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Impact of elevated CO_2 and temperature on Greengram (Vignaradiata L.) and Cowpea (Vignaunguiculata L.) under Soil Plant Atmospheric Research (SPAR)

GOVINDARAJ T, N. MARAGATHAM*, SP. RAMANATHAN,

V. GEETHALAKSHMI** and M. K. KALARANI***

Agro Climate Research Centre, TNAU, Coimbatore – 3,

**Centre for Students Welfare, TNAU, Coimbatore – 3,*

***Vice Chancellor, TNAU, Coimbatore – 3,*

**** Directorate of Crop Management, TNAU, Coimbatore – 3,*

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e mail : mm65@tnau.ac.in

सार – वर्तमान शोध ने 2022 के दौरान कृषि जलवायु अनुसंधान केंद्र, तमिलनाडु कृषि विश्वविद्यालय, कोयंबटूरमें मृदा पादप वायुमंडलीय अनुसंधान (SPAR) में ग्रीनग्राम (cv. CO 8) और ग्वारपाठा (cv. CO 7) के विकास और उपज मापदंडों पर अधिक तापमान और CO_2 स्तरों के अन्योन्य क्रियाशील प्रभावों की जांच की। एक पूर्ण यादृच्छिक डिज़ाइन का उपयोग चार उपायों और चार प्रतिकृतियों के साथ किया गया, जैसे, T1 - (aG) एम्बिएंट ग्रीनग्राम, T2 - (eG) +3° C अधिक तापमान और ग्रीनग्राम में उन्नत CO_2 (600 ppm), T3 - (aC) एम्बिएंट ग्वारपाठा, T4 - (eC) +3° C अधिक तापमान और ग्वारपाठा में अधिक CO_2 600 ppm ।ग्वारपाठा में अधिकतम पौधे की ऊंचाई, अधिक तापमान के साथ पत्ती का क्षेत्र और अधिक CO2 दर्ज किया गया जो अन्य उपायों की तुलना में काफी अधिक था। इसके अलावा, ग्रीनग्राम ने अधिक तापमान के साथअधिक CO_2 के तहत अधिकतम उपज गुण दर्ज किए जो अन्य उपायों की तुलना में काफी अधिक पाए गए। अधिक CO_2 और अधिक हुआतापमान मूंग और ग्वारपाठा के पौधों की वृद्धि और उपज विशेषताओं पर सकारात्मक प्रभाव डालता है।

ABSTRACT. The current research investigated the interactive effects of elevated temperature and CO_2 levels on growth and yield parameters of Greengram (cv. CO 8) and Cowpea (cv. CO 7) in Soil Plant Atmospheric Research (SPAR) at Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore during 2022. AComplete Randomised Design was used with four treatments and four replications, *viz*., T_1 -(aG) Ambient Greengram, T_2–(eG) +3° C elevated temperature and elevated CO_2 (600 ppm) in Greengram, T_3– (aC) Ambient Cowpea, T_4– (eC) +3° C elevated temperature and elevated CO_2 600 ppm in Cowpea. Cowpea recorded maximum plant height, leaf area under elevated temperature cum elevated CO_2 which were significantly higher than other treatments. Furthermore, Greengram recorded maximum yield attributes under elevated temperature cum elevated CO_2 which were found significantly higher than other treatments. Elevated CO_2 and elevated temperature positively effect on green gram and cowpea plant growth and yield attributes.

Key words– SPAR, Greengram, Cowpea, Elevated temperature and Elevated CO_2.

1. Introduction

Climate change is the cause of concern and evince interest due to its capricious nature and complex phenomena. It is one of the most severe threats that world currently confront. Among the most obvious and negative indicators of global climate change is the increase in atmospheric carbon dioxide (CO_2) concentration. Greenhouse gases are the primary source of cause for the rising temperature levels in the atmosphere. According to the Intergovernmental Panel on Climate Change (IPCC) report, human activity aggravates the climate change. During the next two decades, the earth will have warmed by 1.5°C compared to pre-industrial times. In addition, CO_2 level has risen at a pace of 1.9 ppm per year, over the last decade. Consequent to this, the global surface temperature is expected to rise by 2° C at the end of this century. (IPCC, 2021). Predicted global climatic changes, such as those in CO_2 levels, surface temperatures, and rainfall patterns, also have a significant

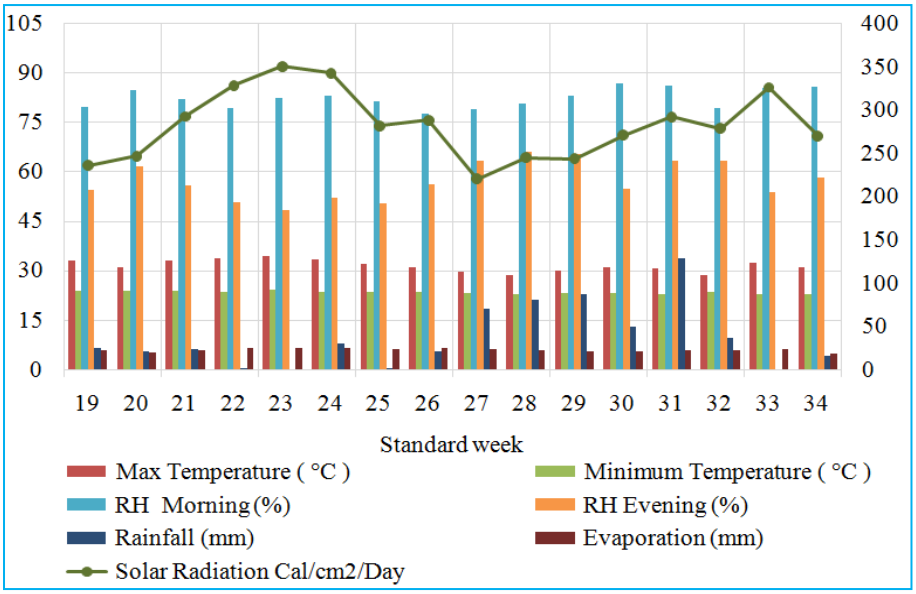

Fig. 1. The weather condition prevailed during research period

impact on agricultural development. Climate change influence on crop growth and productivity, particularly through changes in photosynthetic carbon assimilation (Reddy *et al*., 2010).

CO_2, carbon fertilizer, helps crop growth and development when temperature rises (Van der Kooi *et al*., 2016). The major impact of increased atmospheric CO_2 on plants augmented the photosynthetic rate, leaf area, leaf area index (LAI), leaf thickness, leaf area duration (LAD) and amount of dry biomass production and higher dry matter accumulation under elevated CO_2 conditions which also propels radiation interception by the plants. Crop growth and development at increased CO_2 levels (475-600 ppm) in Free-air carbon dioxide enrichment (FACE) trials increased photosynthetic rate in a variety of plant species by over 40% (Ainsworth *et al.*, 2007). Elevated temperature affects the various phenological phases and crop duration (Cai *et al.*, 2016). Shorter lifecycles and early occurrence of phenophases was recorded in various crops, *viz*., rice, wheat, maize and mungbean under conditions of higher temperature (Haque *et al*., 2005). Increased temperature decreases the crop yield due to reduced photorespiration, ribulose-1, 5-bisphosphate carboxylase activity, heat injury, and physiological disorders in addition, negatively influencing the net photosynthesis in the crops (Cai *et al*., 2018).

In the current climatic change condition, with continual increase in CO_2 concentrations, crop performance in terms of growth, yield and grain quality is at risk. Thus, the current study was carried out with the following objectives :

(*i*) To study the effect of elevated CO_2 and temperature on the growth and development Parameters of greengram and cowpea.

(*ii*) To study the effect of elevated $CO_2$and temperature on the physiology and yield parameters of greengram and cowpea.

2. Data and methodology

2.1. *Location and weather*

The pot culture experiment was conducted in May to August months of 2022 in the Soil Plant Atmosphere Research (SPAR) at Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India. The experimental site is located between 11°83'' North latitude and 76°71'' East longitude at an elevation of 426.7 m above the mean sea level. The range of weather parameters prevailed during the cropping season was represented in the Fig. 1. The mean maximum and minimum temperature of the cropping season was 35.5 °C and 22.5 °C, respectively. In addition, the cropping period received a total Rainfall of 155 mm.

2.2. *Soil characteristics*

The soil is Clay loam in texture with field capacity and permanent wilting point (23.80% and 11.60%, respectively). The soil's pH, electrical conductivity and

organic carbon content were 8.7, 0.34 dSm^{-1} and 0.43%, respectively.

2.3. *Experimental details*

The experiment was formulated in Complete Randomised Design (CRD) with 4 replications and four treatments,

T_1 - (aG) - Ambient Greengram

T_2 -(eG) - +3 °C elevated temperature and CO_2 (600 ppm) Greengram

T_3 - (aC) - Ambient Cowpea

T_4 - (eC) - +3 °C elevated temperature and CO_2 (600 ppm) Cowpea

2.4. *SPAR (Soil Plant Atmosphere Research)*

SPAR system is a micro-climatic data acquisition system and programmable climate modelling tools enclosed with Plexiglass. The SPAR system sustains CO_2 concentration continuously over time with variable climate parameters including air temperature and relative humidity with a lag of 10 minutes from the surrounding environment. The current treatments comprised both ambient and elevated conditions [+3 °C elevated temperature and CO_2 (600 ppm)].

2.5. *Growth and development Parameters*

2.5.1. *Plant height(cm) and number of leaves*

The plant height was measured from the base of the plant to the tip of the longest leaf in all tagged plants and the mean value was expressed in cm. The tagged plant fully opened number of leaves were counted at Emergence, Vegetative Stage, Flowering stage and Maturity stage and were expressed in the unit of numbers per plant.

2.5.2. *Growth Parameters*

Leaf Area Index (LAI)

$$LAI = \frac{L \times W \times K \times Number\ of\ leaves\ plants^{-1}}{Land\ area\ occupied\ by\ the\ plant\left(cm^2\right)}$$

Leaf Area Duration (LAD) (Days)

$$LAD = \frac{LAI_i + LAI_{i+1}}{2} \times \left(t_2 - t_1\right)$$ (Power *et al.*, 1967)

Crop Growth Rate (CGR) ($g/m^2/day$)

$$CGR = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{1}{P}$$ (Watson, 1956)

Absolute Growth Rate (AGR)($cm\ day^{-1}$)

$$AGR = \frac{h_2 - h_1}{t_2 - t_1}$$

where, L - Length of the third leaf from top (cm), W - Breadth of the third leaf from top (cm), and K - Constant (0.6), LAI_i = Leaf area index at i^{th} stage, LAI_{i+1} = Leaf area index at $(i+1)^{th}$ stage $t_2 - t_1$ = Time interval (days), W_1 = Dry matter of the plant (g) at time t_1, W_2 = Dry matter of the plant (g) at time t_2, P = Unit land area occupied by the plant (m^2).

2.5.3. *Leaf gas exchange parameters*

The photosynthetic rate (Pn; µmol CO_2 m^{-2} s^{-1}), transpiration rate (E; mmol H_2O $m^{-2}s^{-1}$) and stomatal conductance (gs; mol H_2O $m^{-2}s^{-1}$) were measured using Portable Photosynthetic System (PPS) Model - LCi-SD of ADC Bio Scientific *Ltd*. The measurement was taken between 9.00 am to 11.00 am. The fully exposed leaf (3^{rd} from the top) was inserted to the leaf chamber (3.0 cm^2) when the steady state was established inside the measurement chamber accordingly the readings were recorded.

2.5.4. *Yield and yield components*

Yield attributes, *viz*., the number of pods per plant, length of the pod, numbers of seeds per pod and seed yield per plant were monitored.

2.6. *Statistical analysis*

The data obtained on various parameters were statistically analysed by using R Studio. One-way ANOVA analysis of the significance at p = 0.05 level was used for the comparison followed by Least Significant Difference (LSD). Correlation was studied to assess the association between the growth indicating parameters. Pearson correlation coefficients were computed and correlograph was plotted using corrplot package in R studio.

3. Results and discussion

The performance of green gram and cowpea with respect to the elevated temperature and CO_2 were observed, along with growth rate and gas exchange pattern. Further, the yield component was estimated on

TABLE 1

Elevated CO_2 and elevated temperature on plant height and Number of leaves

Treatment	Plant height (cm)				Number of leaves			
	Emergence	Vegetative State	Flowering stage	Maturity stage	Emergence	Vegetative State	Flowering stage	Maturity stage
T_1 - (aG)	10.5	29.6	35	38.3	2	11	17	26
T_2 - (eG)	14.5	41.6	48	54.6	2	14	20	32
T_3 - (aC)	15.6	32.6	44.6	54.3	2	20	38	43
T_4 - (eC)	18.2	58.3	94.3	158.0	5	37	51	64
Mean	**14.7**	**40.5**	**55.4**	**76.3**	**2.7**	**20.5**	**31.5**	**41.2**
SEd	**0.1630**	**0.7309**	**0.8641**	**1.5971**	**0.0559**	**0.1915**	**0.4438**	**0.6752**
Cd (p=0.05)	**0.3738**	**1.5926**	**1.8827**	**3.4797**	**0.1218**	**0.4172**	**0.9670**	**1.4710**

TABLE 2

Elevated CO_2 and elevated temperature on Leaf Area Index (LAI) and Leaf Area Duration (LAD)

Treatment	Leaf Area Index (LAI)				Leaf Area Duration (LAD)			
	Emergence	Vegetative State	Flowering stage	Maturity stage	Emergence	Vegetative State	Flowering stage	Maturity stage
T_1 - (aG)	0.0153	0.2453	0.5057	1.3302	0.06	2.2	5.6	22.9
T_2 - (eG)	0.0170	0.8162	1.7788	3.4266	0.07	7.1	19.5	65.1
T_3 - (aC)	0.0310	1.2100	2.6740	3.2813	0.12	10.5	29.1	74.4
T_4 - (eC)	0.1066	2.9247	4.8544	6.2441	0.43	25.8	58.3	138.7
Mean	**0.0424**	**1.2990**	**2.4532**	**3.5705**	**0.17**	**11.4**	**28.1**	**75.2**
SEd	**0.0009**	**0.0124**	**0.0583**	**0.0572**	**0.0011**	**0.2339**	**0.4339**	**1.1007**
Cd (p=0.05)	**0.0019**	**0.0270**	**0.1269**	**0.1247**	**0.0024**	**0.5095**	**0.9454**	**2.3982**

green gram and cowpea under both elevated and ambient conditions.

3.1. *Plant height and Number of leaves*

The plant height and number of leaves of Greengram and Cowpea were depicted in Table 1. The result revealed that the maximum and minimum plant height of Greengram were recorded around 54.6 cm and 10.5 cm respectively, whereas in Cowpea, the minimum and maximum plant heights were 15.6 and 58.3 cm. It was also observed that the plant height (cm) increased gradually over the stages in both green gram and cowpea. On the other hand, comparing the ambient and elevated growth conditions, there was a significant increase in the plant height during all the stages in the +3 °C elevated temperature and CO_2 (600 ppm).

The growth and development of the plant is highly temperature dependent. So, the elevated temperature favored plants' enzymatic and physiological processes, thereby increased the plant height over the stages. However, rate of plant height increase in the cow pea was higher than the green gram. The highest plant height of the bell pepper was observed with elevated CO_2 and elevated temperature, following ambient conditions. (Kumari *et al*., 2019).

Another physiological trait *viz*., number of leaves increased over the stages in the elevated conditions than ambient. The same number of leaves were observed in greengram at emergence stage (2 nos.) during ambient and elevated conditions. The maximum number of leaves were recorded in the maturity stage at the elevated condition (32 nos.). In cowpea, it was recorded with similar results.

TABLE 3

Elevated CO_2 and elevated temperature on Absolute Growth Rate (AGR) and Crop Growth Rate (g/m^2/day)

Treatment	Absolute Growth Rate (AGR)(cm day $^{-1}$)				Crop Growth Rate (g/m^2/day)	
	Emergence	Vegetative State	Flowering stage	Maturity stage	30 DAS	65 DAS
T_1 - (aG)	1.31	1.12	0.36	0.13	0.0308	0.0217
T_2 - (eG)	1.81	1.59	0.43	0.26	0.0796	0.0276
T_3 - (aC)	1.95	1.00	0.80	0.38	0.0393	0.1000
T_4 - (eC)	2.27	2.36	2.40	2.54	0.1052	0.0554
Mean	**1.837**	**1.517**	**0.997**	**0.833**	**0.0637**	**0.0511**
SEd	**0.0366**	**0.0250**	**0.0098**	**0.0034**	**0.0008**	**0.0011**
Cd (p=0.05)	**0.0797**	**0.0545**	**0.0213**	**0.0074**	**0.0017**	**0.0025**

However, there was an increased number of leaves in the emergence stage at the elevated temperature and CO_2 condition. According to Rao *et al.* (2010) plants had considerably consolidated growth parameters (plant height and number of leaves), significantly higher under elevated CO_2 than at ambient CO_2. Numbers of leaves were significantly higher in FACE compared to ambient. This could be attributed to elevated CO_2 acts as Carbon fertilizer increasing leaf number and leaf biomass under elevated CO_2 level (Kaundal *et al*., 2020).

3.2. *Leaf area index (LAI) and Leaf Area Duration (Days)*

The LAI and LAD of Greengram and Cowpea were depicted in Table 2. In green gram and cowpea, maximum LAI was recorded at the maturity stage. In the elevated conditions, a maximum LAI of 3.42 and 6.24 was observed in green gram and cow pea respectively. Amongst the green gram and cowpea, the increase in LAI was maximum in cowpea at both ambient and elevated temperature conditions. In both the crops, leaf area of the crop increased with increase in temperature and CO_2. The variability in leaf area under elevated conditions was more pronounced compared to open conditions. Earlier studies supported that the initiation and expansion of leaves, shoots, branches and reproductive organs were strongly driven by temperature (Morrison and Lawlor, 1999).

In green gram, minimum and maximum LAD was 0.06 and 22.9 at the emergence and maturity stage in the ambient conditions. However, it increased prominently in the elevated conditions. The minimum and maximum LAD observed were 0.07 and 65.1 in the emergence and maturity stage respectively. It was observed that similar trends were followed in cowpea. Maximum LAD of 74.4 and 138.7 was observed in the ambient and elevated conditions respectively. The plants had the highest leaf area when exposed to elevated CO_2, while the lowest was observed the plants were in the ambient condition. Because of the carbon fertilisation effect of elevated CO_2, which led to the production of more structural compounds like proteins, carbohydrates, and amino acids under high rates of photosynthesis (Kumari *et al.*, 2019).

3.3. *Absolute Growth Rate (AGR) and Crop Growth Rate (CGR)*

The AGR and CGR of Greengram and Cowpea were depicted in Table 3. Absolute growth rate of green gram and cowpea under ambient conditions ranged from 1.31 to 1.95 and 0.38, respectively. Under the elevated conditions, AGR among green gram and cow pea ranged from 1.81 to 0.26 and 2.27 to 2.55. In green gram, maximum AGR was recorded at emergence and it has decreased over the stages till maturity. It followed a similar pattern in both ambient and elevated conditions. AGR decreased as the plant matured because of cessation of vegetative growth and senescence of leaves. Under ambient conditions, a minimum absolute growth rate of 0.38 was recorded at the maturity stage in cowpea. On the other hand, a minimum absolute growth rate of 2.27 was observed in the emergence stage and it has significantly increased over the stages under the elevated condition.

Crop growth rate observed at 30 DAS during the cropping period for green gram was 0.0308 and 0.0796 under ambient and elevated conditions respectively. It got decreased to 60 DAS under both conditions. In cowpea, crop growth rate observed at 30 DAS was 0.0393 and

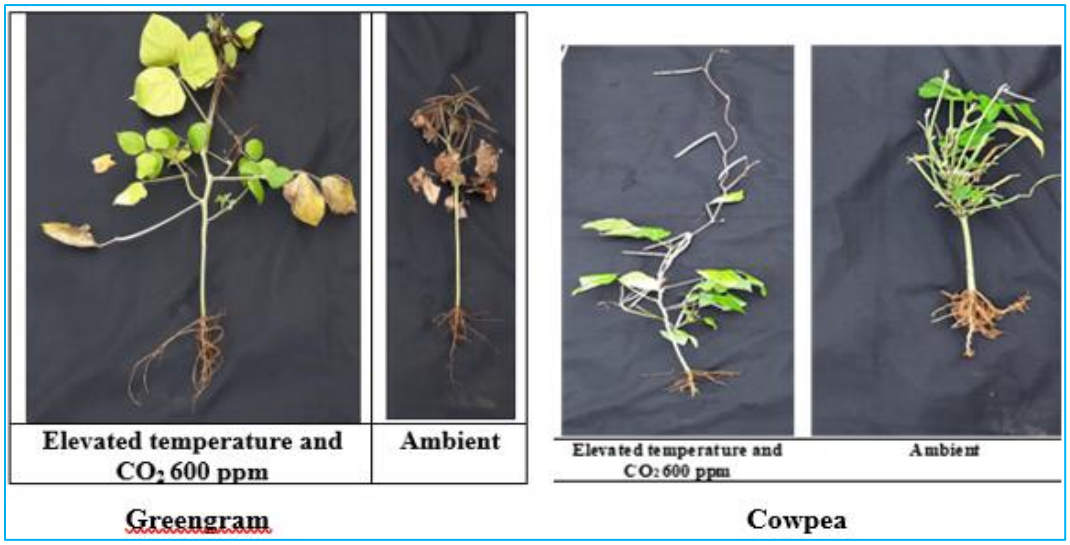

Fig. 2. Observation of growth attributes under both elevated conditions and ambient conditions

TABLE 4

Elevated CO_2 and elevated temperature on Gas exchange parameters (Photosynthetic rate, Transpiration rate, Stomatal conductance)

Treatment	Photosynthetic rate (µmol CO_2 m^{-2} s^{-1})	Transpiration rate (mmol H_2O $m^{-2}s^{-1}$)	Stomatal conductance (mol H_2O $m^{-2}s^{-1}$)
T_1 -aG	13.36	2.74	0.14
T_2 – eG	28.28	3.34	0.25
T_3 – aC	12.5	3.57	0.15
T_4 – eC	24.59	4.22	0.21
Mean	**19.68**	**3.46**	**0.18**
SEd	**0.2868**	**0.1664**	**0.0025**
Cd (p=0.05)	**0.6250**	**0.3625**	**0.0054**

0.1052 under ambient and elevated conditions respectively. Under ambient conditions, crop growth rate has increased with time at 60 DAS.

A similar result was reported that values of crop growth rate were normally low during early growth stages and increase with time, reaching maximum values at the time of flowering (Fageria *et al.*, 2006). Contrarily under the elevated conditions, it decreased over the time. The elevated levels of temperature and CO_2 significantly influenced the differential growth indicating parameters as shown by variation in leaf area, LAI, LAD and CGR. The LAD and CGR were significantly influenced by the elevated CO_2 levels and temperature rather than ambient conditions at all growth stages of the crop (Rangaswamy *et al.*, 2021).

3.4. *Leaf gas exchange parameters*

The photosynthetic rate, transpiration rate and stomatal conductance of Greengram and Cowpea were depicted in Table 4. In greengram and cowpea, photosynthetic rate, transpiration rate and stomatal conductance has a significant increase under the elevated temperature and CO_2 conditions. Among the treatments, greengram and cowpea grown in elevated condition (T_1) recorded the most photosynthetic rate at T_2 (28.28) and at T_4 (24.59) compared to ambient temperature conditions. Higher transpiration rate (3.34 and 4.22) was observed in elevated temperature and CO_2 conditions than ambient conditions in both the crops. Stomatal conductance was an important parameter for deciding the photosynthetic rate. Stomatal conductance had significantly increased at the

TABLE 5

Elevated CO_2 and elevated temperature on yield components of crop

Treatment	Number of pods per plant	Seeds per pod	Pod length (cm)	Pod weights (gram)	100 seed weight	Dry Weight 30 DAS	Dry Weight 65 DAS
T_1 -aG	18	7.6	6.7	0.408	4.254	1.851	3.373
T_2 – eG	28	12	7.5	0.643	4.766	4.778	6.713
T_3 – aC	10	9	11	1.98	14	2.362	9.36
T_4 – eC	14	13	14	2.66	19.77	6.316	10.195
Mean	**17.5**	**10.4**	**9.8**	**1.422**	**10.697**	**3.826**	**7.410**
SEd	**0.1442**	**0.1911**	**0.1631**	**0.0241**	**0.1972**	**0.0587**	**0.0731**
Cd (p=0.05)	**0.3143**	**0.4164**	**0.3553**	**0.0525**	**0.4297**	**0.1278**	**0.1592**

elevated condition in greengram and cowpea (0.25 and 0.21) compared to the ambient condition. The increase in the CO_2 concentration favours the photosynthesis rate, since carbon dioxide is the primary substrate for photosynthesis, leading to a higher plant growth. According to FACE studies, CO_2 enrichment significantly increases the photosynthetic rate for C_3 crops by an average of 30 per cent.

3.5. *Yield attributes*

The yield parameters of Greengram and Cowpea were depicted in Table 5. Similarly, number of pods, pod length, pod weight, 100 seed weight, seeds per pod and dry weight shown a significant increase under the elevated temperature and CO_2 conditions in both greengram and cowpea. The number of pods per plant increased from 18 to 28 and 10 to 14 under elevated conditions in greengram and cowpea. Seeds per pod also increased from 7.6 to 12 in greengram and up to 13 in cowpea. Dry weight has also increased under the elevated conditions. It has also increased over the time as it was observed in 30 DAS and 60 DAS under both the conditions. An increased CO_2 concentration may provide a higher biomass production. Pea crop was recorded highest pod yield, pod size, pod length and pod girth under elevated CO_2 and elevated temperature and the lowest yield was obtained in ambient conditions (Fig. 2). These results were concordance with Martinez *et al.* (2015), Kumari *et al.* (2019).

3.6. *Correlation studies*

The relationship between yield attribute, Growth parameters and physiological parameters by greengram and cowpea under ambient and elevated temperature +3 °C + elevated CO_2 (600 ppm) was interpreted in correlation studies (Fig.3). The correlation values revealed a strong positive relationship between all the

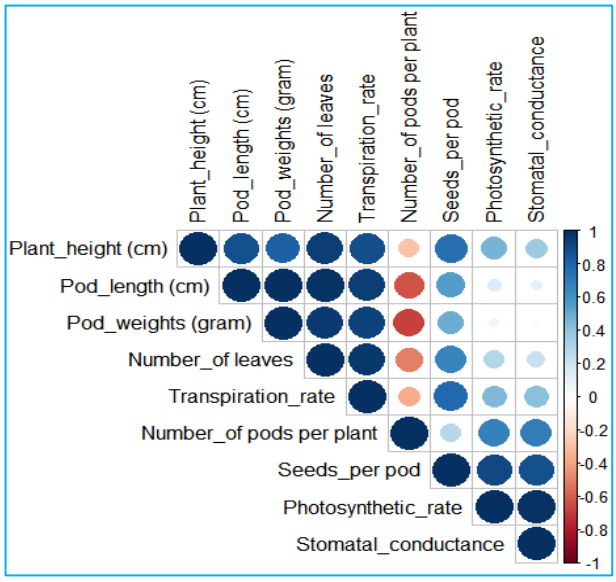

Fig. 3. Relationship between growth parameters and yield parameters of greengram and cowpea under elevated condition [+3°C elevated temperature and elevated CO_2 (600 ppm)] and ambient condition

parameters. The higher plant height and number of leaves favour higher physiological activity under elevated CO_2 and elevated temperature conditions.

4. Conclusion

The study revealed that the elevated temperature and elevated CO_2 had a profound positive impact on the growth and yield parameters of cowpea and greengram. Among two crops under study, Cowpea had a significant positive impact on the growth parameters, *viz.*, plant height, number of leaves, LAI than the greengram. Physiological activity was observed maximum in

greengram which accelerate the yield attributes and had to the attained maximum yield than Cowpea.

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Disclaimer: The contents and views expressed in this study are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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