Growth Gas Exchange Parameters of Maize with Elevated Atmospheric Carbon Dioxide and Temperature

***Abebe A, H. Pathak, S.D. Singh, DK, Sharma, and A. Anand**
College of Agriculture and Environmental Sciences, School of Natural resource management and Environmental Sciences, Haramaya University, Ethiopia; P.O.Box, 31 HU,
E-mail: abebe.aschalew@haramaya.edu.et; abebe.aschalew@yahoo.com

Abstract

Temperature and carbon dioxide (CO_2) are two important parameters related to climate change, which affect gaseous exchange and yield parameters of many cereal food crops. In this study, an experiment was conducted growing maize (Zea mays L.) in open top chambers (OTCs) to determine the effects of elevated CO_2 and temperature on gaseous exchange parameters (leaf photosynthetic rate (P_N), stomatal conductance (gs), intercellular CO_2 concentration (Ci), transpiration rate (Tr) and water use efficiency (WUE) of maize crop in Indian Agricultural Research Institute (IARI), New Delhi, India. Maize (var. PEHM 5) was grown with two levels of CO_2 ambient (400 ppm) and elevated (550 $\pm$ 20 ppm) and three levels of temperature i.e., ambient, ambient +1.5 ^{0}C and ambient +3.0 ^{0}C during (July–October) seasons of 2013 and 2014. The two years average data indicated that the interactive effects of elevated CO_2 with 1.5 and 3.0 ^{0}C temperature rise increased photosynthetic rate by 24.32 & 37.5%, stomatal conductance by 50.0% & 87.5%, intercellular CO_2 concentration by 55.0% &77.16%, transpiration rate by 44.0% & 102.16%, but decreased intrinsic water use efficiency by 7.46% & 28.7%, respectively. On the contrary, elevated CO_2 with 1.5 and 3.0 ^{0}C temperature rise decreased photosynthetic rate by 4.67 & 8.34%, stomatal conductance by 34.78% & 43.48%, transpiration rate by 25.17% & 20.52%, but increased intrinsic water use efficiency by 28.6% & 17.23%, respectively. The interactive effects of elevated CO_2 with 1.5 ^{0}C temperature rise resulted in 10.81% decrease and elevated CO_2 with 3.0 ^{0}C temperature rise resulted in a 14.47% increase in intercellular CO_2 concentration as compared to ambient CO_2 and temperature. Elevated temperature by 1.5^{o}C and 3.0 ^{0}C at elevated CO_2 had no effect on photosynthetic rate and intercellular CO_2 concentration. In addition, elevated temperature by 3.0 ^{0}C at elevated CO_2 had no effect on intrinsic water use efficiency as compared to ambient CO_2 and temperature treatment. From this study it can be concluded that elevated levels of both temperature and CO_2 have significant effects on maize growth gas exchange parameters.

Keywords: Elevated Carbon Dioxide, Elevated temperature, Maize, Photosynthetic Rate, Water Use Efficiency

Introduction

Maize is a C_4 crop and is one of the most versatile cereal crops, cultivated in nearly 150 million hectares in more than 160 countries, contributing 36% (782 million ton (Mt) of the global grain production (FAOSTAT, 2010). Almost 70% of total maize production is in the developing world. In India, maize is grown throughout the year but predominantly as a kharif (June-October) crop with 85% of the area under cultivation in the season. Maize is the third most important cereal crop after rice and wheat in the country accounting for about 9% of total food grain production with a production of 21.28 Mt and productivity of 2.5 t ha^{-1} (CMIE, 2010; Prathyusha *et al.*, 2013; Venkata *et al*., 2014).

The 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). Currently, it is more than 400 ppm i.e., increased by 40% with a consequent warming of the atmosphere by 0.84^{O}C (IPCC, 2014). It is projected that with the rise of GHGs, global average temperature will rise by 3.7 to 4.8^{O}C by the end of 21st century (IPCC, 2014). Crop production will be affected by global warming which is caused by two major factors i.e., elevated atmospheric CO_2 and temperature. Increased concentration of CO_2 will promote growth of many plants through 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 like maize (Ghannoum *et al*., 2000). However, elevated temperature will cause heat injury and physiological disorders resulting in reduced yield (Johkan *et al*., 2011). The increased temperature as a result of elevated CO_2 will have a major influence on regional as well as global crop growth and productivity depending on the locations. Increase in ambient temperature by 1.0-2.0^{o}C in tropical and subtropical countries like India food grain production is projected to decrease up to 30% (IPCC, 2007; Johkan *et al*., 2011). On the contrary, the world population is expected to reach nine to ten billion people by 2050 and production of food should increase by 70% to ensure food security, which should be achieved through increase in productivity (FAO, 2017**).**

Growth gas exchange parameters and productivity of maize is likely be affected by both elevated CO_2 concentration and temperature. Elevated temperature is expected to influence growth, development, yield and quality of maize negatively (Morison, 1996; IPCC, 2007; Mendelsohn and Dinar, 2009; Pathak *et al.*, 2012). The two most familiar responses to elevated CO_2 at the leaf level are an increase in the rate of net photosynthesis and a decrease in stomata conductance that leads to increased crop productivity and water use efficiency. The increase in net photosynthetic rate is much larger in C_3 species (50 to 100%) than in C_4 species (10%) when CO_2 concentration doubles but a substantial decrease in stomatal conductance (30 to 40%) is observed in both types of species including maize crop (Ainthworth and Long, 2005). The increasing atmospheric CO_2 concentration have direct and indirect effects on crop plants and thus there are inconsistent reports varying from little positive effect (Ghannoum *et al*., 2000; Leakley *et al*., 2004), no effect (Kim *et al*., 2007) to increase by 50% in growth and yield of maize (Rogers *et al*., 1983; Samarakoon and Gifford, 1996; Prins *et al*. 2007; Leaky *et al*., 2004). However, the long-term response remains uncertain due to increase in incidence of extreme weather events such as drought, heat waves, and heavy precipitation, making crop production more unpredictable and difficult (IPCC, 2014). In addition to this, most of the experiments on the impacts of elevated CO_2 and temperature on maize growth and yield parameters used controlled environment facilities such as phytotron and plant growth chambers or crop growth simulation models. There are very limited studies on the impacts of elevated CO_2 concentration and temperature interactions on this important cereal crop under field conditions (Mendelsohn and Dinar, 2009; Fang *et al.*, 2010, Pathak *et al.*, 2012). Hence, the objectives of the study was to evaluate the impacts of elevated atmospheric CO_2 and temperature on growth gas exchange parameters of maize in north-west India under near natural field conditions.

Materials and Methods

Site description

An experiment was conducted at the research farm of Indian Agricultural Research Institute (IARI), New Delhi using open top chambers (OTCs). The site is located 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 ranged from 34-35^{o}C and 24-26^{o}C, respectively. The texture of the soil of the experimental site was sandy clay loam with pH 8.43, EC 0.16 dS m^{-1}, organic C 0.45%, available N 185.1 kg ha^{-1}, available P 25.1 kg ha^{-1}, available K 247.9 kg ha^{-1} and dehydrogenase activity 150 µTPF g^{-1} 24 hrs^{-1}.

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	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	72.3
September, 2014	123.3	34.1	24	208.3	70.6

Treatments and experimental design

Maize 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 2013 and 2014 in OTCs and ambient field condition (Table 2). The experiment was conducted in a two factor completely randomized design (CRD) design with three replications. The maize crop was grown with spacing of 20 cm between plants and 60 cm between rows. Sowing was done on July 9 for the first year (2013) and July 8 for the second year (2014). The crop was grown under two levels of atmospheric carbon dioxide (ambient and 550ppm ±20) and three levels of temperature (ambient, ambient+1.5°C and ambient+3.0°C) in 7.07m^2 OTC. The CO_2 concentration was maintained near 550 ppm during the daylight hours from 9:30 AM to 4:30 PM by releasing compressed CO2 gas from cylinders at the perimeter of the ring. It was supplied through tubes on the soil surface at 35cm height. The fluctuation of CO_2 concentrations in the OTC was 20 ppm. The temperatures of ambient+3.0 degrees and ambient + 1.5 degrees in OTCs were regulated by partial covering and not covering of the respective OTCs at the top by transparent Poly vinyl chloride sheets, respectively. Ambient temperature in the OTCs was maintained by making several perforations on side walls of the OTCs and making the gates open.

The crops were fertilized with 120, 26 and 50 kg ha^{-1} N, P and K, respectively. All the P and K and 50% of N were applied at the time of sowing. The remaining N was applied in two equal splits at knee high (25 days after sowing, DAS) and tasseling (45 DAS) stages of maize.

Table 2. Treatment description.

Sl. No.	Name	Description
T1	T0C0	Ambient temperature and ambient CO_2
T2	T1C0	+1.5 ^{O}C & Ambient CO_2
T3	T2C0	+3.0 ^{O}C & Ambient CO_2
T4	T0C1	Ambient temp. & elevated CO_2
T5	T1C1	+1.5 ^{O}C & Elevated CO_2
T6	T2C1	+3.0 ^{O}C & Elevated CO_2

Growth parameters

The physiological data on net photosynthetic rate (P_N), transpiration rate (Tr), intercellular CO_2 concentration (Ci), stomatal conductance (gs) and water use efficiency (WUE) were collected at tasseling and silking stages of maize crop. Gas-exchange measurements were taken on upper most fully expanded leaf using a portable Infra-Red Gas Analyser (IRGA) LICOR 6400 photosynthesis system (Li-Cor Inc. USA). The measurements were conducted between 9.30 to 11.0 AM on bright sunny days. Gas exchange parameters were analyzed at fixed light level by exposing the leaf to uniform PAR of 1000 µmol m^{-2} s^{-1}. Throughout the experiment, gas flow rate to the console and analyzer was maintained at 400 mL min^{-1}. Intact leaflet was clipped into leaf chamber and readings were logged after the leaf internal carbon dioxide (Ci) concentration became stable. Subsequently, net photosynthetic rate (P_N), transpiration rate (Tr), intercellular CO_2 concentration (Ci) and stomatal conductance (gs) were recorded simultaneously. Intrinsic water use efficiency (WUE) was calculated from the ratio of P_N and Tr. Ten readings were taken for each treatment at tasseling and silking stage of maize.

Analysis of soil and plant samples

Soil samples were collected from 0-15cm depth using auger from three places and a composite sample from three places were analyzed for pH and EC(Jackson (1973), organic C (Walkey & Black (1934), dehydrogenase activity (DHA) (Casida *et al*. (1964), and available N (Subbiah & Asija (1956), P (Olsen *et al*. (1954), and K (Hanway & Heidal (1952) contents. Plant samples were also analyzed for crude protein and total N (Yoshida *et al*., 1976), P and K contents (Jackson, 1973).

Statistical analysis

Data were analyzed using SAS 9.3 statistical software for two way analysis of variance (ANOVA) to determine the effects of elevated CO_2, temperature and their interactions on growth and yield parameters of maize. Statistical significance of the data were compared based on their 95% confidence intervals i.e., $P<0.05$ (Gomez and Gomez, 1984).

Results and Discussion

Effect of Elevated CO_2 on Gaseous Exchange Parameters

Elevated CO_2 increased photosynthetic rate in both the years at tasseling and at first year of silking but decreased with same rate in second year at silking stage. Stomatal conductance and transpiration rate decreased in first year but increased in second year at tasseling but decreased in both the years at silking stage whereas intercellular CO_2 concentration increased in both the years at tasseling and decreased at silking stage. On the other hand, intrinsic water use efficiency increased in both the years at tasseling (Table 3) and silking stages (Table 4).

The mean values calculated for the two years data revealed that elevated CO_2 increased photosynthetic rate by 23.49%, stomatal conductance by 30.0% and intercellular CO_2 concentration by 59.80%, transpiration rate by 15.47% and intrinsic water use efficiency by7.22% at tasseling stage of maize (Table 3). However, elevated CO_2 decreased photosynthetic rate by 1.14% and inter-cellular CO_2 concentration by 8.38% though there was no significant effect, stomatal conductance by 30.16% and transpiration rate by 18.65% at silking stage of maize (Table 4). On the other hand, water use efficiency increased by 18.78% under elevated CO_2 because decrease in transpiration rate of plant was greater (18.78%) than photosynthetic rate (1.14%) at silking stage of maize compared to ambient CO_2 level (Table 5). Similar results have been found in line with the present finding. In line with this, some studies indicated that elevated CO_2 can increase plant gaseous exchange parameters like photosynthetic capacity and yield by adjusting its water state, so elevated CO_2 will have positive effect in water deficit condition (Leakey et al., 2006). A number of other controlled environment studies_revealed that T_r decreased at elevated CO_2. The decrease of T_r was associated with decrease of g_s, when elevated CO_2 decreased leaf g_s, and caused increasing resistance from intrinsic leaf to outside, resulting in the decrease of T_r of crops (Allen et al., 2011). Some controlled environment studies also showing that elevated CO_2 could cause a decrease in plant stomatal conductance and partly closing of the stomata (Ainsworth and Rogers, 2007).

Table 3. Effect of elevated CO_2 and temperature on leaf photosynthetic rate (P_N), stomatal conductance (gs), intercellular CO_2 concentration (Ci), transpiration rate (Tr) and water use efficiency (WUE) of maize at tasseling stage.

Treatment*	P_N (µmol CO_2 $m^{-2}s^{-1}$)			gs (mol $H_2Om^{-2}s^{-1}$)			Ci (ppm)			Tr (mmol $H_2Om^{-2}s^{-1}$)			WUE (µmol CO_2mmolH_2O^{-1})		
	2013	2014	Mean	2013	2014	Mean	2013	2014	Mean	2013	2014	Mean	2013	2014	Mean
T1	29.56	25.53	27.55	0.17	0.16	0.16	143.61	88.71	116.16	3.08	4.31	3.70	9.60	5.93	7.77
T2	30.45	28.69	29.57	0.26	0.15	0.21	164.82	44.73	104.77	4.60	5.29	4.95	6.63	5.43	6.03
T3	36.15	26.11	31.13	0.33	0.13	0.23	216.18	32.91	124.54	7.49	8.68	8.09	4.83	3.01	3.92
T4	33.95	39.76	36.85	0.20	0.28	0.24	223.61	108.29	165.95	4.29	8.76	6.52	7.95	4.58	6.27
T5	31.94	36.55	34.25	0.16	0.32	0.24	193.99	166.68	180.33	3.44	7.21	5.33	9.29	5.08	7.19
T6	32.39	43.37	37.88	0.21	0.38	0.30	259.76	151.82	205.79	4.76	10.21	7.48	6.83	4.25	5.54
SEM±	0.69	0.65	0.48	0.01	0.01	0.01	13.05	11.10	4.88	0.13	0.29	0.13	0.28	0.24	0.12
LSD(*P*=0.05)	2.14	2.01	1.46	0.03	0.03	0.02	40.21	34.21	15.04	0.39	0.89	0.40	0.85	0.73	0.36

*Refer Table 2 for the description of the treatment

Table 4. Effect of elevated CO_2 and temperature on leaf photosynthetic rate (P_N), stomatal conductance (gs), intercellular CO_2 concentration (Ci), transpiration rate (Tr) and water use efficiency (WUE) of maize at silking stage.

Treatment*	P_N (µmol CO_2 $m^{-2}s^{-1}$)			gs (mol H_2O $m^{-2}s^{-1}$)			Ci (ppm)			Tr (mmol H_2O $m^{-2}s^{-1}$)			WUE (µmol CO_2 mmolH_2O^{-1})		
	2013	2014	Mean	2013	2014	Mean	2013	2014	Mean	2013	2014	Mean	2013	2014	Mean
T1	25.63	32.66	29.15	0.24	0.23	0.23	174.06	124.65	149.36	7.39	4.21	5.80	3.52	7.75	5.63
T2	27.93	30.93	29.43	0.29	0.20	0.24	193.63	101.53	147.58	9.04	3.63	6.34	3.10	8.54	5.82
T3	22.19	20.42	21.31	0.18	0.14	0.16	168.65	131.20	149.93	6.35	2.84	4.59	3.58	7.28	5.43
T4	27.39	21.55	24.47	0.20	0.13	0.16	129.21	81.27	105.24	6.67	2.65	4.66	4.12	8.29	6.21
T5	28.75	26.83	27.79	0.16	0.14	0.15	213.82	52.62	133.22	5.85	2.84	4.34	4.98	9.51	7.24
T6	32.34	21.09	26.72	0.19	0.06	0.13	230.42	111.51	170.97	6.66	2.55	4.61	4.93	8.28	6.60
SEM±	1.79	1.54	1.21	0.03	0.01	0.02	23.12	20.71	14.65	0.65	0.21	0.34	0.35	0.53	0.33
LSD(P=0.05)	5.51	4.76	3.73	0.09	0.03	0.05	71.25	63.81	45.13	2.01	0.64	1.04	1.06	1.63	1.02

Table 5. Mean individual effect of elevated CO_2 and temperature on leaf photosynthetic rate (P_N), stomatal conductance (gs), intercellular CO_2 concentration (Ci), transpiration rate (Tr) and water use efficiency (WUE) of maize at tasseling and silking stages.

Treatment	P_N (µmol CO_2 m^{-2} s^{-1})		gs (mol H_2O m^{-2} s^{-1})		Ci (ppm)		Tr (mmol H_2O m^{-2} s^{-1})		W (µmol CO_2
	Tasseling	Silking	Tasseling	Silking	Tasseling	Silking	Tasseling	Silking	Tasseling
Effect of elevated CO_2									
Mean ambient CO_2	29.42	26.63	0.20	0.21	115.16	148.96	5.58	5.58	5.91
Mean elevated CO_2	36.33	26.33	0.26	0.15	184.02	136.48	6.44	4.54	6.33
LSD (*P*=0.05)	0.85	NS[a]	0.01	0.03	8.68	NS[a]	0.23	0.6	0.21
Effect of elevated CO_2 (%)	23.49	-1.14	30.00	-30.16	59.80	-8.38	15.47	-18.65	7.22
Effect of elevated temperature									
Mean ambient temperature	32.20	26.81	0.20	0.20	141.06	127.3	5.11	5.23	7.02
Mean ambient temp. + 1.5°C	31.91	28.61	0.23	0.20	142.55	140.4	5.14	5.34	6.61
Mean ambient temp. +3.0°C	34.51	24.02	0.27	0.15	165.17	160.45	7.785	4.60	4.73
LSD (*P*=0.05)	1.04	2.64	0.01	0.03	10.63	31.92	0.29	0.74	0.25
Effect of 1.5°C elevated temp (%)	-0.90	6.71	12.50	0.00	1.06	10.29	0.59	2.10	-5.84
Effect of 3.0°C elevated temp (%)	7.16	-10.43	32.50	-25.64	17.09	26.04	52.35	-12.05	-32.62

[a]NS indicates non-significant at P<0.05

Effect of Elevated temperature on Gaseous Exchange Parameters

Elevated temperature by 1.5 ^oC decreased photosynthetic rate at tasseling (Table 3) but increased at silking stage in both the years (Table 4). Stomatal conductance also increased at tasseling and silking stages. Intercellular CO_2 concentration decreased in the first year but had no effect on second year at tasseling stage where as Ci increased in the first year but decreased in the second year at silking stage. Intrinsic water use efficiency decreased in the first year but had no effect on second year at tasseling but increased both the years at silking stages with elevated temperature of 1.5^{o}C. The mean values calculated for the two years data revealed that elevated temperature by 1.5 ^oC increased photosynthetic rate by 6.71% at silking stage, stomatal conductance by 12.5% at tasseling stage, intercellular CO_2 concentration by 1.06% and 10.29% both at tasseling and silking stages respectively, intrinsic water use efficiency by 10.3% at silking stage but decreased by 5.84% at tasseling stage. However, elevated temperature by 1.5 ^oC had no significant effect on photosynthetic rate, intercellular CO_2 concentration; transpiration rate at both tasseling and silking growing stages. Similarly, elevated temperature by 1.5 ^oC had no significant effect on stomatal conductance and intrinsic water use efficiency at silking stage as compared to ambient temperature (Table 5).

Further increase in temperature by 3.0 ^oC increased photosynthetic rate, stomatal conductance, intercellular CO_2 concentration and transpiration rate in both the years but decreased intrinsic water use efficiency in both the years at tasseling stage (Table 3). On the other hand, photosynthetic rate, stomatal conductance and transpiration rate decreased in both the years at silking stage. Similarly, intercellular CO_2 concentration increased in both the years and intrinsic water use efficiency increased in the first year but decreased in the second year at silking stage (Table 4). The mean values calculated for the two years data indicated that elevated temperature by 3.0 ^oC increased photosynthetic rate by 7.16%, stomatal conductance by 32.5% and intercellular CO_2 concentration by 17.09% and 26.0% at tasseling and silking stage respectively, transpiration rate by 52.35% at tasseling stage and intrinsic water use efficiency by 1.6% at silking stage. Elevated temperature by 3.0 degrees decreased photosynthetic rate by 10.43%, stomatal conductance by 25.64% and transpiration rate by 12.05% at silking stage and intrinsic water use efficiency by 32.62% at tasseling stage. Maximum increment of maize physiological parameter under elevated temperatures by 1.5 and 3.0 ^oC were observed in transpiration rate (52.35%) and stomatal conductance (32.5%) and maximum decrement was observed in intrinsic water use efficiency (32.62%). Elevated temperature by 3.0 degrees had no significant effect on intrinsic water use efficiency at silking growing stage compared to ambient temperature level (Table 5).

Interaction Effect of elevated CO_2 and temperature on Gaseous Exchange Parameters

Physiological gas exchange parameters in maize showed significant differences in the treatments under combined effect of elevated CO_2 and temperatures (ambient +1.5 and 3.0^oC) except stomatal conductance, intercellular CO_2 concentration and intrinsic water use efficiency at silking stage in comparison to ambient temperature and CO_2 concentration (Table 4). Combined effect of elevated temperature by 1.5^oC and 3.0 ^oC with elevated CO_2 concentration increased photosynthetic rate, stomatal conductance, intercellular CO_2 concentration and transpiration rate but decreased intrinsic water use efficiency in both the years at tasseling stage over plants under ambient CO_2 and temperature level. Similarly, increasing the temperature by 1.5 and 3.0 ^oC with CO_2 concentration increased photosynthetic rate and intercellular CO_2 concentration in the first year and intrinsic water use efficiency in both the years. Moreover, photosynthetic rate and intercellular CO_2 concentration in the second year, stomatal conductance and transpiration rate in both the years was decreased under elevated temperature by 1.5^oC and 3.0 ^oC with elevated CO_2 concentration at silking stage of maze compared to ambient CO_2 and temperature treatment. The mean values calculated for the two years data indicated that the interactive effects of elevated CO_2 with 1.5 and 3.0^oC temperature rise increased photosynthetic rate by 24.32 & 37.5%, stomatal conductance by 50.0% & 87.5%, intercellular CO_2 concentration by 55.0% &77.16%, transpiration rate by 44.0% & 102.16%, but decreased intrinsic water use efficiency by 7.46% & 28.7%, respectively at tasseling stage. On the contrary, elevated CO_2 with 1.5 and 3.0^oC temperature rise decreased photosynthetic rate by 4.67 & 8.34%, stomatal conductance by 34.78% & 43.48%, transpiration rate by 25.17% & 20.52%, but increased intrinsic water use efficiency by 28.6% & 17.23%, respectively at silking stage. The interactive effects of elevated CO_2 with 1.5 ^oC temperature rise resulted in 10.81% decrease and elevated CO_2 with 3.0^oC temperature rise resulted in a 14.47% increase in intercellular CO_2 concentration at silking stage as compared to ambient CO_2 and temperature. Elevated temperature by 1.5^oC and 3.0 ^oC at elevated CO_2 had no effect on photosynthetic rate and intercellular CO_2 concentration. In addition, elevated temperature by 3.0 ^oC at elevated CO_2 had no effect on intrinsic water use efficiency at silking stage as compared to ambient CO_2 and temperature treatment (Table 5).

Similar results have been found in studies *of* some plant species which reported a significant increase in P_N under elevated CO_2 and increased precipitation of 15% (Wang *et al*., 2012). Wall *et al*. (2001) also observed that elevated CO_2 increased P_N of sorghum by 9%. The decrease in photosynthesis during the high temperature treatment was less at elevated than at ambient CO_2 concentrations consistent with expectations based on Rubisco thermal kinetics (Llod and Farquhar, 2008).The present study indicated that gaseous exchange parameters of maize improved with both elevated CO_2 and temperature although the response of plant gaseous exchange parameters to each of the environmental variables like water availability, temperature, nitrogen along with the elevated CO_2 has not been sufficiently understood (Lee,2011).

Conclusion

The mean values calculated for the two years data indicated that the interactive effects of elevated CO_2 with 1.5 and 3.0^{o}C temperature rise increased photosynthetic rate, stomatal conductance, intercellular CO_2 concentration, transpiration rate at tasseling stage. On the contrary, elevated CO_2 with 1.5 and 3.0^{o}C temperature rise decreased photosynthetic rate, stomatal conductance, transpiration rate at silking stage. Elevated CO_2 and temperature increased intrinsic water use efficiency at silking stage but decreased at tasseling stage of maize. The effect of elevated CO_2 and temperature on plants growth depends on the availability of other resources mainly nutrients and soil moisture. Hence, further study should be taken to ensure the contribution rate of elevated CO_2 and temperature on different parameters of maize crop.

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References

Ainsworth, E.A. and Rogers, A. 2007. The response of photosynthesis and stomatal conductance to rising [CO_2]: mechanisms and environmental interactions. Plant Cell Environ 30: 258–270.

Allen Jr LH, Kakani VG, Vu JCV, Boote KJ (2011) Elevated CO_2 increases water use efficiency by sustaining photosynthesis of water-limited maize and sorghum. J Plant Physiol 168(16): 1909–1918.

Casida, L., Klein, D., Santoro, T. 1964. Soil Dehydrogenase Activity. *Soil Science* 98, 371-376.

CMIE, 2010. Centre of Monitoring India Economy Pvt. Limited, Apple Apetile, Mumbai. www.cmie.com.

Cure, J.D., Acock, B. 1986. Crop responses to carbon dioxide doubling: a literature survey. Agric For Met. 38, 127–145.

Fang, S.B., Shen, B., Tan, K. and Gao, X.N. 2010. Effect of elevated CO_2 concentration and increased temperature on physiology and production of crops, Chinese Journal of Eco-Agriculture 18, 1116-1124.

FAO, 2017. The future of Food and Agriculture: Trends and challenges, Rome.

FAOSTAT. 2010. Agricultural data. Food and Agriculture Organization of the United Nations,Romeonline at http://faostat.fao.org/.

FICCI, 2014. Federation of Indian Chamber of Competence and Industry , New Delhi, India, Maize Summit 2014, www.ficci.com.

Ghannoum, O., von Caemmerer, S., Ziska, L.H., Conroy, J.P. 2000. The response of C_4 plants to elevated CO_2 partial pressure: a reassessment. Plant Cell & Environment 23:931–942.

Hanway, J.J. and Heidel, H. 1952. Soil analysis methods as used in the Iowa State College Soil Testing Laboratory, Iowa State College Bulletin 57, 1–13.

Gomez, K.A., Gomez, A. 1983. Statistical procedures for agricultural research, 2nd edn. Wiley, New York,USA.

IPCC. 2007. Climate change- impacts, Adaptation and vulnerability Technical summary of Working group II. Fourth Assessment Report Inter-governmental Panel on Climate Change.

IPCC. 2014. Climate change- impacts, Adaptation and vulnerability Technical summary of Working group II. Fifth Assessment Report Inter-governmental Panel on Climate Change.

Jablonski, L.M., Wang, X. and Curtis, P.S. 2002. Plant reproduction under elevated CO_2 conditions: meta-analysis of reports on 79 crop & wild species. New Phytol 156: 9-26.

Jackson, M. L. 1973. Soil chemical analysis. Prentice hall of India Pvt ltd., New Delhi

Johkan, M., Oda, M., Maruo, T. and Shinohara, Y. 2011. Crop Production and Global Warming Impacts, Case Studies on the Economy, Human Health, and on Urban and Natural Environments, http://www.intechopen.com.

Kim, S.H., Gitz, D.C., Sicher, R.C., Baker, J.T. and Timlin, D.J. 2007. Temperature dependence of growth, development, and photosynthesis in maize under elevated CO_2. Environ Exp Bot. 61:224–236.

Leakey, A.D.B., Bernacchi, C.J., Dohleman, W.F.G., Ort, D.R. and Long, S.P. 2004. Will photosynthesis of maize (Zea mays) in the US Corn Belt increase in future [CO_2] rich atmospheres? An analysis of diurnal courses of CO_2 uptake under free-air concentration enrichment (FACE). Global Change Biology.10: 951–962.

Lee, J.S. 2011. Combined effect of elevated CO_2 and temperature on the growth and phenology of two annual C_3 and C_4 weedy species. Agr Ecosyst Environ 140(3): 484–491.

Leakey, A.D.B., Uribelarrea M, Ainsworth, E.A., Naidu SL, Rogers A, et al. (2006) Photosynthesis, productivity, and yield of maize are not affected by open-air elevation of CO_2 concentration in the absence of drought. Plant Physiol 140: 779–790.

Lloyd, J. and Farquhar, G.D. 2008. Effects of rising temperature and CO2 on the physiology of tropical forest trees. Philos. Trans. R. Soc. Lond. B Biol. Sci.363:1811–1817.

Long, S.P., Ainsworth, E.A., Leakey, A.D.B., No¨sberger, J., Ort, D.R., 2006. Food for thought: lower-than-expected crop yield stimulation with rising CO_2 concentrations. Science 312:1918-1921.

Maroco, J.P., Edwards, G.E. and Ku, M.S.B., 1999. Photosynthetic acclimation of maize to growth under elevated levels of carbon dioxide. Planta 210:115–125

Mendelsohn, R. and Dinar, A. 2009. Climate change and agriculture: an economic analysis of global impacts, adaptation and distributional effects. Cheltenham, UK: Edward Elgar,pp. 256.

Meng, F., Zhang, J., Yao, F., Hao, C., 2014. Interactive Effects of Elevated CO_2 Concentration and Irrigation on Photosynthetic Parameters and Yield of Maize in Northeast China. PLoS ONE 9, e98318. doi:10.1371/journal.pone. 0098318.

Morison, J.I.L., 1996. Global environment change impacts on crop growth and production in Europe. Implications of global environmental change for crops in Europe. Aspects Appl. Biol. 45:62−74.

Olsen, S.R 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. Circular No. 939. USDA, Washington, D. C., USA.

Pathak, H., Aggarwal, P.K., Singh, S.D. 2012. Climate change Impacts, Adaptations and Mitigation in Agriculture: methodology for assessment and Application, Indian Agricultural research Institute, New Delhi,ppxix+302.

Prathyusha, C., Hemalatha, S., Sridhar, K., Sharana, Basava., 2013. Growth and productivity of speciality corn as influenced by different levels of nitrogen under pongamia plantations. Int. journal of applied biology and pharmaceutical tech.4: 110-113.

Prins, A., Verrier, P., Kunert, K.J. and Foyer, C.H. 2007. Acclimation of the maize transcriptome to CO_2 enrichment. South African Journal of Botany. 73: 307-308.

Qaderi, M.M., Kurepin, L.V. and Reid, D.M., 2006. Growth and physiological responses of canola (Brassica napus) to three components of global climate change: temperature, carbon dioxide and drought. Physiol Plant. 128,710–721

Rogers, H.H. 1983. Responses of selected plant species to elevated carbon dioxide in the field. *Journal of Environmental Quality*. 12, 569-574.

Samarakoon, A.B. and Gifford, R.M. 1996. Elevated CO_2 effects on water use and growth of maize in wet and drying soil. Australian J. of Plant Physiology, Melbourne. 23: 53-62.

Subbiah, B.V. and Asija. G.L. 1956. A rapid method for the estimation of available N in soils. *Current Science.* 25: 259–260.

Tripathy, R, Ray S.S. and Singh, A.K. 2009 Analyzing the impact of rising temperature and CO2 on growth and yield of major cereal crops using simulation model. In: Panigrahy S, et al. (Eds.), ISPRS Archives XXXVIII-8/W3 Workshop Proceedings: Impact of Climate Change on Agriculture, India

Venkata, R.P., Subbaiah, G. and Veeraraghavaiah, R. 2014. Agronomic responses of maize to plant population and nitrogen availability- a review. Int. Journal of plant, animal and environmental sciences. 4:107-116.

Walkey, A.E. and Black, J.A. 1934. An examination of the Degtiga Vett. Method for determining soil organic matter and proposed modification of the chromic acid titration method. *Soil Science.* 37:29.

Wall GW, Brooks TJ, Adam NR, Cousins AB, Kimball BA,2001. Elevated atmospheric CO_2 improved *sorghum* plant water status by ameliorating the adverse effects of drought. New Phytol 152(2): 231–248.

Wang JL, Wen XF, Zhao FH, Fang QX, Yang XM, 2012. Effects of doubled CO_2 concentration on leaf photosynthesis, transpiration and water use efficiency of eight crop species. Chin J. Plant Ecol. 36(5): 438–446

Yoshida, S., Forno, D. A., Cock, J. H., Gomez, K. A 1976. *Laboratory manual for physiological studies of rice*. International Rice Research Institute, Manila, Philippines, p. 72.

Ziska, L.H., Bunce, J.A., 2006. Plant responses to rising atmospheric carbon dioxide. In: Morison JIL, Morecroft MD (eds) Plant Growth and Climate Change. Blackwell Publishing Ltd, Oxford, UK, pp. 17–47.