Response of Rice (*Oryza Sativa* L.) to Short-term High Temperature: Growth, Development, and Yield[1]

Chwen-Ming Yang[2] and James L. Heilman[3]

Abstract : Effects of short-term high temperature occurring in the vegetative and the grain-filling stages on growth, development, and yield of rice (*Oryza sativa* L. cv. Lemont) were studied in the controlled environment. The results showed that an 8-d 35°C treatment at the vegetative stage changed the growing patterns of plant height, total leaf and tiller numbers, and leaf area relative to a 25 °C treatment. Plant elongation was reduced for 50 days after treatment. Leaf and tiller production were also restrained, though the tillering rates for the 35 °C - treat ed plants eventually caught up to those for the 25°C-treated ones in about 70 days after treatment. Leaf area expansion was restricted by high temperature ; growth of primary leaves 8 to 13 was inhibited. Both leaf length and leaf width were affected. Plant development, in terms of leaf stage, was little affected by temperature treatments in the vegetative stage. Data showed no differences between treatments in the measured yield characteristics. High temperature had little effect on plant height after heading in the grain-filling stage while leaf growth and tillering were stimulated. The panicle numbers per plant increased but spikelets per panicle, percent filled spikelets, and 1000 - grain weight decreased as a result of high temperature. The shoot/root weight ratio was elevated by heat stress in the vegetative stage but was decreased by heat stress in the grain-filling stage.

Key words : Rice, High temperature stress, Growth, Development, Yield, Vegetative stage, Grain-filling stage.

Introduction

Although genetic factors are clearly important, numerous reports in the literature have shown that environmental variables imposed a strong impact on growth, development, and yield of crops. Temperature, a prominent element in determining the natural distribution of plants, affects physical and chemical processes at subcellular, cellular and whole plant levels, depending on species and varieties, physiological status of plant, rate and duration of

1. Contribution No. 1650 from Taiwan Agricultural Research Institute.
2. Agronomist, Department of Agronomy, TARI, Wufeng, Taichung, Taiwan 413, ROC.
3. Associate professor, Department of Soil & Crop Sciences, Texas A&M University, College Station, Texas 77843, USA.

temperature changes (Yoshida, 1981), and preceding growth temperatures (Sawada and Miyachi, 1974; Berry and Björkman, 1980). Since temperature stress as other environmental variations is inevitably a common occurrence in nature, actural yield is therefore only a fraction of the maximal possible production in a given climate. Limited information, however, is available on plant responses to short-term environmental variations due to interactions and fluctuations of environmental fators in the field. It is the primary step to study and discern crop growth and yield response to the changes of the individual factor in order to determine the limiting element(s) in complex environmental conditions.

For rice plant (*Oryza sativa* L.), temperature plays a significant role in vegetative growth as well as in reproduction (McDonald, 1971; Oldeman *et al.*, 1986; Yang, 1990; Yoshida, 1980). Clorosis, reduced tillering, and reduced height occur in rice if extreme temperatures exist during the vegetative growth stage. Increased sterility and reduced spikelet numbers per unit ground area, and reduced percentage of filled grain and smaller grain size occur in the reproductive growth stage and the grain filling stage, respectively (Suzuki, 1983; Tanaka *et al.* 1966; Yoshida, 1981). However, it is not fully understood the impact of a short-term high temperature to the seasonal changes of plant growth and development. How rice regulate its biological functions, as shown in the apperance of the external characteristics and yield, and the period required for its recovery to such stress need also to be uncovered in rice plants. Especially, when strategy dealing with the better management system in regard to weather conditions to yield production is taken into consideration.

The experiments were conducted to study the effects of short-term high temperature occurring in the vegetative stage on the seasonal changes of growth and development of rice. Whether such short periods of high temperature occurring in the vegetative and the grain -filling stages affect yield were also investigated. Rice were grown in the controlled environments with temperature as the only variable.

Materials and Methods

Plants of rice cultivar Lemont were grown in opaque plastic containers (0.25 m diameter, 0.20 m height), three plants per pot with even space, filled with fritted clay (Van Bavel *et al.* 1978), and irrigated with nutrient solutions. Plants were irrigated in excess twice a day, early morning and late afternoon, to keep the soil saturated. To avoid salt accumulation, the pots were flushed with distilled water, every seven days during the vegetative growth phase and every three days during the reproductive growth phase. The pots were plugged in the center so that extra water drained from the soil after irrigation. The composition and the watering schedule of nutrient solutions were the same as described by Yang and Heilman (1990). Rice plants were grown as groups in a controlled-environment chamber (day/night temperatures 30°C/20°C; relative humidity 50—70%/90—100%) circulated with ambient air (CO_2 concentration 330—430 ppm). The daylength was 12 h (0800—2000) with a photosynthetic photon flux density (PPFD) of about 650 μmole m^{-2} s^{-1}. Wind speed was about 0.8 m s^{-1}. Pots were rotated periodically to ensure uniformity within the chamber.

When reaching the leaf 7 (L-7) stage or the grain-filling stage (i.e. R-1 stage), some plants were moved to an assimilation cabinet for 8-d temperature treatments (25°C or 35°C) and then returned back to the growth chamber and grown to maturity unless samplings. The leaf stage (plant age) was assessed by the emergence of the primary leaf on the main culm (Yoshida, 1981). For example, when the eighth primary leaf emerges from the main culm, the plant is said to be at the Leaf 7 stage. The Heading stage is from the first day to the seventh day from heading, the R-1 stage is from the eighth day to the fourteenth day from heading, and so on.

The assimilation cabinet was set for a photoperiod of 12 h (0800-1200) and a constant day/night temperature (25°C/25°C or 35°C/35°C) and absolute humidity. The average value of PPFD, provided by 'Ceramalux' lamps (Philips Corp., New Jersey, USA) at the top of the cabinet was about 1300 μmole m^{-2} s^{-1}. The average wind speed was about 1 m s^{-1}.

Changes of agronomic characteristics such as plant height, leaf and tiller numbers, and leaf area were chosen as indications of plant growth and recorded periodically as a function of temperature during and after treatments for each group of plants. The area of leaf was determined by an area meter (LI-3000, LI-COR, Inc., Nebraska, USA). Yield characteristics such as number of spikelets per panicle, number of panicles per plant, percent filled spikelets, and 1000-grain weight were measured at harvest. The shoot/root wieght ratio was also determined. Dry weights of shoot (leaf plus culm) and root were measured after oven -dried at 80°C for 72 h.

Each treatment was repeated four times and the mean values were taken from the averages of each group. Standard errors were also calculated.

Results

High temperature occurring in the vegetative (L-7) stage

Changes of plant height, leaf number, tiller number, and leaf area were chosen as indications of plant growth. It showed that the elongation of the plant was affected by the temperature treatments (Fig. 1). A period of 8-d 35°C temperature reduced the plant elongation for 50 days after treatment. High temperature also restrained leaf and tiller production (Fig. 1), though the tillering rates for the 35°C treatment eventually caught up to those for the 25°C treatment, about 70 days after treatment. Symptoms of white leaf tip and chlorosis were observed in the heat-treated plants (data not shown).

Leaf area expansion was also restricted by high temperature (Fig. 1). The result was further studied by analyzing the areas and the dimensions of the primary leaves on the main culm, as being representatives of the individual leaves on the plant as plant aged. Growth of primary leaves eight to thirteen was restricted by high temperature (Fig. 2). Both leaf length and leaf width were affected (Fig 2).

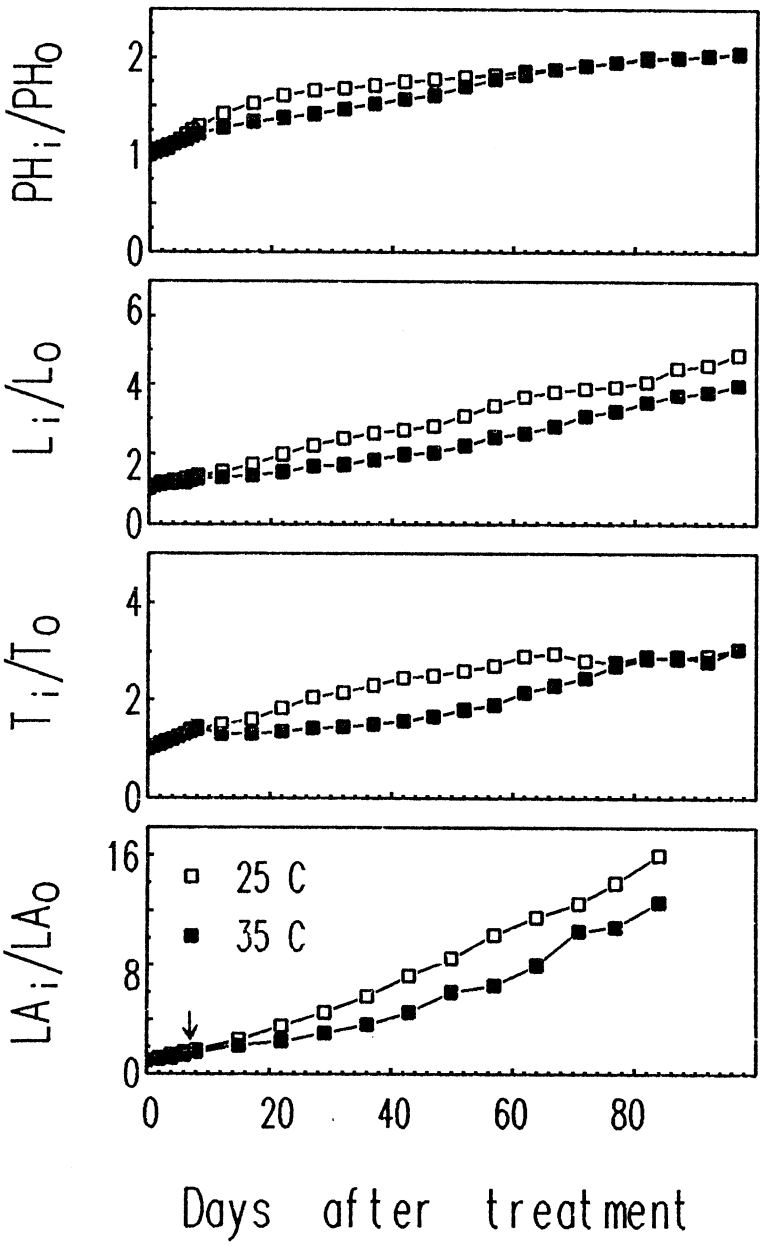


Fig. 1. The ratios of plant height$_i$/plant height$_0$, leaf number$_i$/leaf number$_0$, tiller number$_i$/tiller number$_0$, and leaf area$_i$/leaf area$_0$ after temperature treatments in the vegetative (L-7) stage. Plant height$_0$ was plant height measured at the first day (day 0) of temperature treatment and plant height$_i$ was that measured at the ith day after day 0, and so on. The arrow indicates the first day following the temperature treatments.

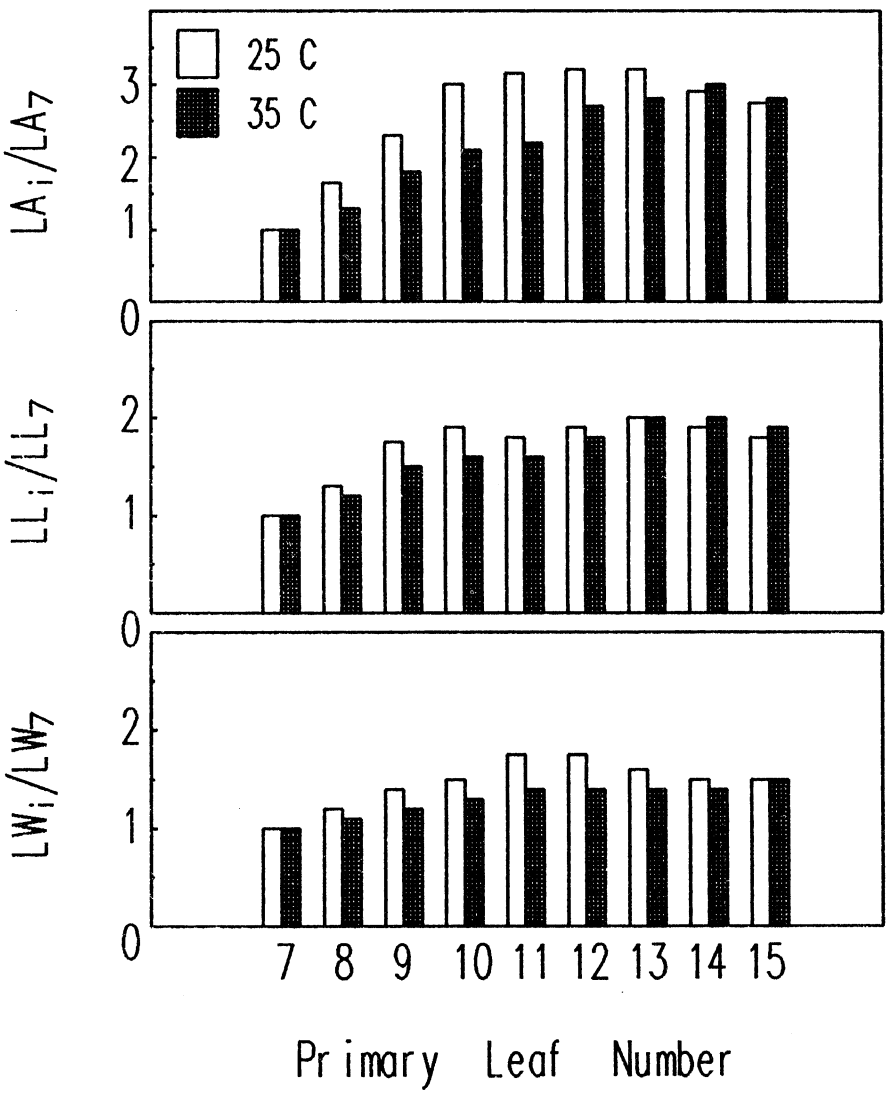


Fig. 2. Effects of high temperature occurred in the vegetetive (L-7) stage on the ratios of leaf area$_i$/leaf area$_7$, leaf length$_i$/leaf length$_7$, and leaf width$_i$/leaf width$_0$ of the primary leaves. Leaf area$_7$ was the leaf area of the 7th primary leaf on the main culm and leaf area$_i$ was the ith primary leaf area, and so on.

The time required for the emergence of each primary leaf after primary leaf number eight was observed. It was shown that plant development, in terms of leaf stage, was little affected by temperature treatments (Table 1).

Table 1. Days required for the emergence of the primary leaves on the main culm after 8-d temperature treatments in the vegetetive (L-7) stage.

Treatment	Time period (days)								
	Primary leaf number								
	9	10	11	12	13	14	15	16	Tatal
25°C	8	12	12	12	13	14	13	16	100
35°C	8	11	12	14	10	12	14	20	101

The yield characteristics between temperature treatments were compared in Table 2. Data showed no difference between treatments in the measured yield characteristics. The shoot/root weight ratio was higher in the 35°C-treated plants than in 25°C-treated ones (Table 3).

Table 2. The yield characteristics measured at harvest between temperature treatments.

Treatment	spikelets per panicle	panicles per plant	percent filled spikelets(%)	100-grain weight (g)
Vegetative (L-7) stage				
25°C	110.2± 9.8@	5.3±1.6	44.1± 5.1	26.2±1.2
35°C	111.6±10.6	5.5±1.4	46.8± 6.3	27.1±1.4
Grain-filling (R-1) stage				
25°C	126.0±11.4	5.6±1.2	60.6± 9.6	20.4±0.6
35°C	80.7±27.1	7.4±1.7	12.4±10.1	13.9±2.3

@Standard error.

High temperature occurring in the grain-filling (R-1) stage

High temperature had little effect on plant height after heading in the grain-filling stage, whereas leaf growth and tillering were stimulated (Fig. 3). Generally total leaf numbers per plant decreased during the process of senescence in the 25°C-treated plants while short-term 35°C caused the emergence of new leaves. Total tiller numbers per plant also increased as a result of high temperature treatment. Consequently, leaf area was maintained until harvest by a shot period of heat stress (Fig. 3).

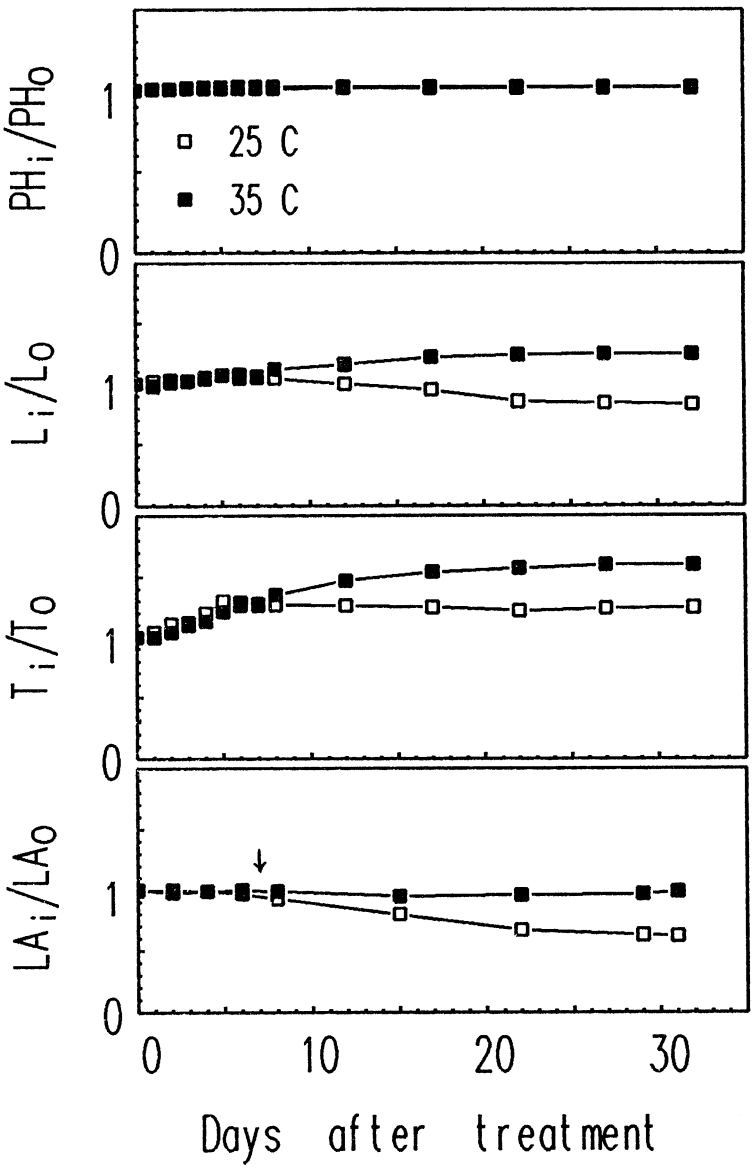


Fig. 3. The ratios of plant height$_i$/plant height$_0$, leaf number$_i$/leaf munber$_0$, tiller number$_i$/tiller number$_0$, and leaf area$_i$/leaf area$_0$ after temperature treatments in the grain-filling (R-1) stage. Plant height$_0$ was plant height measured at the first day (day 0) of temperature treatment and plant height$_i$ was that measured at the ith day after day 0, and so on. The arrow indicates the first day following the temperature treatments.

The effects of short-term high temperture occurring in the grain-filling stage on yield were shown in Table 2. The panicle numbers per plant increased while the other three measured parameters decreased by heat stress. Reductions of 36%, 48%, and 32% were found in spikelets per panicle, percent filled spilelets, and 1000-grain weight, respectively. The increased of panicles per plant was the result of high temperature stimulating heading so that more emerged panicles were counted at harvet.

In the grain-filling stage, high temperature decreased the shoot/root weight ratio (Table 3).

Table 3. The shoot/root weight ratios measured after temperature treatments.

Treatment	Shoot/root weight ratio
Vegetative (L-7) stage	
25°C	1.76±0.25@
35°C	2.03±0.46
Grain-filling (R-1) stage	
25°C	2.00±0.23
35°C	1.85±0.21

@Standard error.

Discussion

Leaves and tillers on a plant are physiologically different in age and activity at a given time. Temperature affects the biological functions that lead to the growth and development of a plant. Lemont, a temperate region rice cultivar (Bollich *et al.*, 1973, 1984 and 1985), is no exception. An 8-d 35°C occurring in the vegetative stage affected the rates of plant elongation, leaf emergence and tillering. The time period required for the emergence of individual leaves and tillers may also be changed. These results, with the additions of the observed symptoms of white leaf tip and chlorosis, were similar to the report published by IRRI (1975). Sutcliffe (1977) pointed out the causes of heat injury in three aspects, i.e., effects on desiccation, metabolism, and protein denaturation.

The results further showed that leaf area expansion rate was influenced by temperature. The reduced leaf area per plant by high temperature treatment was cuased by lower leaf and tiller growth rates and smaller leaf dimensions as a result of alteration of growing processes. Both leaf length and leaf width of individual leaves were affected by temperature. A higher senescence rate was also observed in the heat-stressed plants.

Short-term high temperature occurred in the vegetative growth phase did not affect yield characteristics. Although irregular patterns of growth and development were expressed, rice plants can recover it if no additional heat stress was imposed. The effects of temperature on growth and development of rice under natural conditions can be expected to be much more complicated because of diurnal and seasonal fluctuations of temperature and other climatic variables (Sutcliffe, 1977).

In contrast to the above results, a 35°C temperature treatment in the grain-filling stage stimulated the emergences of leaf and tiller and resulted in maintenance of leaf area until harvest. More tillers and leaves appeared than senesced in the plants that were heat stressed. Although higher temperature produced more photosynthetic tissues throughout the grain-filling stage, the yield was not enhanced. On the contrary, a decrease of 36, 48, and 32% were recorded in spikelets per panicle, percent filled spikelets, and 1000-grain weight, respectively. Such decreases of yield characateristics negated the increase of panicles and strongly reduced yield. It implied that some metabolic processes may be impaired and modified by heat stress and caused the reduction of yield.

The shoot/root weight ratios measured at the end of 8-d temperature treatments showed that stressed-plants (35°C) produced fewer roots than those of non-stressed plants (25°C) in the vegetataive stage. The growth of roots and their functions, therefore, may be affected by heat stress. The water absorption ability and the physiological activity in roots may be impaired and hence affected plant growth and development. High temperature did not restricted root production in the grain-filling stage and root growth and normal root functions may therefore not be suppressed.

Many reports indicated that high temperatures caused injury to rice in the reproductive phase (IRRI, 1975; Suzuki, 1983; Tanaka *et al.*, 1966; Yoshida, 1981). This study further demonstrated that the reduced yield may be caused by lower total spikelet numbers, high percentage of sterility, and reduced grain weight. It may also decrease the grain filling rate due to the impaired biological functions (Suucliffe, 1977). Suzuki (1983) and Tsuno and (1988) also showed that the final grain weight was strongly dependent on the growing conditions at the grain-filling stage. Further, the receving mechanism and enzyme activities of grain may be impaired by heat stress occurring in the grain-filling period (Inaba and Sato, 1976).

References

Berry, J. A. and O. Björkman. 1980. Photosynthetic response and adaptation to temperature in higher plants. Ann. Rev. Pl. Physiol. 31: 491-543.

Bollich, C. N., J. G. Atkins, J. E. Scott and B. D. Webb. 1973. Registration of Labelle rice. Crop Sci. 13: 773-774.

Bollich, C. N., B. D. Webb, M. A. Marchetti, J. E. Scott and J. W. Stansel. 1984. Lemont characteristics and performance. p. 2-10. *In* : The semidwarf-a new era in rice production. The Texas Agric. Exp. Stan., College Station, Texas, USA.

Bollich, C. N., B. D. Webb, M. A. Marchetti and J. E. Scott. 1985. Registration of Lemont rice. Crop Sci. 25: 883-885.

Inaba, K. and K. Sato. 1976. High temperature injury of ripening in plant. VI. Enzyme activities of kernel as influenced by high temperature. Proc. Crop Sci. Japan 45: 162-167.

IRRI (International Rice Research Institute). 1975. Annual report for 1974. p. 246. Los Banos,

Philippines.

Jiang, C.-Z., T. Hirasawa and K. Ishihara. 1988. Physiological and ecological characteristics of high yielding varieties in rice plants. II. Leaf photosynthetic rates. Japan J. Crop Sci. 57: 139-145.

McDonald, D. J. 1971. The effect of temperature and light on the rate of photosynthesis of 20 rice varieties and hybrids. Ph.D. Dissertation. Texas A&M University, Texas, USA.

Oldeman, L. R., D. V. Seshu and F. B. Caby. 1986. Response of rice to weather variables. IRRI, Manila, Philippines.

Sawada, S. and S. Miyachi. 1974. Effect of growth temperature on photosynthetic carbon metabolism in green plants. I. Photosynthetic activities of various plants acclimatized to various temperatures. Plant & Cell Physiol. 15: 111-120.

Sutcliffe, J. 1977. Plant and temperature. p. 1-57. Edward Arnold, London.

Suzuki, M. 1983. Growth characteristics and dry matter production of rice plants in the warm region of Japan. JARQ. 17: 98-105.

Tanaka, A., K. Kawano and J. Yamaguchi. 1966. Photosynthesis, respiration, and plant type of the tropical rice plant. IRRI, Tech. Bill. No. 7. Los Banos, Philippines.

Tsuno, Y. and Y. L. Wang. 1988. Factors affecting the ripening process of different rice cultivars. Japan. J. Crop Sci. 57: 119-131.

Van Bavel, C. H. M., R. Lascano and D. R. Wilson. 1978. Water relations of fritted clay. Soil Sci. Soc. Amer. J. 42: 657-659.

Yang, C.-M. and J. L. Heilman. 1990. Study of leaf area as functions of age and temperature in rice (*Oryza sativa* L.). J. Agric. Res. China 39: 259-268.

Yoshida, S. 1981. Fundamentals of rice crop science. p. 1-110. IRRI, Los Banos, Philippines.

短期高溫對水稻（*Oryza sativa* L.）生長、發育、與產量之影響[1]

楊純明[2]　James L. Heilman[3]

摘要：本項試驗係以半矮性水稻品種 Lemont 爲材料，在控制環境下探討營養生長時期（L-7期）及穀粒充實時期（R-1 期）短期高溫對水稻生長、發育、與產量之影響。根據試驗結果，在營養生長期間施以35°C 八天處理，株高、葉片數、分蘗數及葉面積之生長模式將發生改變。株高伸長降低（長達50天），葉片與分蘗產生減緩，惟分蘗數可於處理後70天增至與25°C處理株相當。葉面積增加亦受到高溫阻滯，包括葉長與葉寬均減少。但營養生長期短期高溫並不干擾稻株發育，也不影響收穫時產量構成要素。穀粒充實期間高溫發生雖不改變株高，葉片數與分蘗數則受到促進，每株（叢）穗數亦增加。然而，每穗粒數、穗粒充實率、與千粒重卻降低。短期高溫在營養生長時期促進（稈／根）重量比值，在穀粒充實時期則抑制之。

關鍵詞：水稻、短期高溫、生長、發育、產量、營養生長期、穀粒充實期。

---

1. 臺灣省農業試驗所　研究報告第 1650 號。
2. 本所農藝系副研究員。臺灣省　臺中縣　霧峰鄉。
3. 美國德州農工大學土壤暨作物系副教授。美國　德州　大學城。