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RESEARCH ARTICLE

Elevated CO_2 and temperature influence on crop-weed interaction in soybean

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ABSTRACT

Soybean [*Glycine max* (L.) Merr.] is an important oilseed crop in central India. Climate change may have a positive or negative impact on crop-weed competition. Hence, an experiment was conducted in open-top chambers (OTC) to study the effect of ambient (A), elevated CO_2 (EC), elevated temperature (ET) and elevated CO_2+ elevated temperature (EC+ET). EC, ET and EC+ET have a significant encouraging effect on overall growth and yield attributes of weeds and soybean crop. The increase in the biomass of soybean at EC, ET and EC+ET ranged from 21-60% as compared to the ambient conditions. The biomass of *Echinochloa colona* (10-65%) and *Ischaemum rugosum* (16-37%) was found to be increased under EC, ET and EC+ET. EC and ET had a positive impact on plant height and leaf area of soybean, *E. colona* and *I. rugosum*. The seed yield of soybean was observed to be significantly higher at EC (13%) and EC+ET (46%), however at ET no significant increment over ambient was observed. A higher number of pods and nodules per plant were observed at EC and EC+ET. In the presence of *E. colona* and *I. rugosum*, the soybean yield was significantly reduced by 27, 59, 45 and 52% at A, EC, ET and EC+ET conditions, respectively as compared to the weed-free condition. The findings of the present study indicate that C_4 weeds may become more competitive with C_3 crops, thereby emphasizing the necessity of conducting future studies on C_3 and C_4 crop-weed competition under changing climatic conditions.

Keywords: Climate change, *Echinochloa colona*, Elevated CO_2, Elevated temperature, *Ischaemum rugosum*, Soybean

INTRODUCTION

Climate change, with measurable long-term shifts in climate patterns like rising temperatures, CO_2 levels, and precipitation, is likely to harm global agriculture (Korres *et al.* 2016). Future climate predictions include higher temperatures, altered rainfall patterns, and increased climate extremes, posing detrimental impacts on agriculture (IPCC 2014, FAO 2016, IPCC 2018). Temperatures have already risen by 0.1 to 0.3°C per decade globally since pre-industrial times, with a projected increase of 1.5°C by 2030-2052 (IPCC 2014, 2018). CO_2 concentrations have surged since the industrial revolution, currently at 419 µmol mol-1, nearly 50% higher than pre-industrial levels, and expected to exceed 700 µmol mol-1 by the century's end (NOAA Mauna Loa Atmospheric Baseline Observatory 2021, Long *et al.* 2004, Ainsworth *et al.* 2008, Salazar-Parra *et al.* 2018). These changes may seriously impact agriculture and threaten global food security (Ozdemir 2022).

C_3 and C_4 plants have distinct photosynthesis temperature responses. In C_3 plants, higher CO_2 levels favor ribulose-1,5-bisphosphate (RuBP) carboxylation, but temperatures above 25°C promote oxygenation, leading to photorespiration and hindering CO_2 assimilation (Jorden and Ogren 1984). Conversely, C_4 plants are minimally affected by temperature due to lower photorespiration and faster CO_2 fixation by PEP carboxylase in bundle sheath cells (Hatch, 1987, Hadi *et al.* 2020). Additionally, high CO_2 enhances dark respiration in soybean via metabolic reprogramming, while this effect is not observed in other species (Leakey *et al.* 2009). Due to these photosynthetic pathway differences, C_3 plants respond more robustly to increasing CO_2 levels, whereas C_4 plants are better suited for heat stress and drought, boasting higher water use efficiency (Osmond *et al.* 1982, Morgan *et al.* 2001).

Weeds are one of the important biotic constraints in agriculture, which may cause

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economic losses of ~USD 11 billion to 10 major crops in India and in soybean it may cause an economic loss of USD 1559 million (Gharde *et al.* 2018). In soybean, *E. colona, I. rugosum, Dinebra retroflexa, Commelina communis, Commelina benghalensis, Alternanthera paronychioides, Eclipta prostrata, Cucumis pubescens etc.* are major competitors, which sometimes cause meagre crop growth and seed yield (Shobha, 2001). *E. colona* and *I. rugosum* are dominant weed species causing significant yield loss and reduced seed quality in soybean (Alarcon Reverte *et al.* 2015, Reddy *et al.* 2013). Weeds have unique traits, *viz.* short life cycle, prolific seed producer, dispersal mechanisms, *etc.* which make them competitively superior to crops under climate change scenarios (Naidu and Murthy 2014).

The continuing rise in the concentration of atmospheric CO_2 would therefore have important consequences for crop-weed competition and crop yield reduction. Various studies have investigated the crop-weed interactions by evaluating the comparative growth and physiology of C_3 crops and C_4 weeds and reported that increased CO_2 concentrations typically promote C_3 plant species vegetative development over C_4 pathways (Patterson 1995). Although not all crops are C_3 based, and not all weeds are C_4 based (Ziska *et al.* 2010). Therefore, the above definition is applicable to cereals such as rice, which primarily compete with grassy C_4 and broad-leaved weeds; this is not a universal situation. There are several economically significant C_4 crops, such as maize, sugarcane and sorghum, which compete with critical C_3 weeds, such as *Chenopodium album* L. (Ziska 2000).

Predicting competition based on isolated species' responses cannot accurately represent weed competition with crops under varying CO_2 conditions, as weeds typically occur in mixtures (Ziska 2001). Evaluating weed competition in mixed environments is crucial since most studies focus on isolated CO_2 effects on crops and weeds. Few reports examine crop-weed response to CO_2 in competitive settings (Ziska 2001, 2004; Valerioa *et al.* 2013), and little attention is given to elevated CO_2 impact on weed distribution in managed ecosystems (McDonald *et al.* 2009). Climate change will likely increase weed competition, leading to higher yield reduction without proper control (Miri *et al.* 2012, Valerio *et al.* 2013). Climate-induced constraints on plant growth resources may alter crop-weed competition in different cropping systems. Detail study is required to identify problematic weeds in future climates to establish effective management strategies.

Soybean is a significant oilseed crop and food legume used for protein in animal feed (Pratap *et al.* 2011). India plays a crucial role in the global soy industry, producing various soy products (Tiwari 2022). Given its importance, studying the effects of climate change on soybean and associated weeds (*E. colona, I. rugosum, D. retroflexa, C. communis, C. benghalensis*) is vital. However, information on this topic is limited. To the best of our knowledge, the data in the present investigation are novel in being the first to demonstrate the implications of significant weeds on soybean growth under the regime of climate change. This study examines the impact of elevated CO_2 and temperature on soybean and associated weeds (*E. colona* and *I. rugosum*) using open-top chambers (OTCs). It was hypothesized that the effects of elevated CO_2, temperature, and weeds on soybean growth, physiological, and yield traits would differ.

MATERIALS AND METHODS

Soil, climate and experimental unit

The interactive effect of crop-weed interaction was studied in Open Top Chambers (OTCs) at ICAR-Directorate of Weed Research, Jabalpur research farm. The location of the experimental site was 23°13'58.63" N latitude and 79°58'05.02" E longitude. Climatic condition is humid subtropical, with summer set about the late march and lasting until June, and summer followed by south-west monsoon which lasts until early October and produces average annual rainfall of ~1386 mm. The soil of the experimental site was clay loam in texture with low organic carbon content having a pH of 7.6. The experiment was laid out in factorial complete randomized design. The levels of CO_2 were ambient (407.4 ppm) and elevated (550±50 ppm), and the temperature was ambient and elevated (ambient+2 ºC). The OTC was made off of polycarbonate sheets (6.0 mm thickness) with an open top and dimension of 2.9 m height with 1.35 m diameter and the total experimental area in each OTC is 5.72 m^2 area. Gaseous CO_2 was supplied continuously to OTCs through nozzles fitted to PVC fiber reinforced hose pipes connected to CO_2 cylinders. CO_2 concentration within the chambers was monitored and maintained through CO_2 analyzer fitted in the chamber and connected to computer system. Elevation in temperature was realized through infrared heaters.

Crop cultivation

Soybean crop, cv. *'RSK-2004-1'* was grown during the rainy seasons of 2018 and 2019. The crop was sown in the first week of July with 40 cm row-to-row and 15 cm plant-toplant spacing. The recommended dose of fertilizer (30–60–40 kg N, P and K/ha) was applied during sowing as basal along with vermicompost at 2.5 t/ha. The cultivable area in OTC was divided into 3 equal parts of 1.80 m^2 each and each OTC plot was marked and seeds of two grassy weeds, *viz. E. colona* and *I. rogosum* (collected from the weed cafeteria of the DWR farm) were broadcasted separately in each plot at the time of soybean crop sowing and one portion was kept weed free. After the emergence of crop and weed, the populations of both the weed species were maintained at 10 numbers/m^2 and other weed seedlings were removed at 5-7 days intervals. One plot was maintained weed-free by weeding 5-7 days intervals. The crop was protected from insect attack by spraying chlorpyrifos 25 EC and triazophos 40 EC 1.5 and 0.75 lit/ha respectively.

Observations

The plant growth parameter *viz*. plant height, above-ground biomass, number of root nodules yield attributes and yield were recorded in soybean. The number of root nodules was recorded at the anthesis stage. The plant height, dry biomass and the number of tillers were recorded in two weed species. Three plants each from crop and weeds were randomly selected for the observations from each treatment. Plant height and dry biomass were recorded at the maturity stage. Plant height was measured from ground level to the apical tip of the plant using a 5 m measuring scale. Dry biomass (above ground) was determined by drying in a hot air oven 60°C. The number of nodules and fresh weight were taken at the maximum flowering stage. The number of pods/plant and seed yield/5 plants were taken at harvest.

Statistical analysis

The recorded data on the selected parameters were analyzed using analysis of variance (ANOVA) as relevant for a completely randomized design. Treatment effects were determined by analysis of variance using the general linear model procedure of the SPSS package program version 16.0 (SPSS Inc., Chicago, IL, USA). Treatment means were separated with the use of Duncan's multiple range test at a 5% level of significance.

RESULTS AND DISCUSSION

Effect of elevated CO_2 and temperature on root nodules

The findings of the present study revealed that the number of root nodules was significantly

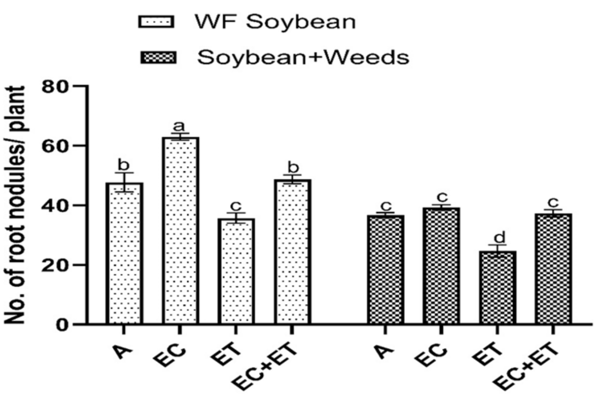

Figure 1. Effect of *E. colona* and *I. rugosum* on number of root nodules in soybean under different climatic conditions (pooled data of two years).

The data presented above are Mean ± SE (n = 3). *A*-Ambient; *EC*-Elevated CO_2; *ET*- Elevated temperature; *EC+ET* combined effect of EC and ET. Different lowercase letters on vertical error bars indicate significant difference at P = 0.05 level in Duncan's test.

increased under elevated CO_2 (EC) by 32.17% in comparison to ambient (A). However, elevated temperature (ET) had a negative effect on root nodules because the nodule count was decreased by 25.17% in comparison to A. Whereas, *E. colona* and *I. rugosum* weed interference severely impaired the root nodule number among all the treatments compared to weed-free soybean and higher reduction was observed under ET (**Figure 1**).

Effect of elevated CO_2 and temperature on yield and yield attributes of soybean

Elevated CO_2: EC had a positive effect on yield and yield attributes under weed-free conditions. An increase in CO_2 concentration by 550 ppm significantly increased the plant height of soybean by 13% over the ambient condition. However, a slight increase (3.25%) in plant height was observed under weedy conditions. Similarly, plant dry weight was increased by 13.42% under EC in comparison with ambient. Likewise, a reduction in plant height (16.48%) was observed under weedy conditions. Under EC the number of pods/plants was increased by 7.88% and this was found to be significantly reduced by 42.42% under weedy conditions. EC had a positive effect on yield and it was significantly increased by 37.61%. However, weed interference reduced the yield by 31.12% in comparison to ambient (**Figure 2a, b, c, d**).

Elevated temperature: An increase in temperature by 2ºC decreased the plant height by 6.25% in weed-free soybean over the ambient condition. Whereas, the plant height of soybean was found to be significantly reduced by 49.47% due to weed interference. Similarly in weed-free soybean, the plant dry weight, the number of pods/plant and yield were impaired and it was observed to be reduced by 19.44%, 26.67 and 5.48, respectively. However, weed interference had a profound effect on yield and yield attributes of soybean and it was observed that the plant height, plant dry weight, the number of pods/plant and yield decreased by 47.80%, 95.42% and 56.40% respectively, over the ambient condition (**Figure 2a, b, c, d**).

The combined effect of elevated CO_2 and temperature

Negative effects of elevated temperature were slightly negated by elevated CO_2. Under the combined effect of elevated CO_2 and temperature, the soybean yield and yield attributes were severely impaired in both weed-free conditions and weedy conditions. The plant height, dry weight, number of pods/plant and yield was found to increase by 6.73%, 7.62%, 4.24% and 7.16%, respectively in weed-free soybean over the ambient conditions. However, weed interference had a negative effect under the combined effect of elevated CO_2 and temperature. It was observed that the plant height, dry weight, the number of pods/plant and yield was significantly decreased by 6.01%, 18.78%, 49.70% and 33.42% in comparison to weed-free ambient condition (**Figure 2a, b, c, d**).

Effect of elevated CO_2 and elevated temperature on weed growth

It was found that *E. colona* and *I. rugosum* biomass, growth traits like plant height, plant dry weight and the number of tillers responded positively under EC and ET and EC+ET as compared to the ambient condition. The plant height of *E. colona* was enhanced by 25.73%, 10.79% and 28.22% under EC, ET and EC+ET, respectively. Similarly, plant dry weight was increased by 62.63%, 64.92% and 9.65% under EC, ET and EC+ET, respectively. The number of tillers/plant increased by 85.92%, 146.48% and

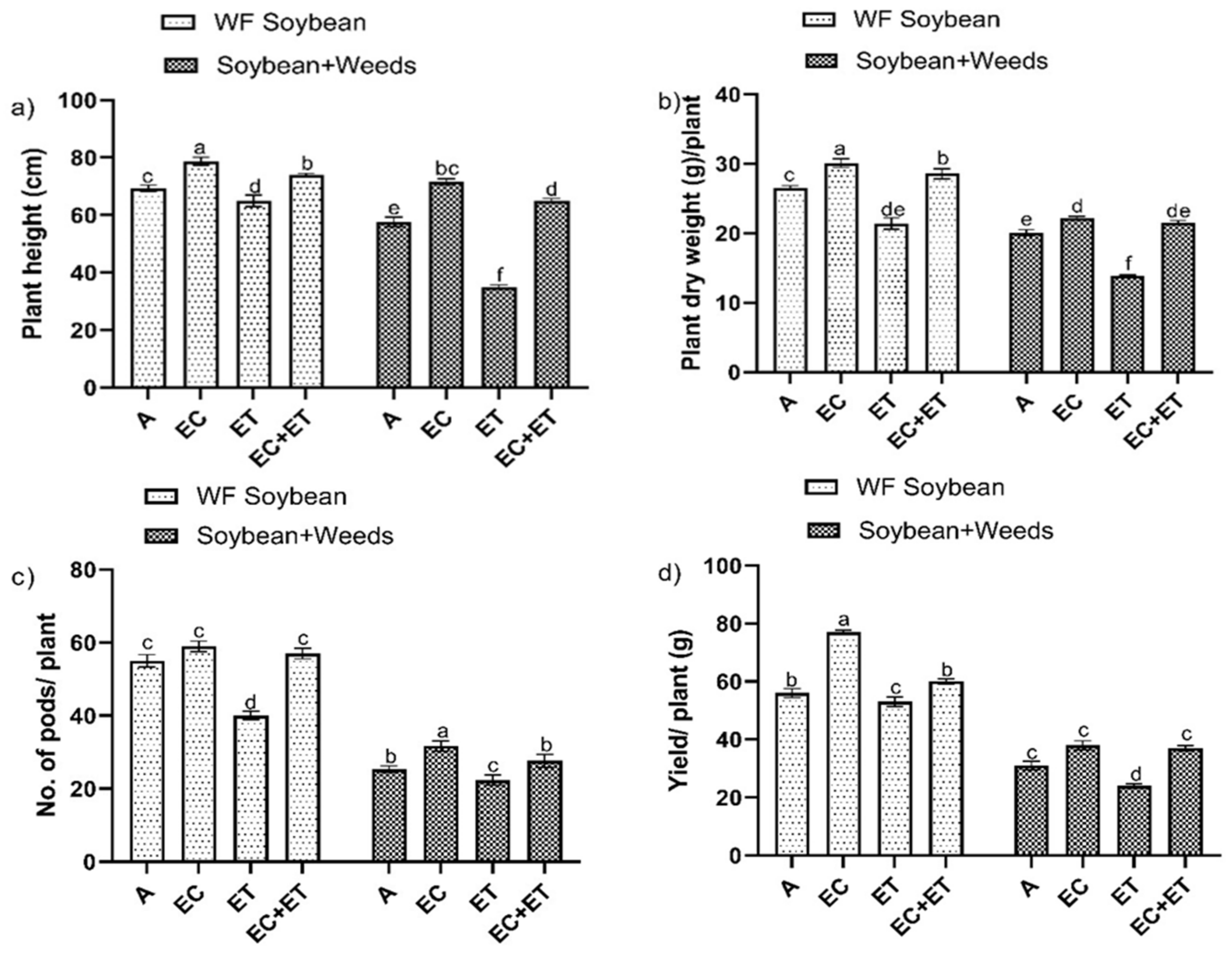

Figure 2. Effect of *E. colona* and *I. rugosum* on plant height (a), plant dry weight (b), number of pods/plant (c) and yield/ plant (d) in soybean under different climatic conditions. (pooled data of two years).

The data presented above are Mean ± SE (n = 3). *A* Ambient; *EC* Elevated CO_2; *ET* Elevated temperature; *EC+ET* combined effect of EC & ET. Different lowercase letters on vertical error bars indicate significant difference at P = 0.05 level in Duncan's test.

33.80% under EC, ET and EC+ET, respectively over ambient conditions (**Figure 3a**).

Similarly, in the case of *I. rugosum*, the plant height was found to be increased by 40.79%, 26.35% and 32.85% under EC, ET and EC+ET, respectively. The plant dry weight was increased by 16.21%, 37.15 and 27.83% under EC, ET and EC+ET, respectively. Likewise, the number of tillers/plant was found to be enhanced by 56.76%, 89.19% and 24.32% under EC, ET and EC+ET, respectively in comparison to ambient conditions (**Figure 3 b**).

EC, ET and EC+ET had a significant encouraging effect on the overall growth and yield attributes of weeds and soybean crop. Increased biomass by 13.42% and 7.62%, under EC and EC+ET, respectively was observed in weed-free soybean. Lenka *et al.* (2017) also reported a 47% increase in soybean biomass at harvest. Increase in biomass in soybean grown under elevated CO_2 was reported earlier (Tobert *et al.* 2004, Ziska 2000 Morgan *et al.* 2005 and Madhu and Hatfield 2016). In a study under EC+ET, Bhattacharyya and Roy (2013) found higher above-ground biomass in rice crops due to the higher rate of carboxylation and reduced rate of photorespiration. The biomass of *E. colona* was found to be increased by 62.63%, 64.92% and 9.65% under EC, ET and EC+ET, respectively. Whereas, the biomass of *I. rugosum* was observed to be increased by 16.21%, 37.15 and 27.83% under EC, ET and EC+ET, respectively. Ziska (2000) reported a significant increase in average biomass in *C. album* and no change in the average biomass of *Amaranthus retroflexus* at EC. However, Alberto *et al.* (1996) reported no significant biomass increase at EC in *Echinochloa glabrescens*. This indicates that *E. colona* is more responsive to EC and ET than *E. glabrescens*. Elevated CO_2 and temperature have increased the plant height of soybean, *E. colona* and *I. rugosum* significantly under OTC condition, which might be due to the increased rate of biochemical processes resulting in cell proliferation due to higher cell division and elongation (Wang *et al.* 1997, Pritchard *et al.* 1999, Geethalakshmi *et al.* 2017). Geethalakshmi *et al.* (2017) reported an encouraging effect of elevated CO_2 and temperature on plant height. However, leaf area, dry weight and grain yield were lower under changing climatic conditions which may be due to the higher temperature level (4 ºC) and higher CO_2 concentration (650 ppm).

The seed yield of soybean was significantly higher 37.61% and 7.6% at EC and EC+ET, respectively; however, at ET conditions there was no significant increment over the ambient conditions.

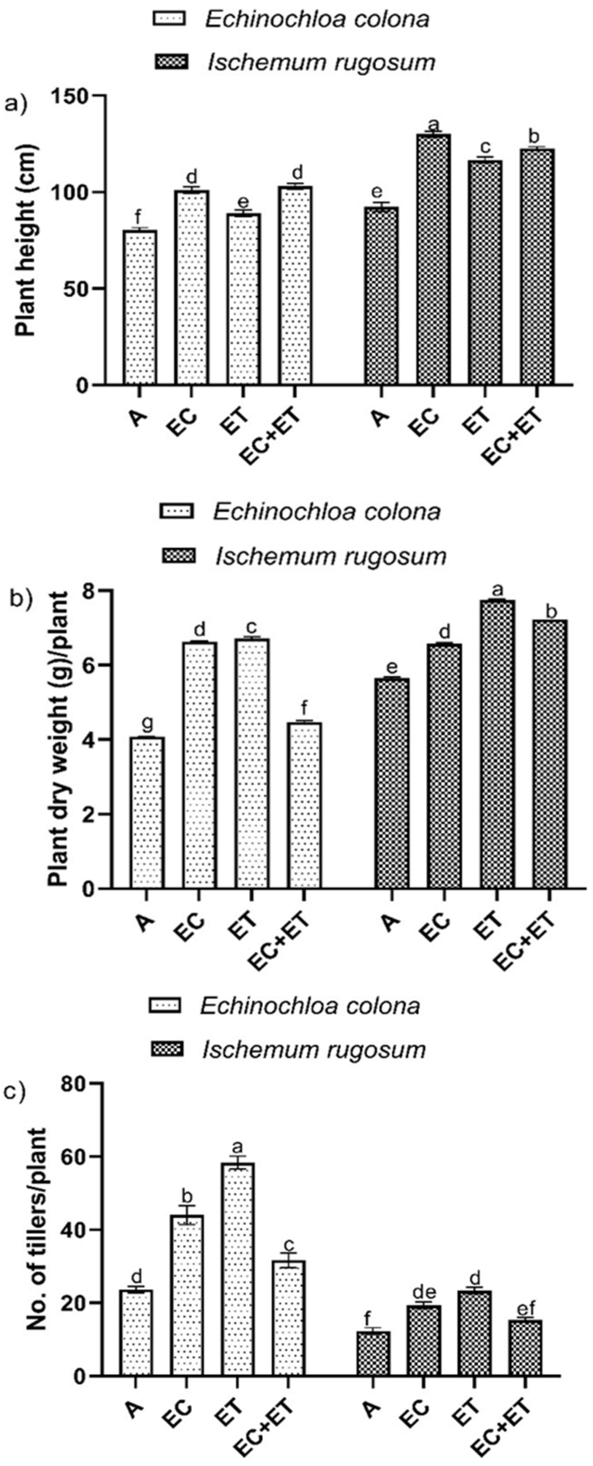

Figure 3. Effect of elevated CO_2 (EC) and elevated temperature (ET) on weed (*E. colona* and *I. rugosum*) growth and biomass (Pooled data of two years)

Plant height (a), Plant dry weight (c) and Number of tillers/ plant (c). The data presented above are Mean ± SE (n = 3). *A* Ambient; *EC* Elevated CO_2; *ET* Elevated temperature; *EC+ET* combined effect of EC & ET. Different lowercase letters on vertical error bars indicate significant difference at P = 0.05 level in Duncan's test.

Lenka *et al.* (2017) reported a yield increase at EC (51%), ET (30%) and EC+ET (65%) over the ambient condition. Bhattacharyya and Roy (2013) observed an increment of 24% in the grain yield of rice in EC. Due to floral sterility in rice at elevated temperatures, a 33.8% yield decrease was noticed; however, 69.6% higher grain yield was observed at EC conditions (Kim and Young 2010). In a pot experiment in a controlled environment of phytotron, Rakshit *et al.* (2012) reported an 11% increase in grain yield of wheat at EC (650 ppm), conversely significantly decreased (38%) the grain yield at ET conditions.

A higher number of pods and nodules per plant was observed at EC and EC+ET, hence this may be the possible reason for the higher seed yield of soybean under EC and EC+ET. Hikosaka *et al.* (2011) reported that legumes have enhanced capacity to fix nitrogen due to the presence of root nodules leading to higher seed weight and yield of soybean under EC and EC+ET conditions compared to the non-nitrogen fixing plants. In soybean growing under the weedy condition of *E. colona* and *I. rugosum*, compared to the weed-free condition, the yield was reduced by 31.12%, 56.40% and 33.42%, respectively at ambient, EC, ET and EC+ET conditions. Ziska (2000) reported that the soybean yield decreased by 28 and 45%, respectively by *C. album* and *A. retroflexus* under ambient conditions, whereas a 39 and 30% decrease was observed respectively by *C. album* and *A. retroflexus* under EC conditions. Similarly, Pawar (2022) observed that the impact of *Alternanthera paronychioides* was more under EC, ET, EC+ET conditions in rice. The data obtained from the current study are in general agreement with the study of Ziska (2000) and Treharbe (1989) that modern cultivars are less diverse than weeds as they possess more physiological plasticity.

It was concluded that the impact of EC, ET and EC+ET had a positive impact on the growth and development of weeds (*E.colona* and *I. rugosum*). This in turn enhanced the competitive strength of these weeds resulting in higher yield reduction of soybean under climate change scenarios. Therefore, both these C_4 weeds may become problematic weeds in soybean crops in futuristic climate change scenarios.

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