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Growth, yield and quality of maize with elevated atmospheric carbon dioxide and temperature in north–west India

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ABSTRACT

An experiment was conducted growing maize (*Zea mays* L.) in open top chambers (OTCs) to determine the effects of elevated atmospheric carbon dioxide (CO_2) and temperature on growth, yield, yield attributes and grain quality of maize. Maize (var. PEHM 5) was grown with two levels of carbon dioxide i.e., ambient (400 ppm) and elevated (550 ± 20 ppm) and three levels of temperature i.e., ambient, ambient +1.5 °C and ambient +3.0 °C during kharif (July–October) seasons of 2013 and 2014 in New Delhi, India. Elevated CO_2 increased grain yield of maize by 53.7% and harvest index (HI) by 2.9% compared to ambient CO_2. Stover yield and yield attributes such as cob length, cob diameter, grain weight cob^{-1}, number of grains cob^{-1} and 100 grain weight also increased with elevated CO_2. However, elevated CO_2 decreased N concentrations in grain by 11.0% and P content by 19.0% but increased K content by 5.0% over ambient CO_2. Elevated temperature by 1.5 °C and 3.0 °C decreased grain yield by 4.9% and stover yield by 37.0% but increased HI by 6.0% compared to ambient temperature. Elevated temperature levels positively affected grain N, P and K concentrations in grain. Simultaneous elevation of CO_2 and temperature increased leaf area index, number of grains row^{-1}, grain yield and harvest index but decreased days to 50% tasseling, cob length, cob diameter, grain weight cob^{-1} and crude protein content in grain. Test weight, stover yield and total biomass increased at elevated CO_2 with ambient +1.5 °C temperature but decreased at elevated CO_2 with ambient +3.0 °C temperature. The results indicated that elevated CO_2 had positive effects whereas elevated temperature had negative effects on growth and yield of maize. With elevation of both CO_2 and temperature, elevated CO_2 reduced the negative effects of elevated temperature on yield and yield components of maize.

1. Introduction

Global climate is changing at an alarming rate due to increased emission of greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The atmospheric concentration of CO_2 was around 280 ppm in 1750 AD (pre-industrial era) but currently increased to more than 400 ppm with a consequent warming of the atmosphere by 0.84 °C (IPCC, 2014). It is projected that with the rise of GHGs, global average temperature will rise by 3.7–4.8 °C by the end of the 21st century (IPCC, 2014). Crop production will be affected by global warming. Elevated atmospheric CO_2 will promote growth of plants through fertilization effect and enhanced photosynthesis. This positive effect of CO_2 on plant growth is more pronounced in C_3 crops such as wheat but less notable in C_4 crops such as maize (Ghannoum et al., 2000). Elevated temperature will cause heat injury and physiological disorders resulting in reduced yield (Johkan et al., 2011). Elevated temperature as a result of elevated CO_2 will have a major influence on food grain production depending on the locations. With temperature increase by 1.0–2.0 °C in tropical and subtropical countries such as India food grain production is projected to decrease up to 30% (IPCC, 2014; Johkan et al., 2011).

Maize is one of the most versatile cereal crops, cultivated in nearly 150 million hectares (Mha) in more than 160 countries, contributing 782 million tons (Mt) i.e., 36% of the global foodgrain production (FAO, 2010). Almost 70% of global maize production is in the developing world. In India, the crop is grown predominantly as a kharif (July–October) crop with 85% of the area under cultivation in the season. It is the third most important cereal crop after rice and wheat in the country accounting for about 9% of total foodgrain production with a production of 21.3 Mt and productivity of 2.5 t ha^{-1} (CMIE, 2010; Prathyusha et al., 2013; Venkata et al., 2014). Area under maize in India is increasing at 2.5% from 7.5 Mha in 2004–05 to 9.4 Mha in 2013–14. Despite occupying large area in

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Table 1
Weather during the maize growing periods in 2013 and 2014.

Month (Year)	Rainfall (mm)	Temperature (°C)		Sun shine (hour)	Relative humidity (%)
		Maximum	Minimum		
July, 2013	460.0	34.8	25.7	113.5	81.4
August, 2013	521.9	32.8	25.1	101.3	88.5
September, 2013	105.9	34.5	24.0	204.7	74.7
July, 2014	228.8	35.9	26.3	136.3	75.3
August, 2014	98.9	35.8	25.8	152.0	72.3
September, 2014	123.3	34.1	24.0	208.3	70.6

the country, productivity is low compared to other major maize producing countries in the world (FICCI, 2014).

Growth and productivity of maize is likely be affected by elevated atmospheric CO_2 and temperature. Elevated temperature adversely affects growth, yield and quality of maize (Morison, 1996; IPCC, 2007; Mendelsohn and Dinar, 2009; Pathak et al., 2012). There are inconsistent reports on the effects of elevated CO_2 on yield of maize varying from little positive effect (Ghannoum et al., 2000; Leakey et al., 2004), no effect (Kim et al., 2007) to increase yield by 50% (Rogers, 1983; Samarakoon and Gifford, 1996; Leakey et al., 2004; Prins et al., 2007; Vanaja et al., 2015). Most of the experiments on the impacts of elevated CO_2 and temperature on maize yield, however, used controlled environment facilities such as phytotron and plant growth chambers or crop growth simulation models (Mendelsohn and Dinar, 2009; Fang et al., 2010; Pathak et al., 2012). There are very limited studies on the impacts of elevated CO_2 concentration and temperature interactions on this important cereal crop under field conditions. The objectives of the study were to evaluate the impacts of elevated atmospheric CO_2 and temperature on growth, yield and quality of maize in north–west India under field conditions.

2. Materials and methods

2.1. Site description

An experiment using open top chambers (OTCs) was conducted at the research farm of Indian Agricultural Research Institute, New Delhi. The site is located in the Indo-Gangetic Plains of north–west India at 28° 37′ N latitude, 77° 12′ E longitude at an altitude of 228.6 m above mean sea level. The climate of the area is sub-tropical, semi-arid with an average annual rainfall of 750 mm, 80% of which is received during July to October (Table 1). Maximum and minimum temperatures of the site range from 34 to 35 °C and 24–26 °C, respectively. The soil (0–15 cm) of the experimental site was Typic Ustochrept with sandy clay loam in texture, pH 8.43 (1:2 soil: water), electrical conductivity (1:2 soil:water) 0.16 dSm^{-1}, organic C 0.45%, alkaline $KMnO_4$ extractable N 185.1 kg ha^{-1}, Olsen P 25.1 kg ha^{-1}, NH_4OAc-extractable K 247.9 kg ha^{-1} and dehydrogenase activity 150 μTPF g^{-1} 24 h^{-1}.

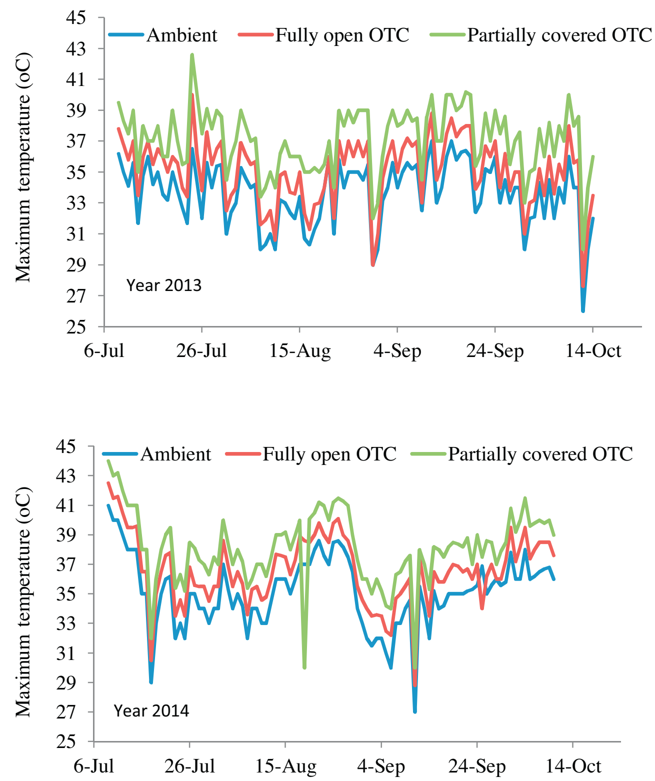

Fig. 1. Daily maximum temperature in the ambient, and fully open and partially covered OTCs during the maize growing season of 2013 and 2014.

2.2. Treatments and experimental design

Maize (*Zea mays* L.) crop (variety PEHM 5) was grown under two levels of atmospheric CO_2 (ambient and 550 ± 20 ppm) and three levels of temperature (ambient, ambient +1.5 °C and ambient +3.0 °C) during kharif (June–October) seasons of 2013 and 2014 in OTCs (chamber area of 7.07 m^2) and ambient field conditions (Table 2). The experiment was conducted in a two factors completely randomized design with three replications. Maize crop was grown with 20 cm spacing between plants and 60 cm

Table 2
Treatment descriptions.

Treatment No.	Name	Description
T_1	T0C0	Ambient temperature and ambient CO_2
T_2	T1C0	Ambient temperature +1.5 °C & ambient CO_2
T_3	T2C0	Ambient temperature +3.0 °C & ambient CO_2
T_4	T0C1	Ambient temperature & elevated CO_2 (550 ± 20 ppm)
T_5	T1C1	Ambient temperature +1.5 °C & elevated CO_2 (550 ± 20 ppm)
T_6	T2C1	Ambient temperature +3.0 °C & elevated CO_2 (550 ± 20 ppm)