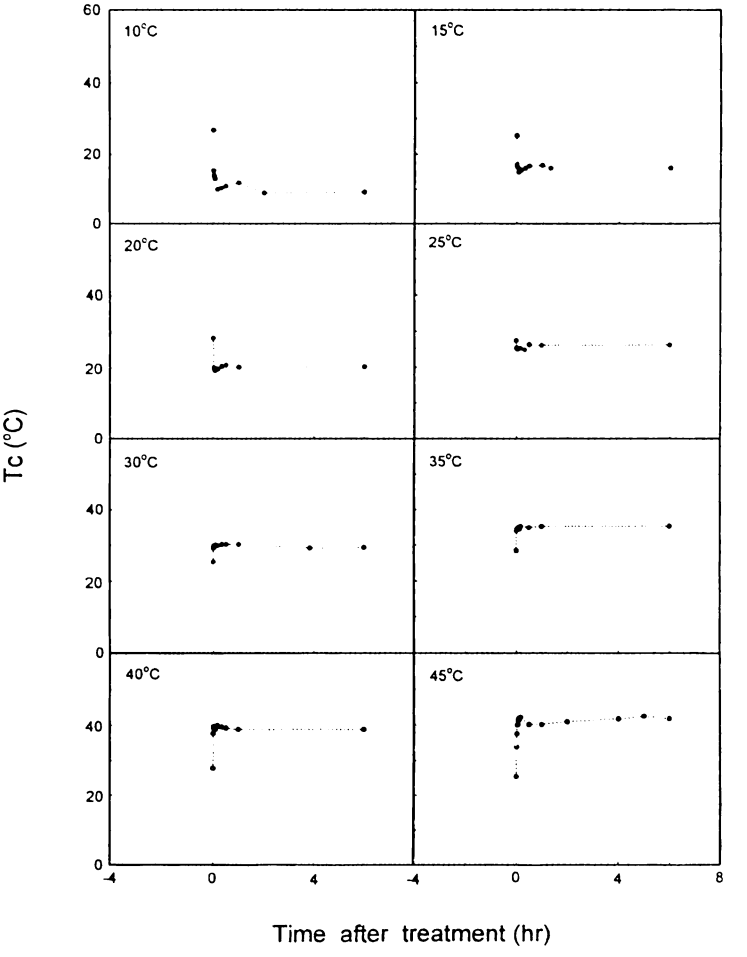


Fig. 2. Changes of canopy temperatures (Tc) of rice (*Oryza sativa* L. cv. Tainung 67) plants in 6 hr after moved from outdoors to growth chambers with temperature setpoints from 10 to 45 °C.

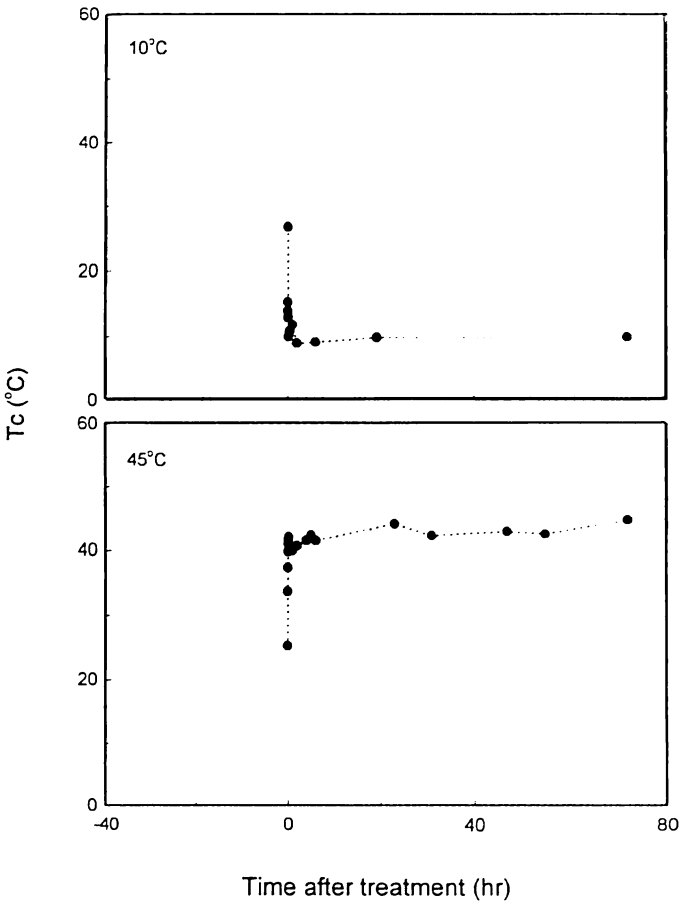


Fig. 3. Changes of canopy temperatures (Tc) of rice (*Oryza sativa* L. cv. Tainung 67) plants in 72 hr after moved from outdoors to growth chambers at 10 (upper) and 45 °C (lower).

results implied that rice is capable of adjusting transpiration rate to ameliorate temperature fluctuation in the surroundings for maintaining normal physiological functions.

In the well-water field, Su and Yang (1998) and Yang (1999) found that canopy temperatures of rice crop were lower than the ambient air temperature throughout the growing seasons. Idso *et al.* (1981) explained that this relationship is governed by vapor pressure deficit (VPD) of the surroundings, over a large range of vapor pressure, net radiation, and wind speed. Under water stress, however, the relationships changed for a given VPD (Kanemasu *et al.*, 1985).

The experimental results prove the effectiveness and availability of thermal infrared imaging radiometer as an efficient tool for measuring canopy temperatures as literature cited (Sachs *et al.*, 1975; Tanner, 1963; Walker and Hatfield, 1983). The instrument is sensitive to thermal electromagnetic radiation (8-12 μ m) and reacts promptly to temperature changes of targets. Thermal infrared image of a plant canopy provides adequate information for analyses of temperature variation and distribution within window area, and temporal change of canopy temperature can be monitored through a series of image measurements. Results show that radiant canopy temperature of rice plant responds rapidly to temperature fluctuation of growth habitat, and the sensitivity depends on the magnitude of temperature alteration. This ability of temperature adjustment enables rice plants tolerating to less favorable conditions which is often the case in the real natural world.

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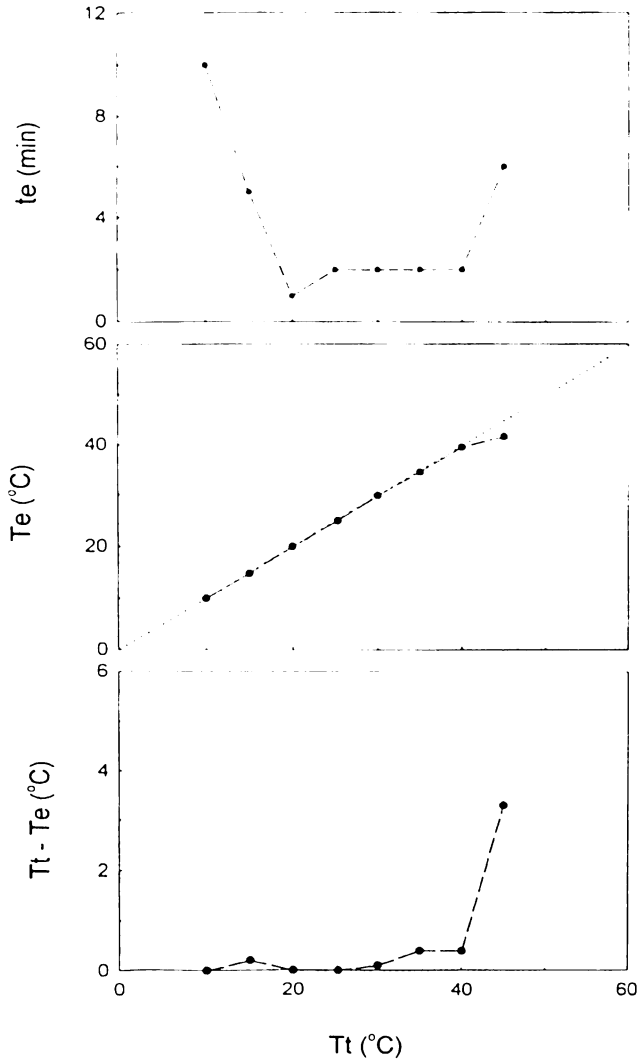


Fig. 4. Time period required to equilibrium (te), equilibrium temperature (Te), and the difference between treatment temperature and equilibrium temperature (Tt-Te) for rice (*Oryza sativa* L. cv. Tainung 67) plants under various short-term temperature impacts.

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