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Research Article

Adaptation to Climate Change: Growth and Development of Rice Varieties Under Ambient and Elevated Temperature Regimes

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Abstract

Open top chamber system was designed for undertaking research into rice crop response to increased temperature during rainy season at Regional Agricultural Research Station (RARS), Khajura, Banke in 2018. With the objective of determining the efficacy of the chamber system and to generate possible differences in climate which could alter plant response between ambient and chamber system, 5 different rice varieties (Radha-4, Sukhkhadhan-3, Sukhkhadhan-2, IR83383-G-B-141-1 and IR87751-20-4-4-2) with three temperature conditions were used: ambient condition, open top chamber with 1.2m height enclosed from base with plastic sheet and open top chamber with 1.5m height enclosed from base with plastic sheet. With 3.1°c higher temperature Sukhkhadhan-2 significantly (p value= 0.0199) produced higher grain yield 4.33 t/ha under chamber condition in contrast to open field (2.93 t/ha) as well as significantly (p value = 0.0175) higher biomass yield 13.62 t/ha under elevated temperature. Also, Sukhkhadhan-2 significantly (p value = 0.0012) attained maximum height (86.99 cm) under chamber condition compared to open field (73.06 cm) during harvest. Statistical analysis showed no significant difference for number of tillers per hill during maturity stage. Significantly sukhkhadhan-3 (p value = 0.02994) showed longer panicle length 25.7cm under chamber than normal field condition (23.74 cm). In addition, Radha-4 significantly (p value = 0.03823) produced more filled grains per panicle (169) under chamber conditions than ambient condition (112). The consideration of crop variety is a good adoption measure to minimize incidence of elevated temperature in farming system.

Keywords: Open Top Chamber; Rice; Climate Change; Temperature; Banke

Introduction

Rice farming is responsible for 31 million tons of methane emission annually [1] and the production of nitrous oxide ranges from 0.01 to 1.0% of the nitrogen fertilizer applied [2]. Upland rice neither produces nor emits CH_4 because it is never flooded for a significant period [1]. According to Poudel and Kotani [3] rice crop is more vulnerable to climatic events in comparison to wheat resulting in reduced rice yield in the tropics, while rice yield may be benefitted in the temperate region. Rice and other crops which were mainly produced in the tropics can now be grown in high altitude [4]. Nepal experiences adverse impact of climate change every year despite its negligible contribution to greenhouse gas emission [5] which could lead to the extinction of aromatic crop varieties like Basmati rice [6]. In Nepal, 80% of the annual precipitation occurs between June and September under the influence of summer monsoon [7]. The mean precipitation in Nepal is increasing annually by 13 mm, while the number of rainy day is decreasing by 0.8 days annually [8]. In order to improve the resilience of farmers to climate change, disasters, price volatility and other shocks, Agriculture Development Strategy (ADS) of Nepal has made provision for conducting research on stress tolerant crop varieties for the development of climate resilient agriculture that are at the same time higher in yield [9].

Open top chamber (OTC) consists of an open top with metal constructions enclosed by plastic (polyvinyl chloride) sheet [10] which helps in the regulation of temperature. Chamber having frustum top with closed side wall creates artificial microclimate,

which increases temperature, alters humidity, radiation and precipitation, and prevents interaction of flora and fauna [11,12]. Closed chamber systems (CCS) are generally small and can significantly alter canopy microclimate compared with plants grown in field conditions [2]. Moya., *et al*. [13] states OTC study was conducted at the International Rice Research Institute (IRRI), Philippines to analyze the impact of climate change, specially carbon dioxide concentration and temperature on the productivity of irrigated rice ecosystem; and it is the first field-based environment control system designed in the tropical region. In an open field, rice yield was 780.6 ± 44.8 g/m^2 while those in ambient condition was 682.9 ± 37.7 g/m^2 which signifies yield in ambient condition was 12.5% higher than in chamber condition. Open top chamber usually have 1-3°c higher temperature than ambient field [14], however temperature may vary between locations. Shrestha., *et al*. [15] conducted open top chamber study with three types of closed chamber and four different rice varieties at RARS, Khajura in 2016. Chamber 1 (with 2.5°C higher temperature than field condition) resulted increase in rice yield by 10 to 22% than ambient condition under irrigation condition. As a result, drought tolerant rice variety Sukhkha-3 gave the highest yield. Similarly, OTC study conducted at Khumaltar in 2016 showed higher yield of rice variety Khumal-10 under chamber (with 7.7°C higher temperature than field condition) [16]**.** Banke is one of the hottest locations in Nepal, where the maximum and minimum temperature recorded are 48°C and 4.2°C. In an enquiry conducted by *Regmi., et al.* [17], 25.7% AMIS farmers reported flooding problem during monsoon season and 92.3% general famers stated drought as a risk factor in rice production. Since most of the research on crop response to environment has been done in temperate conditions Moya., *et al*. [13], this field-based environment control system was done to generate possible effects of future climate change on rice in the tropics. Study on the effect of temperature on rice crop is necessary to analyze its adaptability or vulnerability of new rice varieties [16]. This study was conducted within that conceptual framework.

Research methodology

Regional Agricultural Research Station is situated in Banke, a tropical district between 81°37" East longitudes and 28° 06" North latitude and at an altitude of 181 meters above mean sea level. Agriculture in the district is monsoon dependent with 21.9% of cultivable land facilitated by irrigation AMIS [18].

Open top chamber (OTC) study was conducted from July 31st to November 11, 2018. Three temperature regimes were used: i) ambient condition (as control); ii) OTC with 1.2 m height enclosed from base with plastic sheet; and iii) OTC with 1.5 m height enclosed from base with plastic sheet. Five rice varieties viz. Radha-4 (variety 1), Sukhkhadhan-3 (variety 2), Sukhkhadhan-2 (variety 3), IR83383-G-B-141-1 (variety 4) and IR87751-20-4-4-2 (variety 5) of 22 days old paddy rice plants were transplanted with crop geometry of 20x20cm on July 31, 2018. The size of each plot was 4m x 2m. Four rows of each variety were transplanted per plot. Chemical fertilizer (N: P: K) was applied @ 100:30:30 kg per hectare.

Daily maximum, minimum air temperature was recorded in the morning (8:45 am) and in the evening (5:45 pm) using mobile application Kobocollect, a tool for data collection which design forms quickly and easily and visualizes collected data on map [19]. Plant height was recorded periodically (with 21-day interval) using mobile application Kobocollect. During harvest, agronomic characteristics such as plant height, panicle length, number of tillers per hill, leaves, filled grains per panicle, filled grains weight per panicle, 1000 grain weight, biomass yield, grain yield, straw yield were determined from 20 pants per variety. Crop was harvested on November 11, 2018.

Statistical data analysis was conducted through R software. Results were statistically tested to compare significance of difference between ambient (control) and OTC conditions. For the numeric data t test was applied; and for the proportional data, chi squared test was applied. Level of significance was noted.

Results and Discussions

Diurnal temperature

The temperature inside the chamber was higher than ambient field by 3.1°c (Figure 1) which was on par with [14] who revealed chamber system typically have 1-3°c higher temperature than ambient condition. Allen Jr., *et al*. [20] reported that air temperature inside open top chamber range from 1-2°c above ambient condition. However, IRRI research project stated diurnal temperature up to 6°c above ambient condition [2].

Agronomical characteristics

Plant height

Temperature, along with photoperiod is the main driving force for crop development [21]. The optimum temperature required for the normal development of rice ranges from 27 to 32°c [22]. Plant height elongated until 63 days after transplanting, than slowly

stopped afterwards (Figure 2). High temperature (Figure 1) in OTC showed significant (p value = 0.07437) effect on plant height (Table 1) for Radha-4 and IR3383-B-B-141-1 (p value 0.01942) during 21 days after transplanting whereas high temperature had no significant effect on plant height (Table 1) during 42 days after transplanting. Radha-4 under ambient condition attained maximum height during 63 days after transplanting (Table 2). Chamber temperature (Figure 1) had a significant effect on plant height for Sukhkhadhan-2 during 84 and 103 days after transplanting (Table 2).

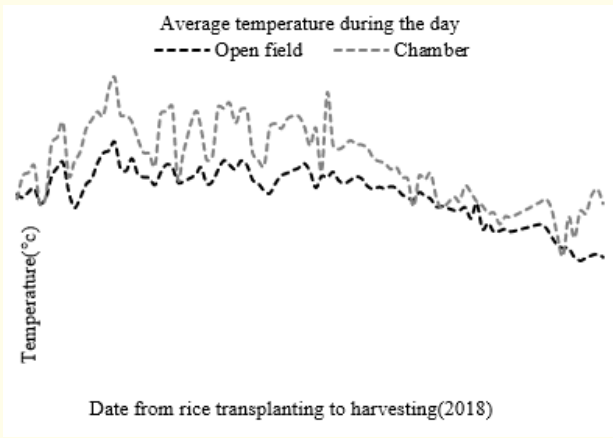

Figure 1: Average daily temperature in the field and chamber during rice growing season at RARS, Khajura in 2018.

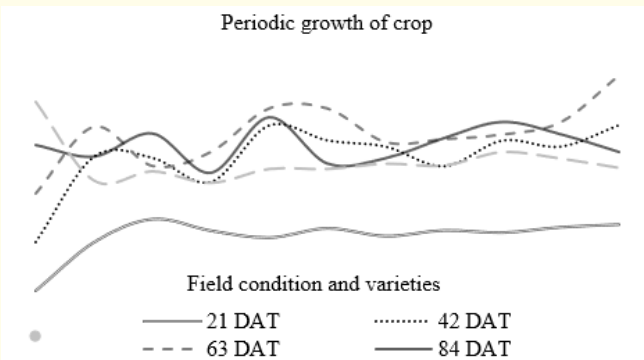

Figure 1: Plant height (cm) recorded periodically in an open field and chamber at RARS, Khajura (2018).

DAT	Varieties	Plant height(cm)		P-value
		Open	Chamber	
21	Radha-4	42.66	48.055	0.07437
	Sukhkhadhan-3	45.66	49.16	ns
	Sukhkhadhan-2	52.33	46.94	ns
	IR83383-G-B-141-1	40.33	49.96	0.01942
	IR87751-20-4-4-2	50.00	47.38	ns
42	Radha-4	75.33	81.44	ns
	Sukhkhadhan-3	74.16	79.11	ns
	Sukhkhadhan-2	79.33	85.72	ns
	IR83383-G-B-141-1	84.5	84.61	ns
	IR87751-20-4-4-2	84.16	86.05	ns

Table 1: Plant height (cm) during 21 and 42 days after rice transplanting at RARS, Khajura, 2018.

DAT	Varieties	Plant height(cm)		P-value
		Open Chamber		
63	Radha-4	93	82	0.0324
	Sukhkhadhan-3	83.33	83.33	ns
	Sukhkhadhan-2	87.33	90.22	ns
	IR83383-G-B-141-1	97.33	92.00	0.08561
	IR87751-20-4-4-2	100	94.77	ns
84	Radha-4	78.66	80.77	ns
	Sukhkhadhan-3	88.66	83.22	ns
	Sukhkhadhan-2	79.33	90.22	0.09344
	IR83383-G-B-141-1	86.66	85.33	ns
	IR87751-20-4-4-2	76.33	80.11	ns
103	Radha-4	71.6	77.22	0.01317
	Sukhkhadhan-3	85.3	83.45	ns
	Sukhkhadhan-2	73.06	86.99	0.00128
	IR83383-G-B-141-1	85.32	77.43	ns
	IR87751-20-4-4-2	79.8	71.16	ns

Table 2: Plant height (cm) during 63, 84 and 103 days after rice transplanting at RARS, Khajura, 2018.

Number of tiller per hill

Statistical analysis showed no significant difference for number of tillers per hill (Table3) during maturity stage. However, on par with our results (Table 3) [23] states the number of tiller was found to be lower in high temperature conditions than in ambient conditions inside a temperature gradient chamber during maturity. On an average, Sukhkhadhan-3, Sukhkhadhan-2, IR83383-G-B-141-1 and IR87751-20-4-4-2 produced more tillers in an ambient condition (Table 3).

Varieties	Open	Chamber	P-value
Radha-4	9.73	9.80	ns
Sukhkhadhan-3	9.39	9.06	ns
Sukhkhadhan-2	9.53	9.19	ns
IR83383-G-B-141-1	9.53	9.20	ns
IR87751-20-4-4-2	9.13	9.20	ns

Table 3: Number of tillers per hill during rice harvest at RARS, Khajura,2018.

Flowering of spikelet

During field inspection at 58 days after transplanting, two varieties Sukhkhadhan-2 and 3 significantly (p value < 0.0001) showed higher percentage of flowering (Table 4) under ambient condition (Figure 1). On par with our result [24] has revealed high temperature is a constraint during floral development. Exposure to 41°c for 4 hours at flowering caused irreversible damage and plants became completely sterile [25]. Drought during flowering is also extremely dangerous and has been reoccurring in the gap of every 6 years in Nepal [26].

Varieties	Flowering %		Chi-square P-value
	Open	Chamber	
Radha-4	5.00	9.15	ns
Sukhkhadhan-3	95.00	49.15	<0.0001
Sukhkhadhan-2	90.00	45.00	<0.0001
IR83383-G-B-141-1	12.50	28.32	ns
IR87751-20-4-4-2	0	9.15	-

Table 4: Percentage of flowering in rice at RARS, Khajura, 2018.

Panicle length

Panicle differentiation occurs generally within a temperature range of 18 to 30°c [26]. Significantly Sukhkhadhan-3 (p value = 0.02994) showed longer panicle length (Table 5) under chamber condition.

Varieties	Panicle length (cm)		P-value
	Open	Chamber	
Radha-4	23.3.0	24.93	ns
Sukhkhadhan-3	23.74	25.70	0.02994
Sukhkhadhan-2	22.66	24.30	0.09213
IR83383-G-B-141-1	27.00	25.86	ns
IR87751-20-4-4-2	28.00	26.21	ns

Table 5: Panicle length (cm) in rice at RARS, Khajura, 2018.

Filled grains weight/panicle

In the tropics, crop may be subjected to temperature stress during grain filling stage [24]. It was not the case with our result. Significantly (p value=0.03823) Radha-4 produced more filled grains per panicle (Table 6) under elevated temperature (Figure 1) than ambient condition which obviously produced more filled grains weight per panicle (Table 6) with significant (p value 0.023). Similarly, Sukhkhadhan-2 also produced significant (p value 0.066) more filled grains weight per panicle under chamber condition (Table 6).

Thousand grain weight

Thousand grain weight of variety 3 i.e. Sukhkhadhan-2 significantly (p value=0.0804) was higher under chamber condition (Table 7) than open field (23.043g). Thousand grain weight of IR83383-G-B-141-1 was similar under two climatic conditions (Table 7) which was on par with [27] who revealed 1000 grain weight of a particular variety is almost constant under different environments. However, [28] observed variation in 1000 grain weight of similar cultivar from 24g at a mean temperature of 22°c in a 3 week period after heading to 21g at a mean temperature of 28°c.

Grain yield

With 3.1°c higher temperature (Figure 1), Sukhkhadhan-2 significantly (p value= 0.0199) produced higher grain yield (Table 7) under chamber condition in contrast to open field. According to Baker., *et al.* [29], rice yield decreased by 7-8% for every 1°c rice in temperature but with altered varieties IPCC (2007) predicted increase in crop productivity by 20% for 1-3°c rise in temperature in the Southeast Asia. In a rice production, high temperature during flowering and grain filling period causing sterile spikelet and shortening the duration of grain filling phase is a major constraint of yield [30,31].

Categories	Varieties	Open	Chamber	P-value
Filled grains/ panicle, number	Radha-4	112	169.66	0.03823
	Sukhkhadhan-3	134.8	155.6	0.05364
	Sukhkhadhan-2	120.6	166.53	0.07294
	IR83383-G-B-141-1	153.8	124.66	0.0777
	IR87751-20-4-4-2	153.8	143.0667	ns
Filled grains wt/ panicle, g	Radha-4	2.864	4.444	0.023
	Sukhkhadhan-3	3.278	3.688	ns
	Sukhkhadhan-2	2.852	3.997	0.06639
	IR83383-G-B-141-1	3.66	3.122	ns
	IR87751-20-4-4-2	3.606	3.124	ns

Table 6: Number of filled grains and filled weight per panicle in rice at RARS, Khajura, 2018.

Categories	Varieties	Open	Chamber	P-value
1000-grain weight (g)	Radha-4	24.266	26.886	ns
	Sukhkhadhan-3	22.583	21.933	ns
	Sukhkhadhan-2	23.043	25.2	0.08041
	IR83383-G-B-141-1	26.078	26.72	ns
	IR87751-20-4-4-2	23.487	25.564	ns
Grain yield (t/ha)	Radha-4	2.856	5.283	ns
	Sukhkhadhan-3	3.453	4.167	ns
	Sukhkhadhan-2	2.934	4.336	0.02012
	IR83383-G-B-141-1	3.067	4.178	ns
	IR87751-20-4-4-2	3.390	4.493	ns

Table 7: Thousand grain weight and grain yield in rice at RARS, Khajura, 2018.

Biomass yield/plot

Significantly (p value=0.02001) Sukhkhadhan-2 produced higher biomass (Table 8) per plot under elevated temperature condition (Figure 1) than open field. This case was similar with Kumal-10 variety which produced fresh biomass yield (13.15 t/ha) under a chamber of 5'4" height in a Khumaltar condition [16].

Dry straw yield

The results showed that variety 3 (Sukhkhadhan-2) significantly (p value=0.0212) produced more dry straw weight (Table 8) under open field in contrast to chamber condition.

Categories	Varieties	Open	Chamber	P-value
Fresh biomass yield(t/ha)	Radha-4	10.18	16.76	ns
	Sukhkhadhan-3	11.55	14.28	ns
	Sukhkhadhan-2	9.19	13.62	0.0175
	IR83383-G-B-141-1	11.32	14.41	ns
	IR87751-20-4-4-2	12.43	14.59	ns
Dry straw yield(t/ha)	Radha-4	0.36	0.362	ns
	Sukhkhadhan-3	0.366	0.397	ns
	Sukhkhadhan-2	0.437	0.299	0.02119
	IR83383-G-B-141-1	0.378	0.295	ns
	IR87751-20-4-4-2	0.349	0.353	Ns

Table 8: Fresh biomass and dry straw yield in rice at RARS, Khajura, 2018.

Conclusion

From a limited number of chamber investigations much of the uncertain estimate arises and these estimates vary between locations. So, understanding the growth and development of rice under elevated temperature is important for identifying and selecting suitable cultivars for a particular region to mitigate the incidence of elevated temperature. The temperature inside an open top chamber differed by approximately 3.1 °c from that in open field resulting highest yield of Sukhkhadhan-2. Thus, the open top chamber system was suitable to analyze the impacts of climate change, especially increased temperature on rice production.

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