



Yield response of important field crops to elevated air temperature and CO₂ level

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ABSTRACT

Field experiment was carried out to study the yield responses of important field crops to elevated air temperature and CO₂ fertilization at the Indian Agriculture Research Institute, New Delhi. One promising variety each of rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.), chickpea (*Cicer arietinum* L.), greengram (*Vigna radiata* (L.) Wilczek), groundnut (*Arachis hypogaea* L.), mustard (*Brassica juncea* (L.) Czern & Coss) and potato (*Solanum tuberosum* L.) were grown to full maturity in small temperature tunnels and FACE (Free Air CO₂ Enrichment) under increased temperature (1 - 4°C) and CO₂ level (550 ppm), respectively. Economic yield reduced gradually with rise in temperature in all the crops. Among the crops rice, chickpea and mustard have shown greater thermal tolerance, while wheat and groundnut proved to be more thermal sensitive. In case of greengram and potato, increased temperature effect was intermediate. On the other hand CO₂ fertilization enhanced the yield to varying degree in these field crops with highest effect in chickpea and least in cereals (rice and wheat). Results indicate that elevated CO₂ could alleviate the negative impact of temperature increase up to 4°C in chickpea and 5°C in mustard. In other crops, elevated CO₂ could counter-effect the temperature increase to lesser extent with least degree in wheat (1.5°C). Thus, counter effect of elevated CO₂ to rising temperature seems to be crop and location specific. Although, these results are preliminary in nature as experiments with more variables such as biotic factors like pests and weeds, geographical locations, agronomical practices are needed to find precise responses of crops to future climate change scenario.

Key words: Carbon dioxide, Climate change, FACE, Field crops, Temperature tunnels, Thermal effect, Yield

The continuing rise in atmospheric carbon dioxide concentration is a major factor driving global warming and associated climate change (Forster *et al.* 2007), which is looming large having immense impact on agriculture. Atmospheric CO₂ is expected to rise up to 550 µmol/mol by 2050 according to the Intergovernmental Panel on Climate Change (IPCC) under emissions scenario A1B (Carter *et al.* 2007). Average global air temperature is expected to increase by 0.2 °C per decade and to be 1.8-4.0 °C above the current level by 2100 (Solomon *et al.* 2007). Earlier studies related to plant responses to elevated CO₂ were done mainly in enclosure systems, but Free Air Carbon dioxide Enrichment (FACE) technology provides better option for near natural field studies under elevated CO₂ (Allen 1992 and Hendrey

and Miglietta 2006). Various types of field chambers and temperature tunnels have been used extensively in determining the impact of high temperature on growth, phenology and yield of crops (Wells and Loy 1993, Waldo *et al.* 1998 and Calderini *et al.* 1999). In general, it is evident that many C₃ crops, in the absence of biotic (pests, diseases and weeds) or abiotic (water and nutrients) stresses will be able to capitalize on elevated CO₂ and convert it into photosynthates and consequently improved growth and yield (Ainsworth and Rogers 2007, Leakey *et al.* 2009 and Pal *et al.* 2012). Fertilization effects of CO₂ on crop production will be necessary in future climate change scenarios to offset the anticipated negative impacts of high temperature and to feed ever increasing human population (Ainsworth *et al.* 2008 and Godfray *et al.* 2010). In India, agriculture and its allied sectors account for 13.9% of the GDP in 2011-12 (ES report 2011-12). These growth rates mainly depend on farm output of major crops grown. Therefore economic yield of major cereals like rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.); pulses like chickpea (*Cicer aritinum* L.), greengram (*Vigna radiata* (L.) Wilczek); oil seed crops like

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mustard (*Brassica juncea* (L.) Czern & Coss) and groundnut (*Arachis hypogaea* L.) plays crucial role in country's food security, export values and inflation rates. In this regard importance to understand yield responses of these crops to the predicted climate change is further amplified and become more relevant. We have assessed the responses of rice, wheat, chickpea, groundnut, greengram, mustard and potato (*Solanum tuberosum* L.) crops to a moderate increase in carbon dioxide concentration and a gradation of warmer temperature during different growth seasons with CO₂ and temperatures experiments and analyzed the yield response under elevated CO₂ and higher temperature to know the extent to which CO₂ fertilization can counter effect the rise in air temperature.

MATERIALS AND METHODS

The experiment was carried out at Climate Change Facilities developed by the Centre for Environment Science and Climate Resilient Agriculture (CESCRA), Indian Agricultural Research Institute, New Delhi, India (28°35'N and 77°12'E). Experimental year, cropping season and variety chosen for study is shown in (Table 1). The Free Air CO₂ enrichment facility (FACE) and temperature tunnels were used for the present study. The CO₂ was set at 550 ppm at crop canopy level using SCADA software based FACE facility (Chakrabarti *et al.* 2012). Among five temperature tunnels four were used for simulating the warmer condition and one as reference control tunnel. A walk in tunnel is a greenhouse like structure having heating or ventilation system, covered with one layer of plastic and sited on field soil (Wells and Loy 1993).

Standard agronomical practices were followed to prepare field inside FACE and tunnels. Seeds of respective variety were sown in treatment facilities and the plants were administered with recommended dose of fertilizers. Rice plants were raised normally and transplanted to cement pots for exposure. The plants kept under water and nutrient non-limiting conditions were subjected to enriched levels of CO₂ at 550 ppm and warmer temperature regimes maximum up to ~4°C above ambient throughout crop growth season.

Table 1 Experimentation year, variety and crop duration of wheat, chickpea, potato, mustard, rice, groundnut and greengram subjected to elevated temperature and CO₂

Crop	Year	Duration	Variety
Wheat	2010-11, 2011-12	Nov-April	PBW 343
Chickpea	2008-09, 2009-10	Nov-April	BGD 72
Potato	2006-07, 2007-08	Nov-April	Kufri Alankar
Mustard	2006-07, 2007-08	Nov-April	Pusa Tarak
Rice	2009-10, 2010-11	July-Oct	Pusa 44
Groundnut	2008-09, 2009-10	July-Oct	B 95
Greengram	2006-07, 2007-08	July-Oct	Pusa Bold

Table 2 Productivity response of different crops to rising atmospheric temperature (+1-4 °C) and CO₂ (550 ppm)

Crop	Effect of increased temperature (°C) (Percent reduction in yield)				CO ₂ fertilization effect (%) 550 ppm	Net loss beyond °C Threshold temp.
	+1 °C	+2 °C	+3 °C	+4 °C		
	Rice	5	10	15	20	15
Wheat	10	20	30	40	15	Loss beyond 1.5°C
Chickpea	5	10	15	20	20	Loss beyond 4.0°C
Groundnut	8	16	24	32	20	Loss beyond 2.5°C
Greengram	6	12	18	24	20	Loss beyond 3.0°C
Mustard	4	8	12	16	20	Loss beyond 5.0°C
Potato	6	12	18	24	20	Loss beyond 3.5°C

Economic yield of these crops were calculated. The temperature increase in tunnels however, was not linear but in fractions like ~1.5, 2.8, 3.2°C etc. To have uniform responses, change in yield per degree temperature increase (thermal effect per degree increase of temperature) was calculated and represented for 1, 2, 3 and 4°C increase.

RESULTS AND DISCUSSION

Results indicate that different crops had varying degree of sensitivity to increase in temperature. The economic yield reduced at warmer temperature regime in all the crops. Thermal effect on yield calculated per degree temperature increase was lowest in rice, chickpea and mustard indicating their greater thermal tolerance (Fig 1). Yield declined by ~5% in these crops with increase in air temperature by 1°C. Thermal sensitivity was more in wheat and groundnut as yield reduced to larger extent (8-40%) at warmer temperature regime (Fig 1). Thermal effect was intermediate in greengram and potato crops. Reduction in yield at elevated temperature is often reported in crops, which may be associated with reduced sink capacity, reproductive sterility and water and resource use efficiency (Wheeler *et al.* 1996 and Wassmann *et al.* 2009). The economic yield was higher in all the crops grown under elevated CO₂ 550 ppm with varying responses among the crops. There was a lesser CO₂ fertilization effect (15%) in cereals (rice and wheat) while it was maximum in chickpea (22%). The increase in yield was similar (20%) in groundnut, greengram, mustard and potato under elevated CO₂. Crop yield is reported to increase due to elevated CO₂ and the effect was more in C₃ plants attributed to manipulation in source in terms of greater photosynthetic surface (leaf area), rate, water use efficiency and other photosynthetic acclimations (Baker 2004, Ainsworth *et al.* 2008 and Pal *et al.* 2012).

Since thermal effect varied to greater extent in studied crops, the counter effect of elevated CO₂ to rise in temperature

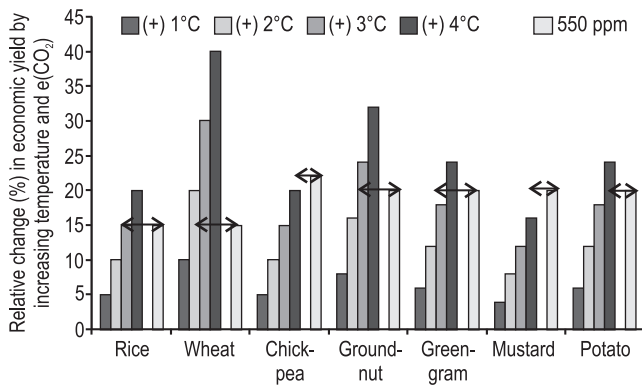


Fig 1 Influence of elevated CO₂ and elevated temperature on economic yield in important field crops grown under water non-limiting condition for complete growth season. Relative decrease (%) in yield under warmer temperature regime and gain in crop yield at 550 ppm CO₂ is represented. The temperature increase where the yield loss would be altered by fertilization effect of elevated CO₂ is represented by double headed arrow

could be crop specific. Results indicate that elevated CO₂ 550 ppm could alleviate the negative impact of temperature increase up to ~4.0°C and 5.0°C in chickpea and mustard, respectively. In other crops elevated CO₂ may counter-effect the temperature increase to lesser extent. The counter-effect of CO₂ fertilization (550 ppm) to increased temperature was up to 3°C in greengram and 3.5°C in potato. In case of groundnut, yield was increased to similar extent as greengram and potato under elevated CO₂, but higher negative thermal effect resulted in lesser thermal tolerance of this crop. Wheat was very sensitive to temperature increase to such an extent that fertilization effect of CO₂ (550 ppm) could resist the effect of increased temperature only up to ~1.5°C, while CO₂ fertilization effect in rice showed thermal tolerance up to ~3°C. In general, cereals (wheat and rice) showed greater thermal sensitivity as compared to pulses (chickpea and greengram), oil seed (mustard) and tuber (Potato) crops.

We do not conclude that these responses are exclusive as other biotic and abiotic factors also control the yield response of various crops under different geographic positions. Although, these results from different seasons could provide a simple strategic planning for further research on combination experiments with multi-location trials on same crop under elevated CO₂ and increased temperature condition to find out a realistic yield response of these crop in future climate change scenario.

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