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Research Article

Growth and Yield of Soybean as Affected by Elevated Carbon Dioxide, Temperature and Cyanobacterial Inoculation

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ABSTRACT

An experiment was conducted in the open top chamber (OTCs) in IARI farm, New Delhi to study the interactive effect of elevated CO_2, temperature and cyanobacterial inoculation on growth and yield of soybean crop. Soybean variety Pusa 9712 was grown in pots under two different CO_2 levels: ambient and elevated and two temperature treatments i.e. ambient and elevated. Four different cyanobacterial inoculations were applied. Elevated CO_2 level significantly increased leaf area of the crop. Temperature elevation by 2.5°-2.8°C reduced leaf area from 370.3 cm^2/plant to 312.7 cm^2/plant. Both number of pods per plant and fresh weight of pod decreased in elevated temperature treatment while elevated CO_2 increased these yield attributes. Pod number per plant was significantly higher (19.8) in biofilm applied treatment than other treatments. Cyanobacterial inoculation with *C.elenkinii* and biofilm significantly increased fresh weight of pods in soybean crop. Application of cyanobacterial biofilm will help in improving growth and pod yield of soybean under future climatic condition.

Key words: Elevated CO_2, Elevated temperature, Soybean, Cyanobacteria

Introduction

Climate change is an approaching threat which will have significant effect in Indian agriculture. The earth's surface temperature has been rapidly rising in recent decades. Earth's temperature has risen by 0.08°C since 1880 (IPCC, 2014). Crop productivity, nutrient cycling, as well as soil hydrothermal regimes will be affected by the increase in atmospheric carbon dioxide (CO_2) concentration and accompanying rise in temperature (Chakrabarti *et al*., 2021; Maity *et al*., 2020; Pramanik *et al*., 2018). Experimental studies showed that under elevated CO_2 concentration there is a significant increase in yield of different crops (Chakrabarti *et al*., 2020a, 2012; Singh *et al*., 2013). But demand for nutrients by crop plants will increase under elevated CO_2 condition (Dey *et al*., 2019; Raj *et al*., 2019). This often results in decreased plant nutrient content (Abebe *et al*., 2016; Poorter *et al*., 1996). Legumes have an advantage under elevated CO_2 condition due to their ability to fix atmospheric nitrogen (N_2) (Rogers *et al*., 2006). Under elevated CO_2 condition, legumes fix more N thereby increasing growth, yield and plant N content (Chakrabarti *et al*., 2020b; Dey *et al*., 2017a). Soybean (*Glycine max* (L.) Merrill) is a legume crop, rich in protein. Experimental results showed that photosynthesis rate and growth of soybean crop increases under elevated CO_2 condition (Rogers *et al*., 2006). Cyanobacteria are diazotrophic agents which have beneficial effects on different crops (Prasanna *et al*., 2015; Bidyarani *et al*., 2016). The legume rhizobia symbiosis contributes one third to

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half of the total nitrogen applied in cultivated soil (Herridge *et al*., 2008). This legume-rhizobia is known to be sensitive to changes in temperature. Root temperature affects nodule formation, development and activity (Hernandez-Armenta *et al*., 1989). A sustained crop productivity under elevated CO_2 condition needs balanced nutrient supply. In several studies it is found that increased CO_2 also enhanced plant growth and nitrogen fixation in legumes. As the concentration of CO_2 increases the demand for nutrients in leguminous crops can increase (Dey *et al*., 2017b). Increase in photosynthesis, carbon uptake as well as leaf carbohydrate was reported in soybean under elevated CO_2 condition (Ainsworth *et al*., 2003; Leakey *et al*., 2009). When CO_2 concentration in atmosphere will be higher CO_2 compensation point will also be higher and photosynthesis will enhance which in turn will decrease stomatal conductance. Lowering stomatal conductance will negate the positives of elevated CO_2 (Long *et al*., 2004). *Trifolium repens,* when grown in Free Air CO_2 enrichment (FACE) conditions there was a substantial increase in yield and photosynthetic efficiency (Ainsworth *et al*., 2003).The interactive effect of elevated CO_2 and temperature on soybean is limited under Indian condition. Hence a detailed study was conducted to study the growth of soybean crop underelevated CO_2 and temperature condition. Earlier we have reported that N fixation and N uptake improved with cyanobacterial biofilm inoculation under elevated $CO_2$and temperature condition (Sanyal *et al*., 2022). Here we present the interactive effect of elevated CO_2 and temperature on growth and yield of soybean.

Materials and Methods

Experimental setup: An experiment was conducted in Genetic-H field of ICAR-Indian Agriculture Research Institute, New Delhi during the *kharif* season (July to October) of year 2018. The site is situated at 28°35′ N and 77°12′ E at an altitude of 228 m above mean sea level. The climate is semi-arid subtropical. Soybean crop (variety Pusa 9712) was grown in pots inside the Open Top Chambers (OTC). Two levels of carbon dioxide (CO_2) concentrations were maintained inside the OTCs *i.e.* ambient concentration of around 400 ppm and elevated CO_2 concentration of around 550 ppm. Elevated temperature levels were maintained inside the OTCs by partially covering the upper portion of the OTCs. Two temperature treatments *i.e.*, chamber control and elevated temperature was maintained. Daily maximum and minimum temperatures were recorded in each OTC using digital thermometer. The pots were filled with 15 kg of soil. The soil was slightly alkaline (pH 7.8), non-saline (EC 0.47 dS m^{-1}) with 0.5% soil organic carbon. Recommended dose of nitrogen (20 kg ha^{-1}) and phosphorus (60 kg ha^{-1}) was applied through Diammonium phosphate (DAP). Seeds were inoculated with crop specific *Rhizobium* inoculant, (*Bradyrhizobium japonicum*). Four cyanobacterial treatments were used *i.e.*, no cyanobacteria, cyanobacterial inoculation with *Calothrix elenkinii* (C0), cyanobacterial inoculation with *Anabaena laxa* (C1) (RPAN8), and cyanobacterial inoculation (C2) with *Anabaena torulosa – Bradyrhizobium japonicum* biofilm (C3). Both *Rhizobium* inoculant and cyanobacterial cultures were obtained from the Division of Microbiology, ICAR-IARI.

Crop growth parameters: Leaf area was measured using the leaf area meter (LI-3100C, LiCOR, USA) at flowering stage of the crop. Chlorophyll content of leaf was determined by the DMSO (dimethyl sulfoxide) extraction method (Hiscox and Israelstam, 1979). Chlorophyll a, chlorophyll b and total chlorophyll content was calculated using the formula given by Arnon (1949).

Yield attributes: Plant samples were collected at maturity. Yield parameters like no of pods per plantand fresh weight of pods were recorded.

Statistical analysis: The design of the experiment was completely randomized design (CRD). There were 16 treatments, each with 3 replications. Statistical analysis of the data was done by SAS software (ver. 9.3; SAS Institute Inc., CA, USA).

Results and Discussion

Temperature elevation in OTC: Results showed that seasonal mean temperature in the elevated temperature treatment was 2.5°C higher than chamber control while temperature in elevated CO_2 plus temperature treatment was 2.8°C higher than chamber control (Fig. 1).Substantial increase in temperature was recorded during day time.

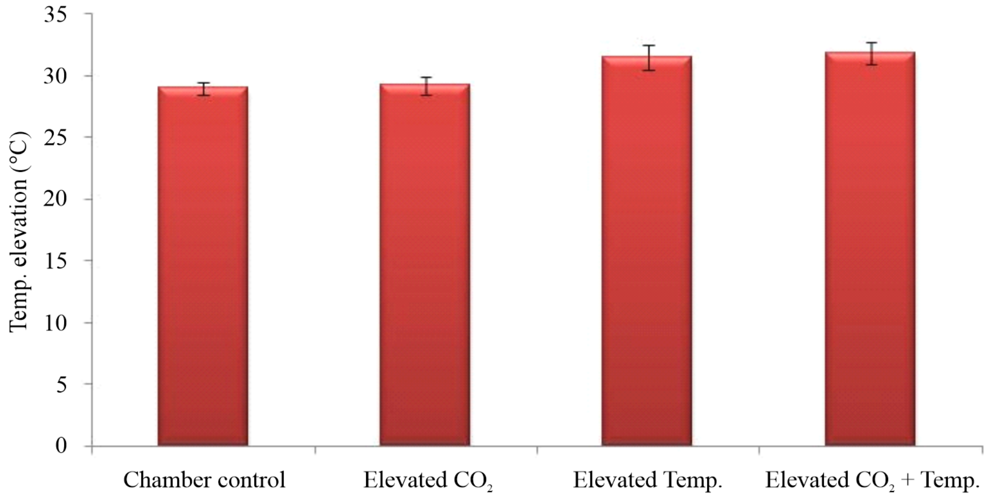

Fig. 1. Temperature elevation in different treatments as compared to chamber control

Leaf area: At flowering stage, leaf area of soybean was significantly enhanced under elevated CO_2 condition. Leaf area in the elevated CO_2 treatment was 354.1 cm^2/plant, while it was 328.9 cm^2/plant in the ambient condition (Fig. 2). Similar results were reported by Dey *et al.* (2017b) who found that leaf area in mungbean increased under high CO_2 compared to ambient condition. Temperature elevation reduced leaf area of the crop. In chamber control treatment, leaf area was 370.3 cm^2/plant and in the elevated temperature treatment, it was 312.7 cm^2/plant. Cyanobacterial biofilm significantly increased the leaf area than other treatments. Saha *et al*. (2013) also reported that CO_2 elevation to 580 ppm increased leaf area in chickpea crop.

Leaf chlorophyll: Total chlorophyll in soybean leaves ranged from 1.5 to 2.3 mg g^{-1} in different treatments (Fig. 3). Leaf chlorophyll was significantly higher in elevated CO_2 treatment (2 mg g^{-1}) as compared to ambient (1.8 mg g^{-1}) treatment. However elevated temperature reduced total chlorophyll content of leaf.

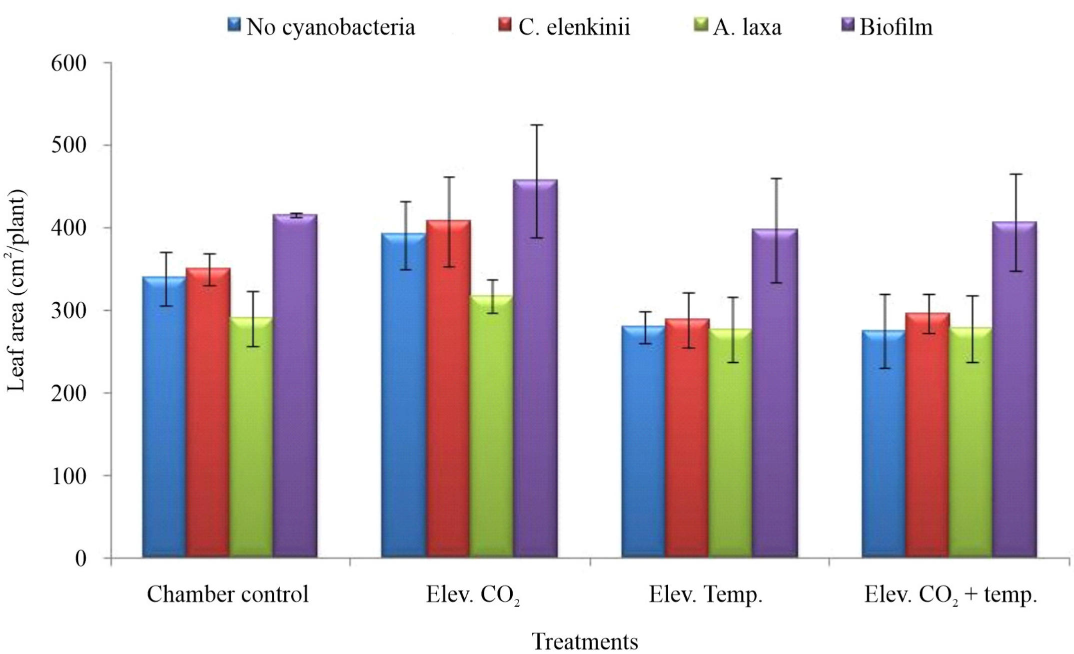

Fig. 2. Leaf area (cm^2/ plant) of soybean at flowering stage

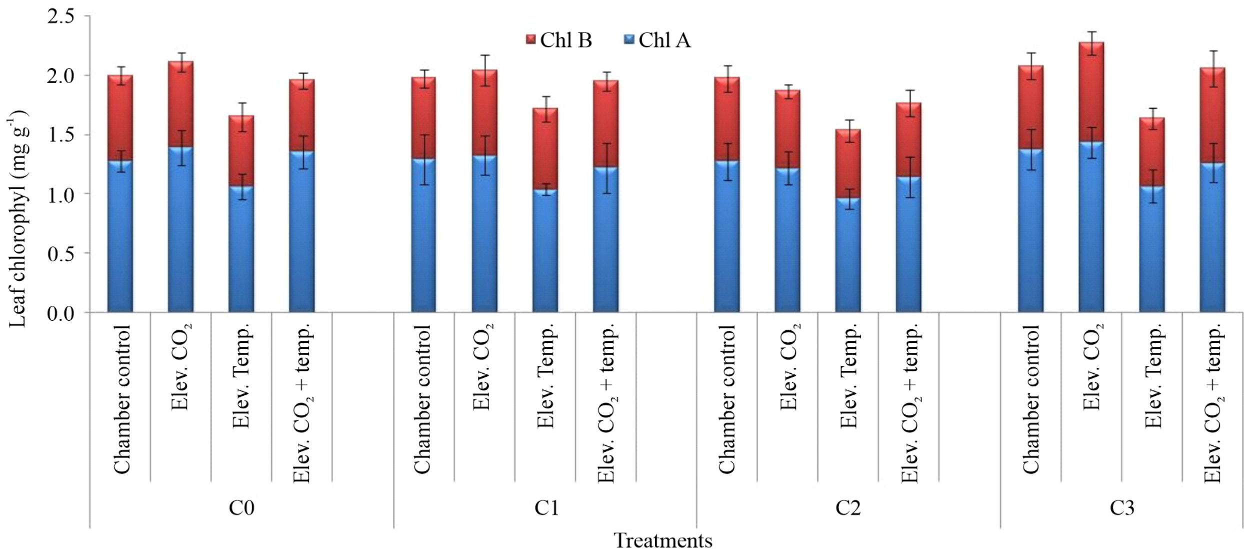

Fig. 3. Chlorohyll a and b (mg/g) at flowering stage of soybean under different treatments

Cyanobacterial biofilm significantly increased leaf chlorophyll as compared to other treatments. Highest amount of leaf chlorophyll was recorded (2.27 mg g^{-1}) under cyanobacterial biofilm applied treatment under elevated CO_2 and chamber control temperature condition. Application of cyanobacterial biofilm in elevated CO_2 treatment further increased leaf chlorophyll content. Elevated CO_2 level significantly enhanced chlorophyll a (1.3 mg g^{-1}) in soybean leaf as compared to ambient CO_2 treatment (1.17 mg g^{-1}). On the other hand elevated temperature decreased chlorophyll a content of soybean leaves. Highest chlorophyll a (1.44 mg g^{-1}) was recorded in OTC with elevated CO_2 and chamber control treatment with cyanobacterial biofilm inoculation. Chlorophyll b was not affected by increased CO_2 level. But high temperature reduced chlorophyll b to 0.64 mg g^{-1} than chamber control treatment (0.72 mg g^{-1}) (Fig. 3).

Number of pods per plant: Elevated temperature decreased number of pods in soybean plants. In chamber control treatment, number of pods/plant was 20 while in elevated temperature treatment, it was 10.8 (Table 1). Elevated CO_2 concentration increased pod number. Pod number per plant was significantly higher (19.8) in biofilm applied treatment than other treatments. More carbon assimilation under elevated CO_2 concentration led to partitioning of more biomass to the storage organs resulting in more number of pods per plant.Wu and Wang (2000) reported increased number of pods inbroad bean under elevated CO_2 condition.

Table 1. Number of pods/plant in soybean in different treatments

Cyanobacteria	Ambient CO_2		Elevated CO_2		Mean				
	CC Temp.	Elevated Temp.	CC Temp.	Elevated Temp.	Cyano	Ambient CO_2	Elevated CO_2	CC Temp.	Elevated Temp.
C0	14.8	8.8	19.6	8.6	13.0	11.8	14.1	17.2	8.7
C1	18.7	8.2	21.9	10.4	14.8	13.5	16.2	20.3	9.3
C2	17.1	9.0	19.8	10.2	14.0	13.1	15.0	18.4	9.6
C3	21.4	15.9	26.6	15.4	19.8	18.6	21.0	24.0	15.7
Mean	18.0	10.5	22.0	11.2		14.2	16.6	20.0	10.8

LSD ($p \leq 0.05$): CO_2: 1.7; Temp: 1.7; Cyan: 2.4; CO_2 × Temp: NS; CO_2 × Cyan: NS; Temp × Cyan: NS; CO_2 × Temp × Cyan: NS

Table 2. Fresh weight of pod (g/plant) in soybean in different treatments

Cyanobacteria	Ambient CO_2		Elevated CO_2		Mean				
	CC Temp.	Elevated Temp.	CC Temp.	Elevated Temp.	Cyano	Ambient CO_2	Elevated CO_2	CC Temp.	Elevated Temp.
C0	16.5	13.5	22.6	12.0	16.1	15.0	17.3	19.5	12.7
C1	21.3	12.5	27.9	14.6	19.1	16.9	21.2	24.6	13.5
C2	19.1	15.3	20.1	15.9	17.6	17.2	18.0	19.6	15.6
C3	24.8	20.2	30.0	20.0	23.8	22.5	25.0	27.4	20.1
Mean	20.4	15.4	25.2	15.6		17.9	20.4	22.8	15.5

LSD ($p \leq 0.05$): CO_2: 1.6; Temp: 1.6; Cyan: 2.3; CO_2 × Temp: NS; CO_2 × Cyan: NS; Temp × Cyan: 3.2; CO_2 × Temp × Cyan: NS

Fresh weight of pod: More crop growth in elevated CO_2 treatment also increased fresh weight of pods than ambient treatment. In ambient treatment fresh weight of pod was17.9 g/plant while in elevated CO_2treatment it was 20.4 g/plant (Table 2). But fresh weight of pod decreased from 22.8 g/plant in chamber control treatment to 15.5 g/plant in elevated temperature treatment. Cyanobacterial inoculation with *C. Elenkinii* and biofilm resulted in significant increase in the fresh weight of pods in soybean crop. Enhanced productivity in soybean under elevated CO_2 condition is reported due to increased pod weight and seed weight of the crop (Twine *et al*., 2013).

Conclusion

From the current study it was observed that elevated CO_2 concentration significantly increased leaf area in soybean than the ambient conditions and elevated temperature reduced leaf area of the crop. Number and fresh weight of pods reduced in elevated temperature treatment while elevated CO_2 increased both these yield attributes.Cyanobacterial inoculation as biofilm improved crop growth and also increased pod weight in soybean crop. Hence it can be concluded that application of cyanobacterial biofilm will help in improving growth and pod yield of soybean under elevated CO_2 and temperature condition.

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