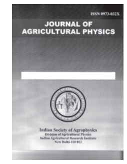
Vol. 22, No. 2, pp. 208-214 (2022)
Journal of Agricultural Physics
ISSN 0973-032X
http://www.agrophysics.in



Research Article

Elevated Carbon Dioxide (CO_2) and Temperature Interaction Effect on Growth of Rice Crop

PARTHA PRATIM MAITY[1], B. CHAKRABARTI[1]*, A. BHATIA[1], S.N. KUMAR[1], T.J. PURAKAYASTHA[2], D. CHAKRABORTY[3], A. SHARMA[1], S. KANNOJIYA[1] AND V. KUMAR[1]

[1]*Division of Environmental Sciences, ICAR-IARI, New Delhi-110 012*
[2]*Division of Soil Science and Agricultural Chemistry, ICAR-IARI, New Delhi-110 012*
[3]*Division of Agricultural Physics, ICAR-IARI, New Delhi-110 012*

ABSTRACT

Greenhouse gas (GHG) emissions from anthropogenic activities are the most significant drivers of observed climate change, which has both direct and indirect effects on crop production. The study was conducted during the *kharif* season of 2019 inside the Open Top Chamber (OTC) at the Genetic-H field of ICAR-Indian Agriculture Research Institute (IARI) to quantify the effect of elevated carbon dioxide (CO_2) and temperature on growth of rice crop. Thirty days old seedlings of rice cv. Pusa Basmati 1509 and Nagina 22 were transplanted in crates inside OTC. There were two different CO_2 concentrations *i.e.*, ambient (410 ppm) and elevated (550 ± 25 ppm) and also two different temperature levels i.e. ambient and elevated (+3.0°C). Recommended dose of fertilizer for rice *i.e.,* 120-60-60 (N-P_2O_5-K_2O) (kg ha^{-1}) was applied. Maturity of Pusa Basmati 1509 and Nagina 22 occurred 4 days and 2 days earlier under high temperature treatment as compared to chamber control. Elevated CO_2 and temperature does not have any significant impact on plant height. Number of tillers in rice decreased in elevated temperature treatment but increased under elevated CO_2 level. High temperature reduced leaf area of the rice varieties but in elevated CO_2 plus temperature interaction treatment leaf area was higher than that of chamber control. Above-ground biomass of Pusa Basmati 1509 and Nagina 22 reduced by 5.9% and 1.2% respectively under elevated temperature treatment as compared to chamber control. But elevated CO_2 was able to compensate this reduction in crop biomass in elevated CO_2 plus temperature interaction treatmentThus this study found that elevated CO_2 level of 550 ppm could alleviate the adverse impacts of high temperature on growth parameters in rice to certain extent.

Key words: Crop biomass, Elevated CO_2, High temperature, Leaf area, Rice

Introduction

The global climate is changing at an alarming rate due to the increase in emission of greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Climate change is predicted to have both direct and indirect effect on crop productivity (Abebe *et al*., 2016; Naresh Kumar *et al*., 2013). In the pre-industrial era (1750 AD), the atmospheric CO_2 concentration was around 280 ppm; today, it is over 410 ppm (IPCC, 2021). The current atmospheric CO_2 concentration has exceeded 400 ppm due to widespread anthropogenic activity, and it is anticipated to exceed 550 ppm by 2050 and 700 ppm by 2100 (IPCC, 2013; Kumar *et al*., 2019). According to IPCC 6th assessment report, the temperature would likely rise by 1.5-5°C in mid of the scenario spectrum and by 3°C in 2100 (IPCC

*Corresponding author,
Email: bidisha2@yahoo.com

2021). High temperature accelerates the maturity of crops and also reduces crop yield (Chakrabarti *et al*., 2021; Sandhu *et al.*, 2017). But elevated CO_2 level increases photosynthetic rate, growth and productivityof crops (Ainsworth and Long, 2005; Dey *et al*., 2017; Pramanik *et al.,* 2018). Therefore, CO_2 fertilization can alleviate the negative impacts of rising temperature on crops to certain extent (Singh *et al*., 2013; Maity *et al*., 2019b).

Rice (*Oryza sativa* L.) is the second-most significant staple food crop in the world with an annual production of 740 million tonnes and cultivation over 160 million ha, (Pathak *et al*., 2018). Rice is the staple food for half of the population of the world and is a main source of calories for about 60% of the world population (Naresh Kumar *et al*., 2013). India grows 43 million acres of rice with a yield of 165 million tonnes (Pathak *et al*., 2018). Since rice is a C_3 crop, it exhibits improved photosynthetic efficiency, which ultimately results in an increase in biomass production and yield at high CO_2 concentrations (Taylor *et al.,* 2018). Maity *et al*. (2020) reported that elevated CO_2 concentration significantly increased grain yield of rice by 24.5% over the ambient treatment. Ainsworth (2008) and Allen *et al*. (2020) reported 13% increase in rice production under elevated CO_2 condition. Exposure of rice crop to high temperature during the anthesis and heading stage may reduce pollen germination and increase the spikelet sterility (Chakrabarti *et al.*, 2010; Matsui *et al*., 2000; Maity *et al.,* 2019a). High temperature stress decreases the number of panicles, number of grain per panicle, spikelet sterility and grain yield of rice (Zacharias *et al.,* 2010; Maity *et al*., 2019b). Studies on the interactive effects of elevated CO_2 and temperature on rice crops in open fields are quite limited especially under tropical condition. Hence the following study was carried out to quantify the impact of elevated CO_2 and temperature on rice growth and productivity.

Materials and Methods

The study was conducted during the *kharif* season of 2019 inside the Open Top Chamber (OTC) at the Genetic-H field of Division of Environmental Sciences, ICAR-Indian Agriculture Research Institute (IARI), New Delhi. The open-top chambers are cylindrical in shape fabricated with galvanized iron (GI) pipe and a diameter of 4 m and height of 3 m. To allow enough room for natural gas exchange and to regulate the surrounding temperature and humidity, the tops of the chambers are left open.The OTCs were maintained at two CO_2 concentrations levels viz. ambient (410 ppm) and elevated (550 ± 25 ppm) and two levels of temperature *i.e.,* ambient temperature and elevated temperature. Elevated temperature was maintained by partially covering the upper portion of the OTCs. Air inside the OTCs is pumped and monitored using an infrared gas analyzer (IRGA) and when the CO_2 concentration dropped, solenoid valves opened, releasing CO_2 into the OTCs. Average maximum and minimum temperatures were 32.6°C and 21.5°C, respectively, throughout the crop growth period in 2019. Daily maximum and minimum temperatures inside the OTCs were measured using digital thermometer.

Rice crop was grown in crates filled with 40 kg soil. The basic physico-chemical properties of the soil (top 0-15 cm) were analysed. The soil was sandy loam in texture, slightly alkaline (pH 7.7), contained 0.5% organic C. Seedlings of two rice varieties namely Pusa Basmati 1509 and Nagina 22 were transplanted in the crates inside the OTCs on third week of July 2019. Six rice seedlings (30 days old) were placed into each crate. Gap filling was also carried out as needed. Recommended dose of fertilizer for rice *i.e.,* 120-60-60 (N-P_2O_5-K_2O) (kg ha^{-1}) was followed. The recommended nitrogen dose was applied in three equal splits, half as a basal application and the other half at the tillering and flowering stages. During the transplantation, phosphorus and potassium were applied. Throughout the cropping period, a 5 cm standing water level was maintained. Crop phenology i.e. dates of 50% flowering and dates of physiological maturity were recorded by visual observations from the field.

During the flowering stage of the crop three rice plants were uprooted from each crate and leaf area was measuredusing LI-3100C Area Meter (LI-COR, Lincoln, NE). The crop was harvested on first week of November. After crop harvest, plant height was measured and numbers of tillers were counted. Plant samples were air dried and dry weight of above ground biomass was recorded.

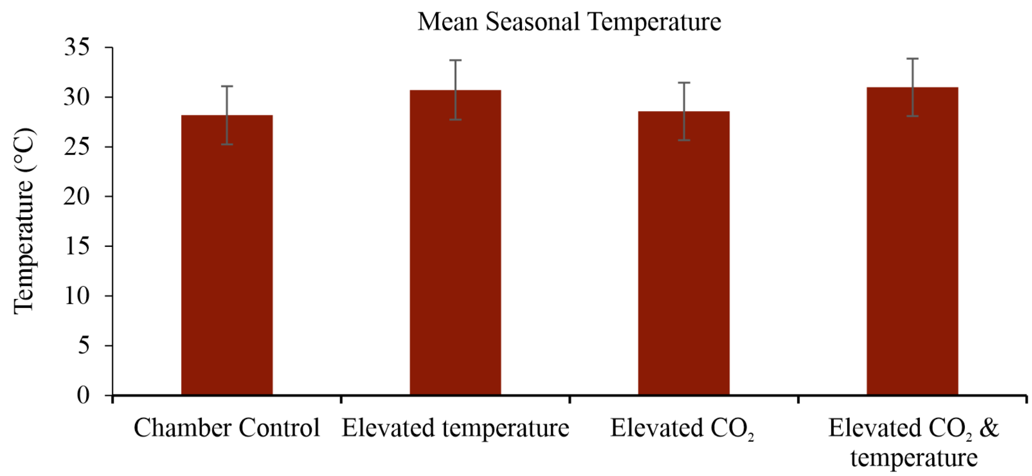


Fig. 1. Mean seasonal temperature inside different OTCs

Statistical analysis

The experiment followed completelyrandomized design (CRD). Statistical analysis of the data was done using SAS software (ver. 9.3) statistical package (SAS Institute Inc., CA,USA).

Results and Discussion

Temperature inside the open top chambers

Daily maximum and minimum temperatures recorded inside the OTCs were averaged for the whole crop growth period. Results showed that, seasonal mean temperatures inside the partially covered OTCs (elevated temperature treatment) and elevated CO_2 plus temperature treatment were 2.5°C and 2.8°C higher respectively compared to the chamber control OTC (Fig. 1).

Crop Phenology

The treatment with elevated temperature accelerated maturity of the rice crop. Days to 50% flowering (anthesis) reduced in Pusa Basmati 1509 and Nagina 22 variety by 3 days and 1 day under elevated temperature treatment (Table 1). On the other hand, maturity of Pusa Basmati 1509 and Nagina 22 occurred 4 days and 2 days earlier respectively as compared to chamber control (Table 1). Chakrabarti *et al*. (2013) also reported that crop yield and biomass tend to decrease with rising temperatures as a result of shortening of crop duration and subsequently shorter period of radiation interception.

Growth and yield parameters

Plant height of Pusa Basmati 1509 and Nagina

Table 1. Phenology of rice varieties as affected by elevated $CO_2$and elevated temperature

Treatment	Days to 50% flowering	Days to maturity
Pusa Basmati 1509		
Chamber control	72	106
Elevated temperature	69	102
Elevated CO_2	72	107
Elevated CO_2 & elevated temperature	67	100
Nagina 22		
Chamber control	69	97
Elevated temperature	68	95
Elevated CO_2	70	99
Elevated CO_2 & elevated temperature	68	96

22 was 80.3cm and 97.3 cm respectively in chamber control treatment (Fig. 2). Elevated CO_2 and temperature did not have any significant impact on plant height. Number of tillers in rice plant significantly increased from 16.1 to 19.7 in Pusa Basmati 1509, and 14.3 to 15.5 in Nagina 22 under elevated CO_2 as compared to chamber control treatment (Fig. 3). High temperature reduced tiller number as compared to chamber control.But in elevated CO_2 plus temperature interaction treatment there was no significant change in tiller number of the varieties than chamber control. Zacharias *et al*. (2010), also reported that high temperature treatment throughout the crop growth period increased tiller mortality in the rice crop, resulting in a decrease in the number of productive tillers and a consequent reduction in grain yield. Raj *et al*. (2019) reported that higher crop growth in rice resulted in increased tiller number under elevated CO_2 condition.

Leaf area in flowering stage significantly increased under elevated CO_2 from 829.5 to 1608.1 cm^2 $hill^{-1}$ in Pusa Basmati 1509 and from 752.5 to 1056.4 cm^2 $hill^{-1}$ in Nagina 22 as compared to chamber control(Fig. 4).High temperature has reduced leaf area to 693 and 591.2 cm^2 $hill^{-1}$ in Pusa Basmati 1509 and Nagina 22 respectively. But in the elevated CO_2 plus temperature interaction treatment leaf area was higher than that of chamber control in both the varieties. Wang *et al*., (2020) reported that leaf area index of rice were significantly impacted negatively by rising temperature, either alone or in combination with high CO_2 at both the PI and HD stages. Reduced LAI was a reflection of the reduction in photosynthetic activity caused by high temperatures (Chakrabarti *et al*., 2013). Moreover, Ruhil *et al.* (2015) showed that under higher CO_2 concentrations, there were a rise in photosynthetic rate as well as an increase in leaf area.

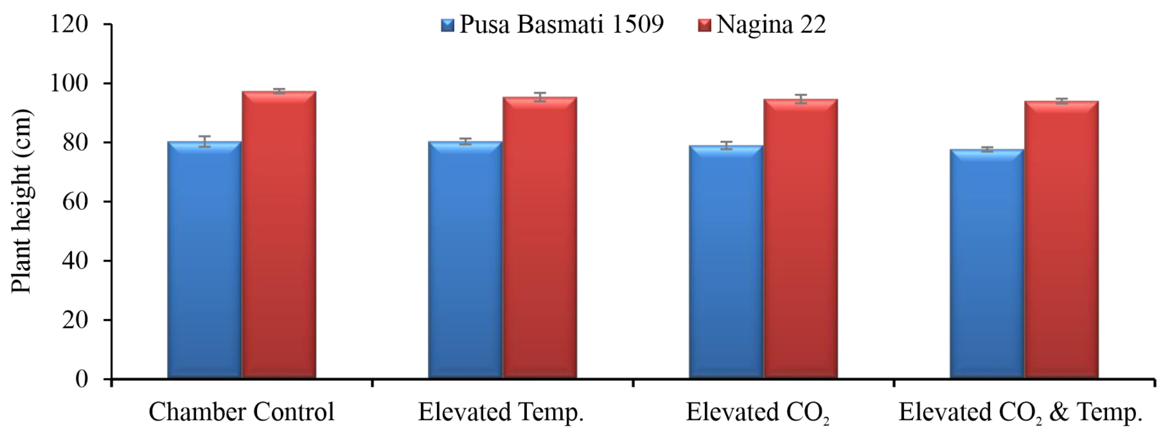


Fig. 2. Plant height of rice varieties under different treatments

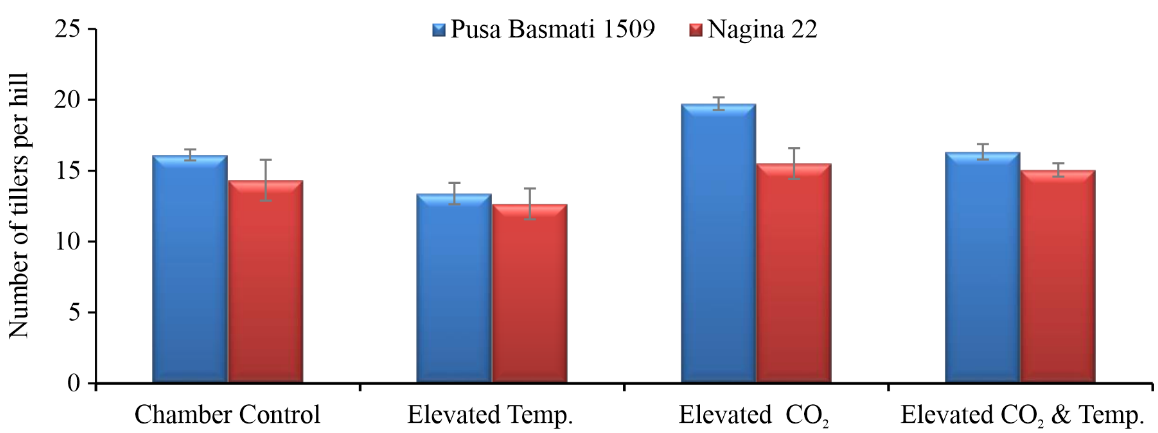


Fig. 3. Number of tillers in rice varieties under different treatments

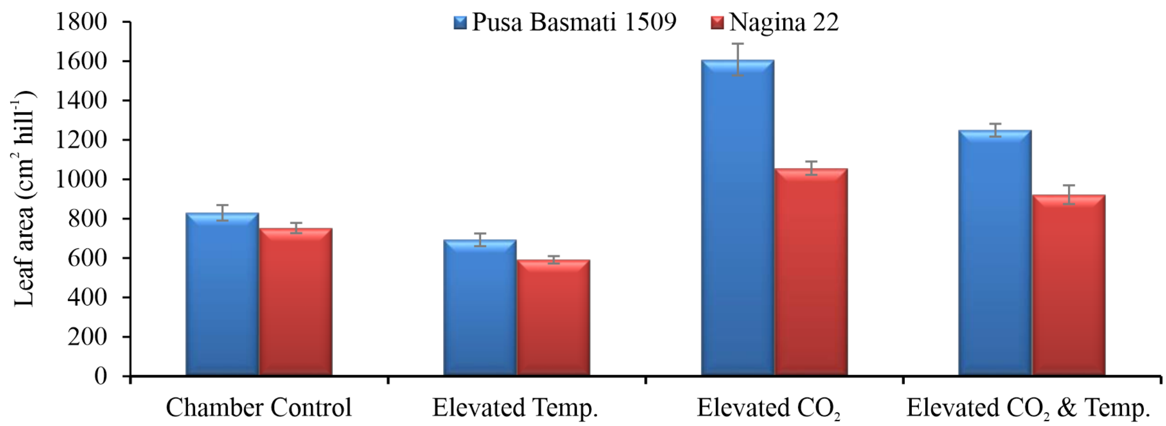


Fig. 4. Leaf area of rice varieties under different treatments

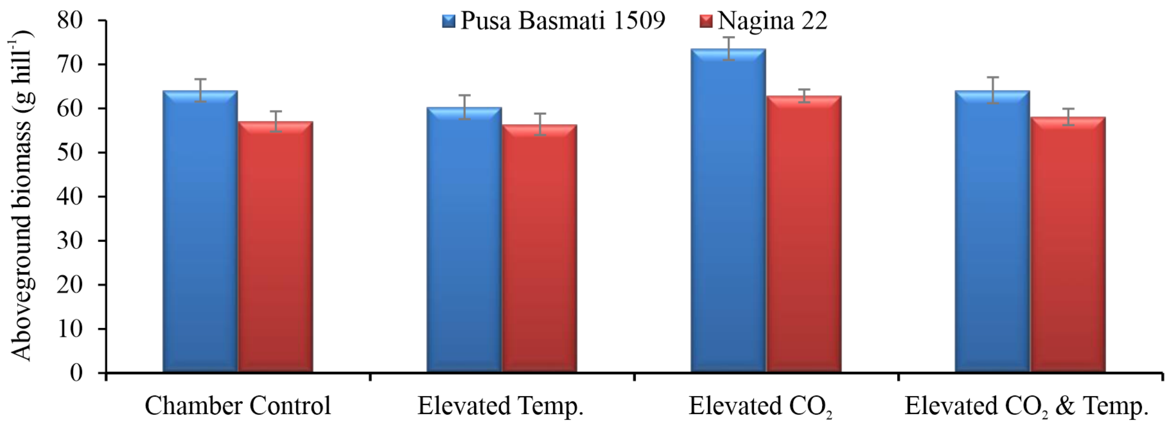


Fig. 5. Above ground biomass of rice varieties under different treatments

The above-ground biomass of the rice varieties significantly increased by 14.8 % and 10.2 %in Pusa Basmati 1509 and Nagina 22 respectively in elevated CO_2 treatment. On the other hand, elevated temperature reduced above-ground biomass by 5.9% and 1.2% in Pusa Basmati 1509 and Nagina 22 respectively. But elevated CO_2 was able to compensate this reduction in crop biomass which was observed in terms of no change in above-ground biomass of the rice varieties in elevated CO_2 plus temperature interaction treatment (Fig.5). Raj *et al.* (2016) has reported that rice grain and biomass yield were significantly decreased with temperature rise of 3.9ºC.Crops frequently report lower yields and biomass in higher temperatures, which may be due to decreased sink capacity, reproductive sterility, and water and resource efficiency (Wassmann *et al.,* 2009). According to reports, higher CO_2 levels improve crop yield and this effect was more pronounced in C_3plants due to source manipulation that increased leaf area, photosyntheticrate, water use efficiency, and other photosynthetic acclimations (Ainsworth *et al.,* 2008;Madan *et al.,* 2012; Chakrabarti *et al.,* 2020a&b).

Conclusions

The results from the studyshowed that elevated temperatures accelerated the maturity of the rice, reduced tiller number, leaf area and growth of rice varieties. However, elevated CO_2 concentrations were able to compensate the loss by enhancing number of tillers, leaf area, and aboveground biomass of rice in elevated CO_2 plus temperature interaction treatment.

Acknowledgements

Authors are thankful to ICAR-Indian Agricultural Research Institute, New Delhi, for providing the opportunity and facilities for conducting the experiment. Author also thankful to UGC-NFOBC for providing fellowship to the first author during Ph.D. programme. Facilities used during this research work were partially funded by the National Innovations in Climate Resilient Agriculture, ICAR.

References

Abebe, A., Pathak, H., Singh, S.D., Bhatia, A., Harit, R.C. and Kumar, V. 2016. Growth, yield andquality of maize with elevated atmospheric carbon dioxide and temperature in north–west India. *Agriculture, Ecosystems and Environment* **218**: 66-72.

Ainsworth, E.A., Rogers, A. and Leakey, A.D.B. 2008. Targets for cropbiotechnology in a future high-CO_2 and high-O_3 world. *Plant Physiology* **147**: 13–9.

Ainsworth, E.A. 2008. Rice production in a changing climate: A metaanalysisof responses to elevated carbon dioxide and elevated ozone concentration. *Global Change Biology* **14**: 1642–1650.

Ainsworth, E.A. and Long, S.P. 2005. What have welearned from 15 years of free air CO_2 enrichment(FACE)? A meta analytic review of theresponses of photosynthesis, canopy properties and plant production to rising CO_2. *New Phytologist* **165**: 351-372.

Allen, L.H., Kimball, B.A., Bunce, J.A., Yoshimoto, M., Harazono, Y., Baker, J.T., Boote, K.J., White, J.W. 2020. Fluctuations of CO_2 in free-air CO_2enrichment (FACE) depress plant photo-synthesis, growth, and yield. *Agricultural and Forest Meteorology* **284**: 107899.

Chakrabarti, B., Singh, S.D., Bhatia, A., Kumar, V. and Harit, R.C. 2020a. Yield and nitrogen uptake in wheat and chickpea grown under elevated carbon dioxide level. *Natl. Acad. Sci. Lett.* **43**: 109-113.

Chakrabarti, B., Bhatia, A., Pramanik, P., Das Saha, N., Bhattacharyya, R., Harit, R.C. and Kumar, V. 2020b. Impact of elevated carbon dioxide (CO_2) concentration on yield of maize crop. *Journal of Agricultural Physics* **20**(2): 208-212.

Chakrabarti, B., Aggarwal, P.K., Singh, S.D., Nagarajan, S. and Pathak, H. 2010. Impact of high temperature on pollen germination and spikelet sterility in rice: comparison between basmati and non-basmati varieties. *Crop and Pasture Science* **61**(5): 363-368.

Chakrabarti, B., Bhatia, A., Pramanik, P., Singh, S.D., Jatav, R.S., Das Saha, N., Raj, A., Joshi, R. and Kumar, V. 2021. Changes in thermal requirements, growth and yield of wheat under the elevated temperature. *Indian Journal of Agricultural Sciences* **91**(3): 435–439.

Dey, S.K., Chakrabarti, B., Prasanna, R., Singh, S.D., Purakayastha, T.J., Datta, A. and Pathak, H. 2017. Productivity of mungbean (*Vigna radiata*) with elevated carbon dioxide at various phosphorus levels andcyanobacteria inoculation. *Legume Research* **40**(3): 497–505.

IPCC. 2013. Summary for Policymakers, In: Climate Change, The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F. *et al* (eds)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

IPCC. 2021. Summary for Policymakers, In: Climate Change, The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte V.P. *et al* (eds)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p 3d32

Kumar, Anjani, Nayak, A.K., Das, B.S., Panigrahi, N., Dasgupta, P., Mohanty, Sangita, Kumar, Upendra, Panneerselvam, P. and Pathak, H. 2019. Effects of water deficit stress on agronomic and physiological responses of rice and greenhouse gas emission from rice soil under elevated atmospheric CO_2. *Science of the Total Environment* **650**: 2032-2050.

Madan, P., Jagadish, S.V.K., Craufurd, P.Q., Fitzgerald, M., Lafarge, T. and Wheeler, T.R. 2012. Effect of elevated CO_2 and high temperature on seed-set and grain quality of rice. *Journal of Experimental Botany* **63**(10): 3843-3852.

Maity, P.P., Chakrabarti, B., Bhatia, A. and Purakayastha, T.J. 2019a. Effect of elevated CO_2 and temperature on spikelet sterility in rice. *Current Advances in Agricultural Sciences* **11**(1): 34-37.

Maity, P.P., Chakrabarti, B., Bhatia, A., Purakayastha, T.J., Saha, N.D., Jatav, R.S., Sharma, A., Bhowmik, A., Kumar V. and Chakraborty, D.

2019b. Effect of Elevated CO_2 and Temperature on Growth of Rice Crop. *International Journal of Current Microbiology and Applied Sciences* **8**(1): 1906-1911.

Maity, P.P., Chakrabarti, B., Purakayastha, T.J., Bhatia, A., Saha, N.D., Jatav, R.S., Sharma, A., Bhowmik, A., Kumar, V. and Chakraborty, D. 2020. Do elevated CO_2 and temperature affect organic nitrogen fractions and enzyme activities in soil under rice crop? *Soil Research* **58**(4): 400-410.

Matsui, T., Omasa, K. and Horie, T. 2000. High temperature at flowering inhibitswelling of pollen grains, a driving force for thecae dehiscence in rice(*Oryza sativa* L.). *Plant Production Science* **3**: 430–434.

Naresh Kumar, S., Aggarwal, P.K., Saxena, R., Swaroopa Rani, Jain, S. and Chauhan, N. 2013. An assessment of regional vulnerability of rice to climate change in India. *Climate Change* **118**(3-4): 683–699.

Pathak, H., Samal, P. and Shahid, M. 2018. Revitalizing rice-systems for enhancing productivity, profitability and climate resilience. In: Pathak, H., *et al*. (Eds.), Rice Research forEnhancing Productivity, Profitability and Climate Resilience. ICAR-National Rice ResearchInstitute, Cuttack, Odisha, pp. 1–17.

Pramanik, P., Chakrabarti, B., Bhatia, A., Singh, S.D., Mridha, N. and Krishnan, P. 2018. Effect ofelevated carbon dioxide on soil hydro-thermalregimes and growth of maize crop (*Zea mays* L.) in semi-arid tropics of Indo-Gangetic Plains. *Environ Monit Assess*. **190**: 661.

Raj, A., Chakrabarti, B., Pathak, H., Singh, S.D., Mina, U. and Mittal, R. 2016. Growth, yield components and grainyield response of rice to temperatureand nitrogen levels. *Journal of Agrometeorology* **18**(1): 1-6.

Raj, A., Chakrabarti, B., Pathak, H., Singh, S.D., Mina, U. and Purakayastha, T.J. 2019. Growth, yield and nitrogen uptake in rice crop grown under elevated carbon dioxide and different doses of nitrogen fertilizer. *Indian Journal of Experimental Biology* **57**: 181-187.

Ruhil, K., Sheeba, Ahmad A., Iqbal, M. and Tripathy, B.C. 2015. Photosynthesisand growth responses of mustard (*Brassica juncea* L.cv Pusa Bold) plants to free air carbon dioxide enrichment (FACE). *Protoplasma* **252**: 935–946.

Sandhu, S.S., Kaur, P., Gill, K.K., Bal, S.K. 2017. Effect of high temperature on performance of rice and its management. *Journal of Agricultural Physics* **17**(2): 249-254.

Singh, S.D., Chakrabarti B., Muralikrishna, K.S., Chaturvedi, A.K., Kumar, V., Mishra, S. and Harit, R. 2013. Yield response of important fieldcrops to elevated air temperature and CO_2 levels. *Indian J. Agri. Sc*. **83**(10): 1009-1012.

Taylor, S.H., Aspinwall, M.J., Blackman, C.J., Choat, B., Tissue, D.T. and Ghannoum, O. 2018. CO_2 availability influences hydraulic function of C_3 and C_4 grass leaves. *Journal of Experimental Botany* **69**(10): 2731–2741.

Wang, Weilu, Chuang Cai, Jiang He, JunfeiGu, Guanglong Zhu, Weiyang Zhang, Jianguo Zhu, and Gang Liu. 2020. Yield, dry matter distribution and photosynthetic characteristics of rice under elevated CO_2 and increased temperature conditions. *Field Crops Research* **248**: 107605.

Wassmann, R., Jagadish, S.V.K., Sumfleth, K., Pathak, H., Howell, G., Ismail, A., Serraj, R., Redona, E., Singh, R.K. and Heuer, S. 2009. Regional vulnerability of climate change impacts on Asian riceproduction and scope for adaptation. *Advances in Agronomy* **102**: 99-133.

Zacharias, M., Singh, S.D., Naresh Kumar, S., Harit, R.C. and Aggarwal, P.K. 2010. Impact of elevated temperature at different phonological stages on the growth and yield of wheat and rice. *Indian Journal of Plant Physiology* **15**(4): 350-358.

Received: 2 July 2022; Accepted: 30 September 2022