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Differential Effects of Day and Night Temperature on Growth of Rice Crop

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Abstract

Climate change, the defining challenge of our generation, is no longer a distant threat, but an emerging reality. High temperature, an imminent product of global climate change, will affect agriculture through direct and indirect effects on crops. The daily minimum night time temperature increased at a faster rate than daily maximum temperature in the last century and differential increase in day and night temperature occurs in many parts of the world. Two rice cultivars, Pusa 44 and Pusa Sugandh 2, were subjected to various thermal treatments such as normal ambient temperature (T_0), high day and night temperature (T_1) (+2.7°C during day and night), high day temperature T2 (+3°C during daytime only) and high night temperature T3 (+2.4°C during night time only) from transplanting to maturity. The study revealed that high day and night temperature (T_1) followed by high night (T_3) and high day (T_2) temperature treatments drastically affected the crop growth, yield and quality.

Key words: Climate change, rice, high temperature, crop growth

Introduction

Agriculture plays a crucial role in the overall economic and social well-being of India. Rice and wheat crop production is a long established grain production system in India. This formed the foundation for Green Revolution and became the backbone of India's food, nutritional, livelihood and economic security (Prasad, 2005). On an average, rice accounts for 27 per cent of all cereal grains production worldwide, second only to wheat at 30 per cent. Rice-Wheat systems are of immense importance for food security in South Asia and China, providing 85% of the total cereal production and 60% of the total calorie intake in India (Timsina *et al.*, 2004). In India, rice and wheat crops contribute more than 75% of its food grain production (Department of Economic Affairs, 2008). The demand for food grain production is increasing significantly due to burgeoning population, urbanization and income growth. Such high production levels need to be achieved in an environment of changing global climate and changes in production practices driven by socio-economic development (Reddy and Hodges, 2000).

The imminent products of climate change can have tremendous impact on agricultural production and hence, food security of any region. The rising temperatures and carbon dioxide and uncertainties in rainfall associated with global warming may or may not have serious direct and indirect consequences on crop production (Aggarwal, 2003). Climate influences plant life in many ways and can inhibit, stimulate, alter or modify crop performance. Its components (temperature, solar radiation, rainfall, relative humidity and wind velocity) independently or in combination, can influence crop growth and productivity (Watson et al. 1996). Crop response to a change in temperature depends on the temperature optima of photosynthesis, growth and yield, all of which may differ (Conroy et al., 1994). Lobell et al. (2005) reported that in case of wheat, there exists a significant negative yield response to higher night time temperatures (roughly 10% reduction of yield for T min = 1°C) with a much smaller and statistically insignificant

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effect of day temperature and solar radiation. Heat stress negatively affected grain yield and its components (Tahir and Nakata, 2005). Weather and climate affect the plant growth and development, and the fluctuations and occurrences of climatic extremes particularly at critical crop growth stages may reduce yield significantly (Peng et al., 1996). Transitory or constantly high temperatures cause an array of morpho--anatomical, physiological and biochemical changes in plants, which affect plant growth and development and may lead to a drastic reduction in economic yield (Wahid et al., 2007). High temperature had a negative effect on the photosynthetic processes. There is clear evidence that thylakoid membranes can affect plant tolerance to high temperature and this can affect overall plant tolerance.

Although effects of projected climate change on crop yields have been evaluated by us, crop-simulation models, there are few studies on the effects of observed climate change on crop growth and yield (Peng et al., 2004).The challenge is to understand crop responses to the differential increase in day versus night temperature on growth, yield and quality of rice so that crop management systems can be devised for high and sustainable yield in the era of global climate change. Having described the detrimental impact of climate change and asymmetric change in temperature and keeping all the above challenges in view, a study was undertaken on differential effects of increase in night versus day temperatures on the growth of rice.

Materials and Methods

Cultural Conditions

The rice nursery was raised with two rice varieties (Pusa 44 and Pusa Sugandh 2) during the third week of June 2006 in the glass house premise of the Division of Environmental Sciences, IARI, New Delhi. After thirty days of sowing, seedlings of each variety were transplanted with a spacing of 18 cm x 10 cm at the rate of four seedlings per hill in the plastic container of 50 cm x 30 cm size containing puddled soil and pre-fertilized with full dose of phosphorus and potassium and one-third of full nitrogen dose. Each plastic container can hold about 45 kg of soil so as to avoid water stress. Each container was provided with a drainage outlet to maintain the water level as per the requirement of the growth stages. Each variety was grown in 24 containers comprising four treatments with six containers each. Following the establishment of transplanted seedlings (15 days after transplanting), the plants were subjected to high day and night temperature treatments using the portable transparent polythene chamber.

Treatment of Rice Plants

The various high temperature treatments are as follows: T_0 - (Control) Plants were grown at normal ambient temperature throughout the growing season; T_1 - (HDNT) Plants were grown at high day and night temperature conditions; T_2- (HDT) Plants were grown at high day temperature condition; T3- (HNT) Plants were grown at high night temperature condition.

The rice plants of the above mentioned cultivars were subjected to high temperature during daytime, night time and throughout day and night as per the requirements of thermal treatment mentioned above. The plants were covered with portable transparent polythene chamber of above mentioned dimensions during day, night and throughout day and night so as to provide specific growth conditions. The plants at normal ambient temperature throughout the growing season were taken as control (T_0). The plants at T_0 were not covered with portable transparent polythene chamber. The cultural practices like weeding, irrigation, fertilizer scheduling and crop pest control were practiced uniformly irrespective of the treatments. The polythene sheets of the portable transparent polythene chamber were washed frequently with water to allow the maximum light intensity to pass through the polythene sheets. The observations on growth parameters were taken at flowering and maturity stages.

Results and Discussion

Plant height is generally controlled genetically but it is also influenced to some extent by environment. Irrespective of the variety, plant height was found more in plants subjected to different higher day and night thermal conditions

Table 1. Effect of differential increase in night versus day temperature on growth of rice varieties at flowering stage

Variety	Plant height em)	Dry weight (g)			Leaf			Leaf area (CI11²)		Specific leaf area (em'/g)	Specific leaf weight (mgl em')	Days to flowering
		Stem	Leaf	Total	Length	Width	LLlLW	Per shoot	Per hill			
						Pusa Sugandh 2						
T0	90.6	145.7	100.7	246.3	400	1.6	24.9	225.8	2285.4	211.3	4.8	94
T1	99.0	108.0	85.0	193.0	44.5	1.4	31.7	243.1	2970.2	370.4	2.9	89
	(9.19)	(-25.9)	(-15.6)	(-21.7)	(11.3)	(-12.0)	(27.3)	(7.6)	(30.0)	(75.3)	(-39.6)	(-5.3)
T2	95.0	130.0	93.0	223.0	41.8	1.54	27.1	231.2	2754.8	329.0	3.1	90
	(4.37)	(-10.8)	(-7.6)	(-9.5)	(4.5)	(-3.5)	(8.8)	(2.4)	(20.5)	(55.7)	(-36.0)	(-3.5)
T3	96.4	122.0	92.0	214.0	43.8	1.49	29.4	233.2	2600.0	282.1	3.6	91
	(6.07)	(-16.2)	(-8.6)	(-13.1)	(9.4)	(-6.5)	(18.07)	(3.3)	(13.8)	(33.5)	(-25.4)	(-2.8)
						Pusa 44						
TO	76.6	122.0	76.0	198.0	39.9	1.3	29.8	161.0	2056.1	271.0	3.7	101
Tl	82.3	105.0	66.0	171.0	43.0	1.24	34.6	168.8	2409.4	415.2	2.4	95
	(7.39)	(-13.9)	(-13.2)	(-13.6)	(7.8)	(-7.0)	(16.2)	(4.9)	(17.2)	(53.2)	(-35.7)	(-5.9)
T2	79.0	110.3	71.7	182.0	40.5	1.27	31.8	164.9	2205.6	315.1	3.2	98
	(3.1)	(-9.6)	(-5.7)	(-8.1)	(1.5)	(-5.2)	(6.7)	(2.5)	(7.3)	(16.3)	(-15.2)	(-2.3)
T3	80.1	109.0	69.3	178.3	41.2	1.26	32.6	163.2	2263.9	332.7	3.0	99
	(4.56)	(-10.7)	(-8.8)	(-9.9)	(3.3)	(-6.0)	(9.3)	(1.4)	(10.1)	(22.8)	(-19.7)	(-1.65)
						LSD at 5%						
V	3.35	4.87	3.52	6.24	1.37	0.1	1.76	10.1	348.9	NS	0.4	2.48
T	4.75	6.89	4.99	8.83	1.93	NS	2.49	NS	NS	58.0	0.6	3.51
VXT	NS	9.74	NS	12.49	NS	NS	NS	NS	NS	NS	NS	NS

Value in the parentheses indicate percentage deviation from control (TO)

TO - (Control) Normal ambient temperature
T2 - High temperature only during daytime
Tl - High temperature throughout day and night
T3 - High temperature only during nighttime

(Table 1). High day and night temperature would have enhanced plant growth and internodes elongation of stem by way of increasing the cell elongation in the internodal region in conformity with the study already reported (Singh, 2000). However, high day temperature and high night temperature treatments are not statistically different as for as the plant height is concerned and the height increase in these treatments is not appreciable. The early maturing variety Pusa Sugandh 2 was found to be more sensitive to high temperature than Pusa 44 reflecting the point that basmati varieties are sensitive to growth temperature. Also, the magnitude of increase in plant height was more in Pusa Sugandh 2.

Higher tiller production by plants grown under normal ambient condition enable the plants to make maximum use of the available space and helps in increasing biomass production. On the contrary, the higher day and night temperature treatment greatly reduced the tiller production and their development (Table 2). The reduced number of tillers was due to increased mortality of tillers occurring due to shorter growth crop duration and greater respiratory loss which reduces biomass production under high temperature stress environment. The later emerging tillers will die in order to support the growth of remaining tillers in heat stressed plants. The maximum tiller mortality occurred in high day and night temperature (T_1) condition because of limiting biomass and increase

Table 2. Effect of differential increase in night versus day temperature on growth of rice varieties at maturity stage

Variety	No. of tillers/hill	Productive tiller *(‘Yo)*	Dry weight (g)				DMI’ (%1)		Photosynthetic contribution (%)		Days to maturity
			Stem	Leaf	Panicle	Total	Pre-anthesis	Post anthesis	Current	Reserve	
					Pusa Sugandh 2						
T0	19.6	98.6	125.0	85.0	167.0	377.0	65.5	34.5	66.0	34.1	132.0
TI	17.5	94.0	96.0	67.0	108.0	271.0	71.3	28.7	58.7	41.4	127.7
	(-10.7)	(-4.6)	(-23.2)	(-21.2)	(-35.3)	(-28.1)	(8.9)	(-16.8)	(-11.1)	(21.4)	(-3.3)
T2	18.5	97.0	115.0	78.0	138.0	331.0	67.5	32.5	64.7	35.3	130.0
	(-56)	(-1.6)	(-8.0)	(-82)	(-17.4)	(-12.2)	(3.0)	(-5.7)	(-1.9)	(3.6)	(-1.5)
T3	18.0	96.5	110.0	730	128.0	311.0	68.8	31.2	62.8	37.2	130.3
	(-8.2)	(-2.1)	(-12.0)	(-14.1)	(-23.4)	(-17.5)	(5.1)	(-9.6)	(-4.8)	(9.2)	(-1.3)
					Pusa 44						
TO	18.6	97.3	93.0	620	134.0	289.0	68.7	31.3	54.0	46.0	138.0
TI	16.6	90.0	77.0	52.0	101.0	230.0	74.4	25.6	38.4	61.6	129.7
	(-10.8)	(-7.5)	(-17.2)	(-16.1)	(-24.6)	(-20.4)	(8.3)	(-18.2)	(-28.9)	(34.0)	(-6.0)
T2	17.2	95.0	86.0	59.0	112.0	257.0	70.9	29.1	47.2	52.8	132.3
	(-7.5)	(-2.4)	(-7.5)	(-4.8)	(-16.4)	(-11.1)	(3.2)	(-7.1)	(-12.6)	(14.8)	(-4.1)
T3	17.1	94.0	80.0	55.0	108.0	243.0	73.5	26.5	41.8	58.2	130.3
	(-8.2)	(-3.4)	(-14.0)	(-11.3)	(-19.4)	(-15.9)	(7.1)	(-15.5)	(-22.6)	(26.6)	(-5.6)
					LSD at 5%						
v	1.02	1.2	4.54	3.44	6.66	12.9	2.29	2.29	4.36	4.36	2.34
T	1.44	1.7	6.43	4.87	9.42	18.25	3.23	3.23	6.17	6.17	3.31
VXT	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Value in the parentheses indicate percentage deviation from control (TO)

TO - (Control) Normal ambient temperature

Tl - High temperature throughout day and night

T2 - High temperature only during daytime

T3 - High temperature only during nighttime

if both photorespiration and dark respiration. The detrimental effect of thermal treatments on tiller production was more in Pusa Sugandh 2 because of its early maturing character and reduced crop duration as evident from the Table 2 and therefore the variety is more thermal sensitive than Pusa 44. Similarly, the lower productive tiller percentage in heat stressed plants is more because of reduced biomass production and inability of heat stressed plants to maintain favorable balance between photosynthesis and respiration.

The increase in leaf length of high temperature treated plants resulted in greater leaf area per shoot and leaf area per hill (Table 1). However, the leaf width decrease under higher day and night temperature treatments was statistically significant and hence not influenced the leaf area of differential temperature treated plants. In view of the fact that the leaf length increased under different high day and night temperature, the leaf length/width ratio consequently increased in the plants under thermal stress (Table 1). Increasing the size of leaves causes increase in total leaf area per shoot and per plant. This is in congruence with the observation made by Sharma and Singh (1999), who stated that increase in total leaf area per plant was caused mainly by increasing the size of the successive leaves. Increased leaf area per plant would have increased the accumulated contribution to grain yield (Ishii, 1993) but higher day and night temperature accelerated the photorespiration and resulted in less favorable balance between photosynthesis and respiration, causing reduction in grain yield.

Murata and Matsushima (1975) reported that the significance of the leaf photosynthetic rate in determining the drymatter production decreases as the leaf area increases. With an increase in leaf area, photosynthetic rate decreases due to increased mutual shading, but respiration increases. However, the increase in the leaf area did not increase the leaf dry weight because the high day and night temperature condition increased the dark and photorespiration and metabolically drained the photosynthates. Similar reasons were responsible for decreased stem dry weight in high temperature treated plants. In fact, the increased plant height caused more respiration to occur and reduced the dry stem weight of the plants. In view of these facts, the high day and night temperature treatment (T_1) registered maximum reduction in biomass production (18.1 %) followed by T_3 (11.7%) and T_2 (6.8%) as given in Table 2. Similarly the biomass production at maturity decreased under high temperature condition due to high respiratory demand and high degree of tiller mortality (Table 2). The panicle dry weight declined drastically in all plants subjected to high temperature treatments. This may be due to the insufficient grain filling and spikelet sterility in high temperature stressed plants. This is in agreement with Zakaria (2002). The reductions in current photosynthetic contributi6n (Table 2) also reduced the panicle weight.

At flowering stage, as given in theTable 2, the plants grown under differential high day and night temperature showed greater specific leaf area than the plants grown under T_0. This may be again due to increased leaf area under high temperature as reported by Singh (2000). The specific leaf area increased due to decreased leaf thickness, resulted because of high day and night temperature conditions. The decrease in leaf thickness caused the specific leaf weight to decrease under high temperature conditions. In order to have high degree of cooling through transpiration and reduce the canopy temperature under high temperature treatment condition, the leaf expansion was more in heat stressed plants. Therefore, increase in leaf expansion has resulted in increased specific leaf area and decreased specific leaf weight (Table 1).

The plants grown under higher day and night temperature treatment recorded lesser post-anthesis dry matter production than the plants grown under normal ambient temperature condition (T_0) (Table 2). The decrease in post-anthesis biomass production is due to the reduction in days to maturity and inability of the plants to increase the rate of biomass production because of photosynthesis-respiration imbalance. So, the reduction in days to maturity cannot be fully compensated by increase in rate of biomass production. Since, the pre-anthesis biomass production is the difference between the total biomass and current biomass, the pre-anthesis production showed increasing trend under different high day and night temperature treatment conditions. The results indicate that in heat stressed plants, the pre-anthesis biomass production was higher in order to compensate for reduction in post-anthesis biomass production.

Due to the decrease in days to maturity and hence crop growth duration, the plants grown under high day and night temperatures showed significant reduction in current photosynthetic contribution to grain yield as compared to the plants grown under normal ambient condition (Table 2). The decrease in crop duration also hastens the leaf senescence process and reduces the photosynthetic activity in heat stressed plants. This also reduces the current photosynthetic contribution to grain yield. This is because the area of leaf surface that intercepts solar radiation is the most important factor and the photosynthetic efficiency of leaf per unit area is of secondary importance (Yoshida, 1972). Grain carbohydrates of rice are mostly derived from photosynthesis after heading. So, the temperature stressed plants produced low grain yield due to reduction in photosynthesis after heading. The difference between total photosynthetic contribution and current photosynthetic contribution is reserve photosynthetic contribution to grain yield. Therefore, the plants grown under high day and night temperatures showed significant increase in reserve photosynthetic contribution to grain yield. The reserve photosynthates serve as a buffer to support grain growth under the period of high day and night temperature stress.

The plants grown under high day and night temperatures showed reduction in the days to flowering and days to maturity (Tables 1 and 2). It is well known that the rate of growth and metabolism increase with increase in temperature. This reduces the number of growing days of the plant (Morita et al., 2005). The shortened duration for panicle growth is often accompanied by decreased grain yield (Yoshida, 1972). In the present study, the duration of grain growth was reduced by high temperature both day and night. Bahlouli and Bouzerzour (2006) reported that the speed of filling of the grains is negatively related to the duration of grain filling. However, Morita et al. (2005) reported that the rate of grain growth was lower in HNT than in HDT. The average cell area in endosperm was smaller in HNT than in either control or HDT. So, the decrease in grain filling duration and no concomitant increase in rate of grain growth under high night temperature resulted in reduced grain yield in the present study. High night temperatures are more harmful to grain weight in rice than high day temperatures. To conclude, high day and night temperature (T_1) followed by high night (T_3) and high day (T_2) temperature treatment drastically affected the rice crop growth.

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