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Effect of elevated temperature and carbon dioxide on wheat (*Triticum aestivum*) productivity with and without weed interaction

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ABSTRACT

Wheat (*Triticum aestivum* L.) crop is one of the most valuable crops, and further boost in wheat yields is essential to meet the food demand of the emerging world population. It is therefore necessary to know the influence of future climate change on wheat yields. Present investigation was conducted in temperature gradient tunnel (TGTs) to evaluate the effects of elevated temperature, CO₂ concentration, weed and their interactions on grain, biological yield and other yield attributes (number of spikes/m², number of spikelets/spike, number of grains/spike and 1000-grain weight, harvest index) of wheat. Wheat crop was grown in TGT at three different temperature levels, i.e. T₁ ambient, T₂ ambient+1.5°C, T₃ ambient+3°C and two levels of carbon dioxide, i.e. ambient (ACO₂) 400 ppm and elevated (ECO₂) 550±50 ppm with and without weed interaction. The study revealed that yield and yield attributes of subsequent wheat crop increased due to ECO₂. Mean individual effect of ECO₂ increased grain yield of wheat by 14% and biological yield by 12% compared to ACO₂. On the contrary, the yield was decreased with elevated temperature where a decrease in the grain yield from -12% to -20% and biological yield from -11% to -18% was observed at 1.5°C and 3°C, respectively. Similarly the interaction of weeds in wheat crop, reduced the grain yield by 8% and biological yield of wheat by 6%, irrespective of CO₂ and temperature levels. The statistical analysis (P<0.05) revealed significant effect of the interactions (C×T, C×W, W×T, and C×T×W) on yield. Overall results the study proposal to adapt an effective weeds management strategy to controlled conditions of yield of wheat crop under the controlled conditions of CO₂ and temperature.

Key words: Carbon dioxide, Elevated temperature, Weed, Wheat yield

Globally, climate change is occurring at an alarming rate because of enhanced greenhouse gas emission such as carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O). Pre-industrial level of CO₂ was around 280 ppm in 1750 AD which has now increased to more than 400 ppm which has caused warming of the planet by 0.84°C. An increase in the global average temperature by 3.7 to 4.8°C is expected by the end of the 21st century IPCC (2014) which is likely due to the continuous increase in concentrations of CO₂ and other GHGs in the atmosphere (Abebe *et al.* 2016). Changing climate has a considerable impact on agriculture and food security especially for those countries which have a large population dependent on rainfed agriculture. According to IPCC (2014) forecast,

climate change in South Asia would possibly result in 20% reduction in wheat production by 2030 (McKersie *et al.* 2015). Wheat is among the most widely cultivated crops in the world and 2nd most important staple food crop in India. Climate change is expected to influence the productivity of the wheat crop. An increase in CO₂ resulted in higher grain yield, whereas an increase in temperature reduced the grain yield by 10-12% grain yield. At present, many reports are indicating that rising carbon dioxide concentration and projected changes in climate could favour the growth and development of weeds over crops. This can have negative consequences for agricultural productivity (Peters *et al.* 2014, Ziska 2007). Agriculture scientists have started paying more attention to crop-weed competitiveness in a high CO₂ environment, and it has been suggested that possibly recent increases in atmospheric CO₂ concentration during the 20th century may have been an important factor in the selection of weed species and a contributing factor of invasiveness weeds species like *Lantana* and *Parthenium* may become more aggressive under climate change mainly due to increasing carbon dioxide concentration in the atmosphere. The study of weed plants, their abundance and allocation are useful in the determination of how a plant population

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is altering their behavior over time in response to different climatic conditions (Nkoa *et al.* 2015). The major weed flora recorded in the wheat field under weedy check plot was little seed canary grass (*Phalaris minor*) accounted for 56% and common lambsquarters (*Chenopodium murale*) (7.5%) (Radhey *et al.* 2009). In agriculture, weeds cause more damage compared to insects, pests and diseases but due to hidden loss by weeds in crop production, it has not drawn much attention (Pisal and Sagarika 2013). Due to CO₂ enrichment, the wheat plant could gain biomass against *P. minor* (Oerke *et al.* 2006). Keeping above facts in view, the present investigation was undertaken to assess yield response of wheat to elevated temperature and CO₂ in relation to crop-weed competition.

MATERIALS AND METHODS

The field experiment was conducted during winter season of 2015-16 at ICAR-Indian Agricultural Research Institute, New Delhi (latitude 28°37' and 28°39' N, longitude 77°9' and 77°11' E). The climate of site is semi-arid, sub-tropical, sub-humid with hot dry summer and severe cold winters. During experimentation, The average maximum temperature during the crop season was 32°C while the average minimum temperature was 6.1°C. Average relative humidity (RH) was 77% during crop season December to March. The experiment was laid out in two separate temperature gradient tunnels (TGTs) tunnel-1 with ambient CO₂ level 400 ppm and tunnel-2 with elevated CO₂ level 550±50 ppm were used in order to study the effect of both temperature and carbon dioxide. Both the tunnels were divided into 3 thermal regimes (T₁, T₂, T₃) fitted with temperature sensors to monitor the temperature gradient during the crop growing season and again the area in both tunnels was further divided into two parts along the tunnel to grow the wheat crop with and without weeds infestation and all the temperature and weed treatments were replicated thrice (Table 1). Wheat variety HD 2967 was sown in the last week of November with recommended practices. During the sowing time, seeds of *Phalaris minor* and *Chenopodium murale* were broadcasted in the field. Weedy plots were retained with five numbers of each weed species, while all the weeds were removed from weed free wheat plots. Management of crop was done throughout the growing season as per the recommended agronomic practices. All treatments were provided with nitrogen at the rate of 120 kg/ha N by way of urea and phosphorus at the rate of 60 kg/ha P₂O₅. Half quantity of N and full quantity of P₂O₅ and K₂O was applied at the time of sowing and remaining half quantity of N was top dressed after first irrigation. Under elevated CO₂ treatment, level of CO₂ was maintained at 550±50 ppm inside the TGT by releasing from compressed CO₂ gas cylinders. The gas was supplied through 30 kg capacity CO₂ cylinder from the inlet side of tunnel using perforated PVC pipe of 1 inch diameter. Desired levels of temperature and CO₂ level inside the tunnels were maintained by adjusting the speed of exhaust fans and regulator of CO₂ cylinder. Temperature recorded by the three sensors are in

Table 1 Treatment details with abbreviation

Treatment	Treatment description	
ACO ₂ T1W1	Weed free plots	Ambient temperature and ambient CO ₂
ACO ₂ T2W1		Ambient temperature+1.5°C and ambient CO ₂
ACO ₂ T3W1		Ambient temperature+3°C and ambient CO ₂
ACO ₂ T1W2	Weedy plots	Ambient temperature and ambient CO ₂
ACO ₂ T2W2		Ambient temperature+1.5°C and ambient CO ₂
ACO ₂ T3W2		Ambient temperature+3°C and ambient CO ₂
ECO ₂ T1W1	Weed free plots	Ambient temperature and elevated CO ₂
ECO ₂ T2W1		Ambient temperature+1.5°C and elevated CO ₂
ECO ₂ T3W1		Ambient temperature+3°C and elevated CO ₂
ECO ₂ T1W2	Weedy plots	Ambient temperature and elevated CO ₂
ECO ₂ T2W2		Ambient temperature+1.5°C and elevated CO ₂
ECO ₂ T3W2		Ambient temperature and ambient CO ₂

the following order S1< S2< S3. During the experiment, crop growing the average air temperature of temperature gradient tunnels were higher than average outside condition. Temperature elevation created inside (both TGTs) for whole growing period season 2015-16 were in the order of near ambient (T₁) < ambient +1.5°C (T₂) < ambient +3°C (T₃) than outside temperature condition.

Wheat samples were collected at maturity stages from both tunnels. The wheat samples were collected to assess grain yield and biological yield, after physiological maturity and found related yield attributes such as numbers of spikes/m², spikelets/spike, number of grains/spike, 1000-grain weight and harvest index. Harvest index is the ratio of the economic yield to biological yield. The biological yield included both economic yield and biomass produced. The harvest index is expressed as percentage using the formula given here.

$$\text{Harvest Index (HI)} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

The data obtained from study for year 2015–16 were tested and analyzed statistically by ANOVA using randomized block design (RBD) and the means were compared between the treatments and their interactions by critical difference (CD) at P<0.05 level of significance.

RESULTS AND DISCUSSION

Effect of elevated CO₂, temperature and crop-weed interaction on yield and yield attributes of wheat

The crop yield is generally defined by grain yield and

biological yield. Further, the yield is depicted by many attributes, viz. number of spikes/m², number of spikelets/spike, number of grains/spike and 1000-grain weight (g), harvest index. Different treatments of elevated temperature, CO₂ and weed interaction given during growth of the crop affect different crop characters which has direct impact on crop yield. For comparing the effect of individual treatment at a time, the mean values obtained under the particular condition were compared. The results of study are presented as effect of individual treatment and their interaction on different parameters.

Effect of elevated carbon dioxide level in the air

The current study revealed that grain yield of wheat increased by ~14% under the exposure of elevated levels of CO₂ (550±50 ppm) across the temperature gradient tunnels irrespective of temperature and weed treatments. The enhancement of yield was mainly attributed to marked increase in the number of spikes/m² (10.6%) and grains/spike (7.8%) while on the contrary 1000-grain weight was least affected by the same. An increase in the total grain yield in wheat was also reported by Amthor *et al.* (2001), Singh *et al.* (2013) and Wang *et al.* (2015) at increased CO₂ levels. Similarly, CO₂ fertilization enhanced the biological yield of wheat regardless of the thermal regimes and weed treatments. After CO₂ treatment an increase of ~12% was observed in the biological yield (Table 2) similar trend in increase in yield was reported by Kimball *et al.* (2011)

where an increase from 8 to 26% in the grain yield was observed at elevated CO₂ levels. The increase in yield was mainly attributed to marked increase in the number of spikelets (~7%) and grains/spike (23%). With increase in number of spikes bearing tillers under elevated CO₂ levels an increase in grain yield of wheat was also reported by Fangmeier *et al.* (1996). However, 1000-grain weight and harvest index remained least affected by elevated CO₂ levels, where an increase of 3.21% and 1.76% was observed after treatment. These findings are supported by study of Hoky and Fangmeier (2008) on wheat exposed to increased CO₂ level. This increase in yield and yield attributes is mainly attributed to marked increase in photosynthetic rate of leaves under enhanced CO₂ level, which is a limiting factor in many C₃ crops as stated by Kimball *et al.* (2002). On the other side, Leakey *et al.* (2009) reported that the accumulation of carbohydrates in leaves is one of the most apparent responses of C₃ plants to raised CO₂ level, causing acclimation of photosynthetic capacity.

Effect of elevated temperature

On the contrary to effect of CO₂, exposure to elevated temperatures, in general led to a significant depletion in grain and biological yields of wheat crop irrespective of CO₂ and weeds treatments. The extent of reduction in grain yields increased from -12 to -20% when temperature was raised from 1.5 to 3°C. Prabhjyot-Kaur and Hundal (2006) also supported same trend and found 29% decrease in grain yield

Table 2 Effect of elevated temperature, carbon dioxide and weed on yield and yield attributes of wheat crop

Treatment			No. of spike/m ²	No. of spikelets/spike	No. of grains/spike	1000-grain wt (g)	Grain yield (g/m ²)	Biological yield (g/m ²)	Harvest index
ACO ₂	W ₁	T1	510.50	18.00	50.37	36.20	645.83	1439.51	44.86
		T2	457.01	17.00	47.29	34.32	570.53	1288.78	44.27
		T3	410.23	15.73	44.30	32.70	521.18	1195.30	43.60
	W ₂	T1	486.23	15.99	44.47	34.52	615.23	1400.20	43.94
		T2	430.23	15.23	44.87	32.56	536.20	1232.50	43.50
		T3	390.23	14.85	43.20	31.56	495.30	1164.50	42.53
ECO ₂	W ₁	T1	562.30	19.25	54.30	37.50	760.23	1652.20	46.01
		T2	510.23	18.50	50.23	35.23	665.25	1478.20	45.00
		T3	470.05	17.65	48.20	33.25	603.52	1370.23	44.04
	W ₂	T1	522.66	18.32	48.78	36.00	684.23	1537.20	44.51
		T2	470.23	17.65	48.03	34.23	605.15	1375.20	44.00
		T3	432.50	16.51	46.25	32.12	536.23	1225.20	43.77
<i>CD (P = 0.05)</i>									
Carbon dioxide (C)			3.09	2.91	1.98	0.96	2.91	3.09	0.21
Temperature (T)			3.78	3.56	2.42	1.18	3.56	3.78	0.25
Weed (W)			3.09	2.91	1.98	0.96	2.91	3.09	0.21
Interaction C × T			5.34	5.04	ns	ns	5.04	5.34	ns
Interaction C × W			4.36	4.1	ns	ns	4.11	4.36	ns
Interaction W × T			5.34	ns	ns	ns	ns	q	ns
Interaction C × W × T			7.56	7.13	ns	ns	7.13	7.56	0.51

ns, non-significant at P<0.05

of rabi crops such as wheat under increased temperature levels of 1-3°C. Similarly, the biological yield also reduced by 11% at elevated temperature (+1.5°C) and this reduction was further pronounced to 18% when the temperature was increased by 3°C in comparison to the ambient temperature. The results depicted low thermal sensitivity of biological yield as compared to grain yield (Table 2).

This reduction in grain and biological yield was a result of decrease in the number of spikes/m² (-10% and -18%); 1000-grain weight (~5% and ~10%) and number of grains/spike by ~4% and ~8% at 1.5°C and 3°C, respectively. However, harvest index was least affected by rise in thermal regimes (2% and 3%). Sinha and Swaminathan (1991) also reported the decline in wheat yield with 2-4°C rises in temperature. Several other studies have also reported eminent reduction in grain yield of wheat, which was attributed to gradual reduction in spikes/m², grains/spike, 1000-grain weight and also due to spikelet sterility and shortening of crop growth duration (Chakrabarti *et al* 2013). This reduction was due to effect of elevated temperatures on grain yield which accelerates phenology and reduce biomass production (Van Ittersum *et al* 2003).

Effect of crop-weeds interaction on yield

Irrespective of CO₂ and temperature treatments, weed interaction caused about ~8% and ~6% reduction in grain and biological yield of wheat, respectively Gharde *et al.* (2018) summarised a yield loss of 7.5–41.0% due to the infestation of weed. The reason for increased yield losses due to weed interaction is because of the similar photosynthetic pathway and nutritional level of weeds and main crop (Pagare *et al.* 2017). Further, weed shows better survival mechanisms, greater interspecific genetic variation and physiological

plasticity as compared to most crops plants under changing conditions (Upasani *et al.* 2018).

Combined effect of elevated CO₂ (C), temperature (T) and weed (W) interactions on wheat yield

Most of the interaction combinations (C×T, C×W, W×T, and C×T×W) was significant (P<0.05) in reducing both grain and biological yield except the interaction of W×T for grain yield.

The combined effect of elevated temperature (C×T) by 1.5 and 3 °C and CO₂ in both tunnels (ACO₂ and ECO₂) was recorded. The wheat parameters like number of spikelets/spike, number of grains/spike, grain yield, biological yield and harvest index increased by 6%, 1.5%, 0.7%, 0.6%, 0.1%, respectively, while, the number of spikes/m² and 1000-grain weight decreased by 1.7% and 1.8 %, respectively, at 1.5 °C and 550 ppm CO₂ (Table 3). Thus, assessment of wheat crop response to both elevated temperature and CO₂ revealed that detrimental effect of rise in temperature by 1.5°C (-12%) was counteracted by elevated CO₂ level of 550±50 ppm (+13.9%), while the negative effect of further rise in temperature to 3°C (-20%) could not be offset by elevated CO₂ level and thus significant reduction in wheat yield (6%) was recorded under elevated temperature by 3°C despite exposure to enhanced CO₂ level (550±50 ppm). These findings are in support with the reports of Long (1999), Polley (2002) and DaMatta *et al.* (2010). The combined effect of different variables could be explained by the fact that high temperature reduces the net carbon gain in C₃ species by increasing photorespiration while by reducing photorespiration, enrichment of CO₂ is expected to increase photosynthesis more at higher temperatures than low temperatures and thus partially offsetting the temperature effect on yield. Similarly Cai

Table 3 Mean individual effect of elevated temperature and CO₂ on yield and yield attribute of wheat crop with and without weed interaction

Treatment	No. of spikes/m ²	No. of spikelets/spike	No. of grains/spike	1000-grain wt. (g)	Grain yield (g/m ²)	Biological yield (g/m ²)	Harvest index
<i>Effect of elevated CO₂</i>							
Mean ambient CO ₂	447.41	16.13	45.75	33.64	564.05	1286.80	43.78
Mean elevated CO ₂	494.66	17.98	49.30	34.72	642.44	1439.71	44.56
Effect of elevated CO ₂ (%)	10.56	11.45	7.76	3.21	13.90	11.88	1.76
<i>Effect of elevated temperature</i>							
Mean ambient temperature (T ₁)	520.42	17.89	49.48	36.06	676.38	1507.28	44.83
Mean ambient temperature (T ₂ 1.5°C)	466.93	17.10	47.61	34.09	594.28	1343.67	44.19
Mean ambient temperature (T ₃ 3°C)	425.75	16.19	45.49	32.41	539.06	1238.81	43.49
Effect of 1.5°C elevated temperature (%)	-10.28	-4.44	-3.79	-5.46	-12.14	-10.85	-1.42
Effect of 3°C elevated temperature (%)	-18.19	-9.53	-8.07	-10.12	-20.30	-17.81	-3.00
<i>Effect of weed</i>							
Mean without weed plot	486.72	17.69	49.12	34.87	627.76	1404.04	44.63
Mean with weed plot	455.35	16.43	45.93	33.50	578.72	1322.47	43.71
Effect of weed infestation (%)	-6.45	-7.14	-6.48	-3.92	-7.81	-5.81	-2.07

et al. (2016) reported that the yield of wheat and rice was decreased by 10-12% and 17-35%, respectively with 3°C rise in temperature and also reported that elevated CO₂ enhances the photosynthetic activity and mitigates the adverse effects of high temperatures only to a certain extent. The reduction in wheat yields due to weed was recorded to be doubled under elevated CO₂ compared to ambient CO₂ level. However, the percentage of reduction calculated for the interaction of C×W for both grain and biological yield was higher (10% and 8%) under elevated CO₂ condition than under ambient CO₂ condition (5% and 3%) respectively. Moreover at elevated CO₂ grain yield was lowered by 11% in weed infested plants in comparison to weed free crop (17%). The reason for increased yield losses due to weed interaction may be because of similar photosynthetic pathway existing in crop and weed plants, but weeds have benefited more under ambient and elevated CO₂ levels as compared to crops as stated by Pagare *et al.* (2017). Regardless of CO₂ concentration interaction, with temperature (W×T), the grain and biological yield reduced by about (12% and 11%) at elevated temperature of 1.5°C and further enhanced to the extent of (20% and 18%) at elevated temperature of 3°C and the degree of reduction in yield was almost at par for both under weed free and weed infested wheat crops. The decline in grain yield by the presence of weeds in wheat crop at elevated CO₂ and temperature was mainly attributed to marked reduction in spikes/m² (6%) and grains/spike (7%) while 1000-grain weight was least affected by weed interaction. Similar finding by Valerio *et al.* (2013) reported that potential crop losses increased from 33 to 55% and 32 to 61% at 21/12°C and 26/18°C day/night temperature under ambient and elevated CO₂, under crop-weed interactions respectively.

Thus it can be concluded from the above findings that elevated CO₂ levels of 550±50 ppm in the atmosphere was able to compensate the yield loss with only 1.5°C rise in temperature but further increase in temperature of 3°C showed detrimental effect on yield which could not be offset by 550±50 ppm level of rise in CO₂ level. Under rising CO₂ and thermal scenario the yield loss due to weed interaction could be accelerated compared to weed free crops due to enhancement of competitiveness of weeds with crops and greater response of weeds than crop to elevated CO₂ level in the air. Increase in CO₂ concentration and temperature in the atmosphere provides the new weeds to become problematic for field crops. Hence, new and better weed management approaches may be required to control them.

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