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Full Length Research Paper

Photosynthetic responses of pea plants (*Pisum sativum* L. cv. Little marvel) exposed to climate change in Riyadh city, KSA

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Pots study was conducted to determine interactive effects of climate change (NO_2, SO_2 and O_3) on photosynthetic responses in pea. The seeds of pea plants (*Pisum sativum* L. cv. Little marvel) were grown full-season in three pots arranged at four localities in Riyadh city, KSA. Photosynthetic rates (P_n) were measured three times during vegetative and reproductive stages with portable gas exchange system (LI-COR 6400). In general, P_n rates were highly stimulated at Elsefarat area and highly reduced at the 2nd Industrial city but variable at other localities in Riyadh city. The data showed continuous increases in P_n rates during pre-flowering and early seed formation and drops during late seed formation stage. This study supports that the agricultural areas could have a protective role against adverse impacts of gases exposure in highly polluted areas.

Key words: Photosynthesis, growth stages, pea, gases, KSA.

INTRODUCTION

Many models are available to assess the impacts of climate change on biochemical processes of crops and their productivity (Stockle et al., 2002; Ali et al., 2002). Greenhouse gases have abilities to absorb infrared radiation being emitted by Earth resulting in the reemission of this energy into the troposphere. Also, tropospheric gases are vary widely over the earth's surface such as in KSA and are influenced by a number of factors including localized meteorological parameters, levels of solar radiation as influenced by latitude, proximity to carbon emission centers, background levels of O_3 precursors including volatile organic carbons (VOC's) and other reactive organic compounds in the air mass, and long range transport processes (Krupa and Kickert, 1989; Barnes and Wellburn, 1999).

Global climate change treatments influence leaf photosynthesis rates predominately and have little or no direct effect on structural traits such as height, leaf angles, and vertical leaf distribution; nor do they exert an influence on light transmission through a leaf or through the canopy. However, treatment effects on leaf area can explain the difference in canopy photosynthesis (Teughels et al., 2005; Stockle et al., 2002). All greenhouse gases like nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and ozone (O_3) have fundamental effects on CO_2 exchange by plants. The CO_2 uptake (photosynthesis) may be affected, with the net C gain allocated to different plant processes. The P_n is the most famous parameter affected by gases pollution (Saxe, 1991). Studies of photosynthesis are important to understand the effect of air pollutants including stress on crops (Miller, 1988). Chronic high levels of exposure to O_3 air pollution may produce responses such as reduced photosynthetic rates and earlier senescence

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of leaves, reduced stomatal conductance, reduction in growth and yield of crops and natural vegetation (Krupa and Kickert, 1989; Mulchi et al., 1992; Hakan et al., 1996). Yunus et al. (2006) showed that regional levels of O_3 are likely continuing to increase as major cities (e.g. Riyadh, Cairo, Mexico and Bombay) continue to show rapid population growth and use of fossil fuels in automobiles and industries.

Unsworth and Black (1981), on soybean, noted that O_3 caused seed yield losses which were related to the reduction in leaf area (LA) and leaf area duration (LAD). In addition to the reduction in LA (less photosynthetic leaf tissue) with increasing O_3 concentration, leaves became less efficient in converting atmospheric CO_2 into seed yield as was suggested by the reduced seed yield to LAD ratio. Also, the P_n rates of wheat plants were reduced when they exposed during senescence to several concentrations of O_3 such as 15, 30, 70 and 100 nmol O_3 mol^{-1} full seasons for 8 h per day (Lehnherr et al., 1988)

Soybean plants exposed to chronic O_3 doses also had reduced leaf P_n rates with increased O_3 concentrations (Reich et al., 1986; Mulchi et al., 1992). Chernikova (1998) found only minimal responses in P_n to increased O_3 exposures for soybean cultivars during pre-flowering; however, during podfill, P_n rates declined in a linear fashion over the range of O_3 levels 27 to 60 nmol O_3 mol^{-1}. The reduction in P_n rates of bean plants during chronic O_3 exposure observed early in the growing season (0 to 44 days after emergence), but recovered over night. Later in the season, (i.e. 60 days after emergence), photosynthetic capacity and stomatal conductance gradually decreased as the severity of O_3 injury increased (Sanders et al., 1992). The P_n is stimulated in C_3 species under increased intercellular CO_2 concentration due to increased carboxylation of Rubisco (Bowes, 1991). However, sensitivity to high CO_2 concentrations might be reduced over time due to saturated CO_2 binding to Rubisco and limited regeneration of ribulose 1,5-bisphosphate (RuBP) and/or inorganic phosphorus (Pi) (Stitt, 1991). Barnes and Pfirrmann (1992) exposed radish plants to two levels of O_3 (24 h mean of 20 and 73 nL L^{-1} O_3) and two levels of CO_2 (around 380 and 760 µL L^{-1} CO_2) and measured photosynthesis rates at 14, 22 and 27 days after treatment exposure. They observed that O_3 decreases the P_n rates after 14 and 22 days exposure.

This study aims to investigate the possible interactive effects of NO_2, SO_2 and O_3 on photosynthetic rates of pea plants grown in pots at four localities in Riyadh city, KSA.

MATERIALS AND METHODS

Design

This study was initially carried out at the greenhouse of Botany and Microbiology Department, College of Sciences, King Saud University, KSA. The soils of 24 pots were seeded at the beginning of December, 2007 with pea plants (*Pisum sativum* L. cv. Little marvel) and amended with fertilizers at the rates recommended for plants and pre- or post-emergence herbicide was applied to control weeds. Irrigation units were utilized to maintain soil moisture levels near field capacity of all pots at the greenhouse. Pea plants were grown in pots two weeks until reaching maturity of vegetative growth. Then, 6-pots were transferred to four localities in Riyadh city namely: Elsefarat area, King Abdullah road area, Alsahafah area and the 2nd Industrial city area. Two moisture regimes well-watered (3-pots) and restricted water (3-pots) conditions are included for each locality.

Climate

Air and soil temperatures were recoded. Monthly concentrations of ambient NO_2, SO_2 and O_3 were measured using AEROQUAL series-200 Monitor with multi-heads (Air Monitors Limited, UK).

Leaf photosynthesis rates

Leaf photosynthesis rates (µmol m^{-2} s^{-1}) under different exposures from four localities emissions were measured from all pots with a portable closed gas exchange system (Model LI-6400 primer, LI-COR, Lincolin, NE). Photosynthesis measurements where taken three times during vegetative, flowering and reproductive growth stages of pea plants on expanded leaves of the upper canopy under direct sun light. The P_n rates were measured on three plants per pot three times per day 10.00 am, 12 and 2.00 pm.

Pea yield

Pea yield was calculated for harvested plants after reaching the maturity and removing pods and seeds from each plant. Pods were lengthed and weighed. Seeds were left until reaching the constant weight. The collected seeds were weighed for each pot and expressed as g/pot.

Statistical analysis

Treatments mean were separated using least significant difference comparisons. Data analyzed using analysis of variance (ANOVA) procedures. Significant was tested at the $P \leq 0.05$ levels. The software developed by the SPSS (ver. 11) was used to perform all analysis.

RESULTS

Changes in climate

The measurements of temperature for the air surrounding pea plants and soil temperature are shown in Table 1. Gradual increase occurred in air temperature for all growth stages till reaching 2 pm. The soil temperature for all growth stages was not taking clear manner.

Changes in mean concentrations of NO_2, SO_2 and O_3 during the growth stages of pea at four localities, Riyadh, KSA are listed in Table 2. Mean concentrations of O_3 gradually increased from vegetative to reproductive stages for all studied localities reaching maximum in reproductive stage of the 2nd Industrial city area at 2 pm being 108 nL L^{-1} and recording the lowest concentration in

Table 1. Mean values of air and soil temperatures (°C) for surroundings and pots of pea at different growth stages under four air quality localities treatments in Riyadh city, KSA.

Localities	Growth stages	Air temperatures			Soil temperatures		
		10 am	12 pm	2 pm	10 am	12 pm	2 pm
Elsefarat area	Vegetative	18	20	21	11	12	13
	Flowering	20	21	22	13	14	14
	Reproductive	23	24	26	14	15	16
King Abdullah road area	Vegetative	19	20	21	12	12	13
	Flowering	20	21	22	13	14	14
	Reproductive	23	24	26	15	16	18
Alsahafah area	Vegetative	18	19	20	11	12	13
	Flowering	20	21	22	13	14	14
	Reproductive	23	24	26	14	15	16
2nd Industrial city area	Vegetative	22	23	24	12	14	17
	Flowering	25	26	27	14	14	18
	Reproductive	26	28	29	15	15	18
LSD (*P< 0.05*)		3.2	3.1	3.4	2.9	3.5	4.3

Table 2. Mean values of NO_2, SO_2 and O_3 concentrations (nL L^{-1}) for pea grown in pots at different growth stages under four air quality localities treatments in Riyadh city, KSA.

Localities	Growth stages	NO_2 concentrations			SO_2 concentrations			O_3 concentrations		
		10 am	12 pm	2 pm	10 am	12 pm	2 pm	10 pm	12 pm	2 pm
Elsefarat area	Vegetative	12	13	14	11	12	13	22	23	23
	Flowering	13	14	14	13	14	14	24	24	25
	Reproductive	15	16	16	14	15	16	26	27	26
King Abdullah road area	Vegetative	18	23	25	22	24	23	44	65	73
	Flowering	20	25	23	23	24	25	54	64	77
	Reproductive	23	24	24	25	26	23	55	66	78
Alsahafah area	Vegetative	17	19	17	18	19	17	43	44	45
	Flowering	19	22	22	25	32	34	52	54	54
	Reproductive	21	24	22	22	22	23	56	60	54
2nd Industrial city area	Vegetative	24	25	24	23	24	27	77	84	88
	Flowering	28	29	33	28	31	32	82	88	98
	Reproductive	32	34	33	32	34	37	88	94	108
LSD (*P< 0.05*)		5.5	3.4	4.2	4.3	5.3	4.8	9.8	11.4	12.1

vegetative stage of Elsefarat area being 22 nL L^{-1}. Also, gradual increase in SO_2 and NO_2 concentrations was observed. For both gases, high values were recorded in the 2nd Industrial city area during hot months being 34 nL L^{-1} at 12 pm and 37 nL L^{-1} at 2 pm for NO_2 and SO_2, respectively.

Responses of leaf photosynthesis

Effects of NO_2, SO_2 and O_3 on leaf P_n measured at three growth stages under two soil moisture regimes are summarized in Table 3. Generally, the P_n values were higher under wet conditions comparing to that at dry treat-

Table 3. Mean values of leaf photosynthesis rates (μmol m^{-2} s^{-1}) for pea at different growth stages under four air quality localities treatments and two soil regimes in Riyadh city, KSA.

Localities	Growth stages	P_n rates Well-watered			P_n rates Restricted-watered		
		10 am	12 pm	2 pm	10 am	12 pm	2 pm
Elsefarat area	Vegetative	250	270	290	230	250	220
	Flowering	420	440	400	360	390	380
	Reproductive	330	350	330	250	260	230
King Abdullah road area	Vegetative	220	230	200	190	200	200
	Flowering	290	300	260	230	250	220
	Reproductive	220	250	210	200	210	200
Alsahafah area	Vegetative	240	270	250	210	240	220
	Flowering	300	330	300	290	300	280
	Reproductive	230	250	200	200	230	190
2nd Industrial city area	Vegetative	200	230	200	180	200	190
	Flowering	250	260	270	200	230	220
	Reproductive	190	220	210	170	200	180
LSD (*P< 0.05*)		35	41	55	42	34	23

Table 4. Mean values of pods and seeds characters for pea at different growth stages under four air quality localities treatments and two soil regimes in Riyadh city, KSA.

Localities	Water treatments	Pods characters			Seeds characters		
		Fresh wt (gm/pot)	Length (cm)	No./pot	No./ pot	%	Yield (gm)
Elsefarat area	Well-	52.4	7.98	12	75	18.3	854.5
	Restricted-	45.5	7.11	10	71	17.2	8.41.2
King Abdullah road area	Well-	35.4	5.23	8	49	12.7	701.0
	Restricted-	33.3	5.01	6	44	11.0	700.2
Alsahafah area	Well-	42.3	6.91	9	55	15.7	778.3
	Restricted-	38.2	6.11	7	51	14.3	741.3
2nd Industrial city area	Well-	31.5	4.47	6	25	10.1	676.1
	Restricted-	30.5	4.12	5	22	9.2	655.5
LSD (*P< 0.05*)		9.21	1.43	2	15	5.61	42.5

ments. The P_n rate values were increased gradually starting from 10 am of vegetative growth stage reaching up at 12 pm of flowering stage but decreased slightly at the stage of reproductive. Pea plants grown in pots at studied localities exhibited big difference in P_n values. The data showed that Elsefarat area had the highest values of P_n being 440 μmol m^{-2} s^{-1} at 12 pm, while the 2nd Industrial city area recorded the lowest values of P_n being 190 μmol m^{-2} s^{-1} at 10 am of well-watered conditions. In general, leaves of pea plants grown under enriched NO_2, SO_2 and O_3 at King Abdullah road and 2nd Industrial city areas had lower P_n rates than other ones grown under less gas pollutants. In few cases, the gases enrichment had no significant effect on P_n rates under dry conditions, while significant differences between all studied localities and the time of measurements. Chronic NO_2, SO_2 and O_3 exposure tended to more reduce P_n rates at 10 am but these results were significant when compared to that ones measured at 2 pm. Significant lower P_n rates were observed at 10 am and 2 pm for all growth stages and highly variations between localities of restricted water conditions.

Responses of yield quality

The NO_2, SO_2 and O_3 induced a significant ($P < 0.01$) decline in pea plant grain yields in both soil moisture regimes (Table 4). The ambient-air treatments of highly polluted localities (2nd Industrial city area) also reduced the number of fresh weight of pod, length of pod, number of pos per pot and pods per pot. The treatments of 2nd

Industrial city area and King Abdullah road area reduced the pod length by 44 and 34%, respectively. The number of seeds per pod of pea plants exposed to Elseferat area air pollution was significantly higher than that of plants treated with air pollution of other localities. In case of number, pea seeds per pot recorded the highest values of well-watered treatments at Elsefarat area being 75, while the lowest values recorded at 2nd Industrial city area being 22. Maximum and minimum losses in pea seed % are similar to number of pea seeds per pot.

DISCUSSION

Climate changes (NO_2, SO_2, O_3), predominantly a warming of the ecosystems, caused soil carbon to decrease overall, especially in desert. They alone project a carbon loss after 50 years (Hall et al., 1995). Also, global climate change treatments influence leaf photosynthesis rates predominantly by decreased production of CO_2 (Teughels et al., 2005). The pea plant (C_3) species exhibited significant responses to the atmospheric treatments. The mechanism(s) involved a possible protective role via CO_2 production. In addition, the results from the present study support a hypothesis that these CO_2 concentrations somehow protects the pea's ability to partition the photosynthates to developing sinks as grains.

The collected data from this work supported that the elevated CO_2 can increase the productivity of pea plant in less polluted areas (Elsefarat, Alsahafah). DaCosta et al. (1986) suggested that CO_2 release or uptake of a full crop in the field could be predicted with reasonable accuracy from knowledge of the air temperature and soil moisture content. On the other hand, cultivated pea plants at highly polluted areas (King Abdullah, 2nd Industrial city) may produce less CO_2 which lead to less photosynthesis. Electron microscope examination of climate change (NO_2, SO_2 and O_3) injury revealed that the considerable disruption including tonoplast rupture may have caused a complete disruption of the osmotic balance within the cell inactivating the photosynthetic process (Sanders et al., 1992). Also, the sensitivity of P_n to air pollutants is affected by genotypes (Reich and Amundson, 1985; Miller, 1987), development stage (Lehnherr et al., 1988), and various environmental factors such as light intensity, ambient CO_2 levels, nutrient status and water availability (Runeckles, 1992). Leaves of pea grown in pots at all study localities recorded less P_n rates in compared to Elsefarat locality. This reduction in P_n rates of pea plants during senescence are might be associated with increased stomatal conductance and decrease in various components of the photosynthetic apparatus such as chlorophyll concentration, soluble protein, adenylates, RuBP regeneration, and Rubisco (ribulose 1,5-biphosphate carboxylase/oxygenase) activity. Farage et al. (1991) concluded that the first inhibitory effect of NO_2, SO_2 and O_3 on P_n is a loss of carboxylation efficiency (i.e. CO_2 uptake/internal leaf CO_2 concentration) due to decreased activity of Rubisco. Also, this may be attributed to the fact that plants were fully acclimated to the CO_2 enriched environment (Allen, 1990).

During the later stages of vegetative growth, perhaps CO_2 was no longer a limiting growth factor. During this period, sink capacity becomes limited and P_n rates are likely become reduced due to a possible accumulation of starch grains in the chloroplast which triggers feedback mechanisms that inhibit photosynthesis (Stitt, 1991). However, during the late handling process and during the early handing process, significant CO_2 effects were again observed which might be attributed to the greater demand for carbohydrates in response to increased sink capacity by the plant (Woodword et al., 1991; Stitt, 1991). Later in the season, when plants were in the ripening stage, no significant difference was found but plants grown under enriched CO_2 presented higher P_n rates for each of the two last readings (early seed formation and late seed formation), respectively. This can be attributed to a small delay in leaf senescence observed for plants grown under enriched CO_2. Barnes et al. (1995) reported that interactions between carbon assimilation, carbohydrate status and chemical composition (nutrient status) may dictate the manner in which plants respond to rising CO_2 concentrations, and governed the ability of the plant to sustain its positive response to CO_2 enrichment.

Pea plants recorded less photosynthetic rates and low yield under low irrigated water for all studied localities. Restricted water in soil affect vegetation during reproductive stages for cotton where yields were lower in response to increase in the rate of boll abscission (Grimes et al., 2007). Early stress caused square shedding and a subsequent depression in bloom rate; mid-season stress decreased boll retention and hastened cutout (i.e. temporary cessation of growth and blooming); and late stress caused abscission of almost all young bolls but not of older bolls (Grimes et al., 2007). On the other hand, well-watered conditions gave the best yield. This is due to its influence soil properties, and hence physiological and internal biochemical activities of plants. Water stress induces a decrease in leaf water potential, which causes reductions in the rates of photosynthesis assimilation (Havaux and Lannoye, 1985). Photosynthesis in alfalfa plant was inhibited by about 35% (Nicolodi et al., 1988) and in soybean by 71% (Dornbos et al., 1989) during severe moisture deficits. The effect of short-term water stress on photosynthesis in sunflower hybrids differing in productivity under field conditions was examined by Gimenez et al. (1992). They found that the amount of chlorophyll and soluble protein did not differ significantly between hybrids. Water stress developed over four days decreased the assimilation rates of both hybrids by a similar degree. Changes in the amounts of chlorophyll and soluble protein were small and were not sufficient to explain the decrease in photosynthesis; neither was observed decreases in stomatal conductance.

Agriculture soils at Elsefarat area may also increase the root growth of pea plants. This may lead to increase plant efficiency for retrieval of nutrients from soil. Timlin et al. (1992) suggested that a major factor in nutrient transport mechanisms in soil is root distribution of plants. The response to elevated CO_2 involve increasing the rates of photosynthesis and growth, especially increased allocation of carbon below ground, particularly root exudates, sloughing of root tissues, death of fine roots and mycorrhizae readily available carbon in soil (Zak et al., 1993). Varvel (1994) indicated that C could be sequested at 10 to 20 g m^{-2} yr^{-1} in some cropping systems with sufficient levels of N fertilizer. Greater storage of C in soil suggests CO_2 emissions from agriculture soils could be increased in the long term and may have significant effect on CO_2 in the atmosphere under current climatic conditions.

The effects of NO_2, SO_2 and O_3 were found to be the cause of large changes in grains quality. Reduction of grain yield in pea in response to gases levels induced stress was attributed to reduced P_n due to early senescence and reduced capacity of plants to provide photosynthetic assimilate to grains (Lehnherr et al., 1987; Miller, 1987). Also, the decrease in photosynthetic rates paralleled the content of Rubisco (Lehnherr et al., 1987) in response to premature senescence of the flag leaf triggered by O_3-induced stress (Lehnherr et al., 1987). Kull et al. (1996) explained the impact of O_3 on plants by depression of photosynthetic activity and the accelerated senescence of leaves. Moreover, a genotype considered tolerant with normal CO_2 levels appears to have decreased O_3 tolerance with elevated CO_2.

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