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Effect of Ambient Gasess on Respiration of Soil Supporting Four Crops in Central Saudi Arabia

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Abstract: This study was conducted at four localities (Maseef, Naseem, Oleya and Industrial City) in Riyadh city, KSA to determine the effect of increased tropospheric gases on responses of *in situ* soil respiration (Rs) of wheat (*Triticum aestivum* L. cv. Giza 68), broad bean (*Vicia faba* L. cv. Lara), kidney bean (*Phaseolus vulgaris* L. cv. Giza 3) and pea (*Pisum sativum* L. cv. Perfection) rhizosphere soil. These plants were grown to a full-season in pots to recieve four air quality localities treatments. Daily mean of O_3, SO_2, NO_2 and CO_2 concentrations were recorded by portable gas analyzers in the center of studied localities. The Rs values were measured monthly before seed germination, during all growth stages and after harvesting (October, December, February, April and June) at three times during the day (morning, noon and afternoon) for each stage. The maximum values recorded for O_3 in mid June, 2007 were 39, 77, 95 and 166 nL L^{-1}, in Maseef, Naseem, Olea and Industrial City localities, respectively. Significant decreases in Rs were observed for all polluted localities in compared Maseef site (less polluted). The greatest decreases in Rs were found at Industrial City followed by Naseem and Oleya. More reductions in Rs were observed for the Industrial City treatments during flowering and grainfill stages, while normal respiration at Maseef area was recorded. This study concluded that O_3 injury can reduce the R_s by decreasing the activities and reactions in soil supporting plants.

Key words: Climate change, CO_2, O_3, respiration, microbes, Riyadh city

INTRODUCTION

The role of tropospheric gases like ozone in altering plant growth and development has been the subject of thousands of publications over the last several decades[1, 9]. Still, there is limited understanding regarding the possible effects of ozone on soil processes. In this study, the ozone effects on the flow of carbon from the atmosphere, through the plant to soils, and back to the atmosphere as a framework. A conceptual model based on some signaling is used to illustrate changes in response to ozone, and to discuss possible feedbacks that may occur. Despite past emphasis on above-ground effects, ozone has the potential to alter below-ground processes and hence ecosystem characteristics in ways that are not currently being considered[3].

Since the Industrial Revolution (around 1750), human activities have substantially added to the amount of heat-trapping greenhouse gases in the atmosphere [2,4]. The burning of fossil fuels and biomass (living matter such as vegetation) has also resulted in emissions of aerosols that absorb and emit heat, and reflect light[2]. The addition of greenhouse gases and aerosols has changed the composition of the atmosphere. The changes in the atmosphere have likely influenced temperature, precipitation, storms and sea level[2]. However, these features of the climate also vary naturally, so determining what fraction of climate changes are due to natural variability versus human activities is challenging. The summary of the atmosphere and climate changes observed during the Industrial Era and, where possible, current understanding of why the changes have occurred are atmosphere, temperature, precipitation, storm and sea level changes[2,4].

The use of vegetation to simulate the response of the terrestrial biosphere to climate changes showed an increase in C storage on the land after a substantial loss during the transient phase[4]. Globally increases in O_3concentrations change in the flux of C to and from soils (respiration) and cycling of C and N will occur.

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This has important implications for the functioning of ecosystems because soil C and nutrient cycles are closely associated. Due to much debate about how the various roles of agro-ecosystems and natural terrestrial ecosystems in global phenomena will be affected by future changes in climate and a changed atmospheric composition[6]. Since terrestrial soils contain about 71% of total terrestrial C stocks[7], any change in the net flux of carbon into or out of soils may have major repercussions on atmospheric CO_2 concentrations and the potential for global change. As the most biologically active portion of soil, the rhizosphere (the soil immediately adjacent to plant roots) is likely to be affected most by environmental stresses.

Therefore, it is essential to understand how specific stressors like O_3 will affect the rhizosphere, which acts as an interface between primary carbon processes and primary nutrient and water processes. Exposure of plants to O_3 produced an decrease of respiration in the rhizosphere soil of *Triticum aestivum*[8]. Also responses were noted in canola (*Brassica napus* L.), cotton (*Gossypium hirsutum* L.), maize (*Zea mays* L.), and soybean [*Glycine max* (L.) Merr.] in soil respiration upon exposure to O_3 in growth chambers[9,10].

Functional ecosystems are essential for supplying adequate clean air and water, habitat for wildlife, commercial fiber and food products, recreational resources and for preserving biodiversity[11]. In addition to the many natural stresses that may affect ecosystem structure and function, introduced pathogens and pests, including exotic plants and animals and pollution may also extract a toll. Ozone is the most important phytotoxic air pollutant in KSA. It is omnipresent in our ecosystems, even at distance from important sources of the precursor pollutants, often in concentrations that affect plant growth, development and productivity.

Ozone affects above-ground parts of plants directly, but often the first manifestations of exposure are measured below-ground where root growth may be inhibited, respiration increased and symbiotic relationships disrupted[12]. Given a sufficient exposure, growth of individual plants may be reduced and normal plant–parasite interactions may be modified. In addition, ozone exposure may disrupt normal development of forest stands resulting in shifts in composition, changes in genetic structure and biodiversity and in impaired ecosystem function. The possible interactions of ozone with a changing climate are unknown, but could, depending on species and specific conditions, range from an amelioration of ozone-induced effects on plant growth to an increase in the deleterious effects of ozone[11].

This research was conducted to focus on respiration in rhizosphere soil of four plants grown under air pollution stresses of four different polluted localities.

MATERIALS AND METHODS

Experiment: The research study was conducted first for two weeks at greenhouse of Botany and Microbiology Department, College of Sciences, King Saud University, KSA. The seeds of studied plants were planted on a loam soil with a pH of 6.6. The treatments were begun as soon as plants were reached to 15 cm length (the time of transferring plants to studied localities). Plants were transferred to four localities (Maseef, Naseem, Oleya and Industrial City) in Riyadh city, KSA. Weeds were controlled during the growth of plants using recommended solution or by hands.

Seeds of wheat (*Triticum aestivum* L. cv. Giza 68), broad bean (*Vicia faba* L. cv. Lara), kidney bean (*Phaseolus vulgaris* L. cv. Giza 3) and pea (*Pisum sativum* L. cv. Perfection) plants were planted in the last week of October 2006 in 4 m length x 1 m width x ½ height pots in rows spaced 0.5 m apart with seeds spaced 10 cm apart. The pots were covered with plastic membrane during rainfall.

Atmosphere measurements: Meteorological parameters for all studied localities were measured monthly. Atmospheric gases O_3, SO_2, NO_2 and CO_2 were measured monthly starting from October till June using AEROQUAL series-200 Monitor with multi-heads (Air Monitors Limited, UK). Each month we selected the 1st week for complete daily measuring.

***In situ* respiration rates (Rs):** The Rs (μ mol CO_2 m^{-2} sec^{-1}) was measured using a model 6000-09 soil respiration chamber attached to a model 6400 Portable Photosynthesis System (LICOR, Inc., Lincolyn, NE). It was measured five times: before seed germination, during all growth stages and after harvesting (October, December, February, April and June) at three times during the day (morning, noon and afternoon) for each stage. Approximately 1.0 h prior to measurements, six plastic rings (10 cm diameter ×5.0 cm height) were randomly installed per pot into soil in between rows of wheat, broad bean, kidney bean and pea plants. The rings were inserted to a depth about 1.5 cm each and allowed to outgas prior to CO_2 flux measurements. Also, prior to beginning measurements, the internal CO_2 concentrations within the respiration chamber and gas analyzer were reduced to about 100 μL CO_2 L^{-1} below the existing ambient CO_2 levels to ensure steady-state flux conditions. After observing that soil CO_2 flux activities were indeed steady state, readings were taken for 60 sec with mean CO_2 flux rates calculated every 15 sec. It was determined during initial procedures that longer reading periods presented problems with excess moisture build up in the gas analyzer. Using the 60 sec $ring^{-1}$ protocol, soil CO_2 flux rates could be completed in all 16 chambers within a period of 8-h duration. In situ CO_2 measurements were repeated on a monthly basis beginning in mid-October, 2006 and finshedd in June, 2007. In January, 2007 due to a very cold, soil respiration rates were initiated in the last two days of the month.

Statistical procedure: Data were analyzed using analysis of variance (ANOVA) procedures for random design. The least Significance Difference (LSD) evaluated the mean differences between the four air quality localities treatments. Statistical analysis was performed using SPSS (version 11).

RESULTS AND DISCUSSION

Air quality: Mean values of meteorological data including temperature, wind velocity, precipitation and radiation from studied localities experimental sites are summarized in Table 1. It showed low values during months of January, June, October, May and June, and October, November and June for air temperature, humidity, wind velocity and rain-fall, respectively. While an increase in June, January, November and January for air temperature, humidity, wind velocity and rain-fall, respectively. Gradual decrease in the air temperature occur, reaching to a minimum of 18°C in January followed by gradual increase reaching to a maximum of 42°C in June. On the other hand, the gradual decrease in humidity and rain-fall tend to be in summer months, while wind velocity vary throughout the year. Monthly and daily mean values of gases' (O_3, SO_2 and NO_2) concentration (nL L^{-1}) in Riyadh city, KSA during the growth period of studied crops (2006/2007) were listed in Tables 2, 3. The results showed that O_3 levels are higher in the urban (Industrial City and Olea) than in the suburban (Naseem) or surrounding rural sites (Maseef), because the presence of high concentrations of NO in the city centre is a major cause of destroying O_3[12]. When the behavior of the localities is compared, it was observed that monthly values captured at Industrial City were significantly high in comparing to other localities (Table 2). The greatest values follow the highest solar radiation, which is the basis of the photochemical reactions, involving the components of vehicle emissions and other sources. This behavior is typical of the urban areas where O_3 quickly increases during the day through the photochemical cycle and just as quickly decreases in the reversible reaction $NO+O_3 = NO_2+ O_2$[11]. Industrial City showed the highest O_3 values at the mid-day. In every examined day, it is recorded higher concentrations than the other localities, showing values ranging from 43-167 nL L^{-1}. This site observed the greatest hourly average of 185 nL L^{-1}, recorded on 8 June 2007. This is largely believed to be from horizontal air transport, high solar radiation (temperature and light), heavy traffic and a subsequent

Table 1: Mean values of meteorological parameters in Riyadh city, KSA (2006/2007)

Years/Months	Air temperature (°C)	Soil temperature (°C)	Humidity (°C)	Wind velocity (km h^{-1})	Rain-fall (mm)
October 2006	39	35	30	6	0.00
November 2006	30	24	33	9	0.00
December 2006	22	21	35	8	3.12
January 2007	18	15	36	7	18.8
February 2007	20	16	35	8	12.6
March 2007	32	30	30	7	13.6
April 2007	36	35	30	8	1.78
May 2007	41	40	28	6	0.55
June 2007	42	40	22	6	0.00

Table 2: Monthly mean values of gases concentration in Riyadh city, KSA during the growth period of studied crops (2006/2007)

Localities Years/Months	O_3 levels (nL L^{-1})	SO_2 levels (nL L^{-1})	NO_2 levels (nL L^{-1})	CO_2 levels (µL L^{-1})
Maseef				
October 2006	38	13	12	355
November 2006	33	13	12	365
December 2006	29	13	12	355
January 2007	25	11	11	350
February 2007	26	10	11	355
March 2007	34	11	12	360
April 2007	35	13	11	365
May 2007	36	12	13	355
June 2007	39	12	12	365
Naseem				
October 2006	64	18	22	350
November 2006	64	18	22	360
December 2006	46	18	15	350
January 2007	33	17	15	350
February 2007	33	10	13	350
March 2007	46	12	14	360
April 2007	58	13	16	355
May 2007	62	14	19	365
June 2007	77	15	20	365
Olea				
October 2006	82	24	26	385
November 2006	60	23	25	375
December 2006	44	23	22	365
January 2007	45	16	15	370
February 2007	55	16	17	375
March 2007	79	16	18	380
April 2007	93	18	19	385
May 2007	95	19	23	385
June 2007	95	29	27	390
Industrial city				
October 2006	115	29	26	395
November 2006	85	24	23	385
December 2006	55	20	22	375
January 2007	50	15	21	360
February 2007	52	20	24	375
March 2007	77	25	25	380
April 2007	89	33	35	395
May 2007	120	35	33	415
June 2007	166	41	32	425

Table 3: Daily mean values of gases concentration in Riyadh city, KSA during the growth period of studied crops (2006/2007)

Localities/Days	O_3 levels (nL L^{-1})	SO_2 levels (nL L^{-1})	NO_2 levels (nL L^{-1})	CO_2 levels (μL L^{-1})
Saturday	178	43	40	385
Sunday	135	33	32	395
Monday	131	33	33	385
Tuesday	129	32	31	375
Wednesday	130	30	33	370
Thursday	86	17	11	375
Friday	54	11	10	360

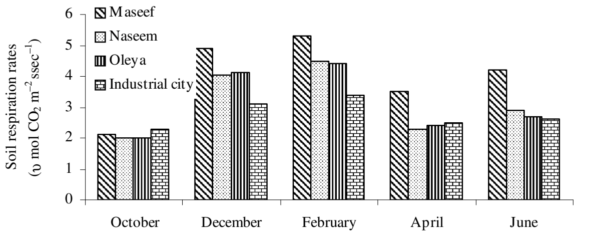

Fig. 1: *In situ* soil respiration rates (μ mol CO_2 m^{-2} sec^{-1}) for soils of wheat grown in pots under four air quality localities treatments at Riyadh city, KSA

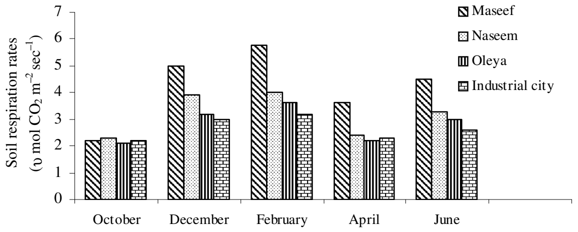

Fig. 2: *In situ* soil respiration rates (μ mol CO_2 m^{-2} sec^{-1}) for soils of broad bean grown in pots under four air quality localities treatments at Riyadh city, KSA

accumulation of photochemical products, which is common in all big cities[12]. This value is above the threshold for public warning (ca. 184 ppb). Saturday recorded the highest ozone levels in comparing to other days of the week due to the heavy traffic at the beginging of the work days (Table 3).

Effect of air quality on Rs rates: The effects of atmospheric O_3 on Rs rates for soil supporting wheat at four growth stages of plant development (vegetative, flowering, grainfill and pre-harvesting) are shown in Fig. 1. Pre-seed germination produced non-significant effects for allprepared soils Air quality treatments in four localities caused significant differences during the 1st day of vegetaive growth in compared to pre-cultivation, while significant decreases in the Industrial City site in compared to Maseef site. Moreover, gradual increase in Rs rates during vegetative and flowering stages, then droped starting at grainfill (Fig. 1).

In situ soil respiration rates for soil supporting broad bean plants grown in pots under the effect of four air quality localities are showed in Fig. 2. Naseem, Oleya and Industril City localities exhibited slightly higher rates of respiration, while Maseef area recorde high Rs rates at vegetative growth in compared to soils before seeding. The effect of air quality in Oleya and Industril City localities on CO_2 flux rates in soil supporting broad bean showed little significant decreases in compred to Naseem site. Generally, air quality treatments increased the rates of flux in Maseef in compared to other sites (Fig. 2).

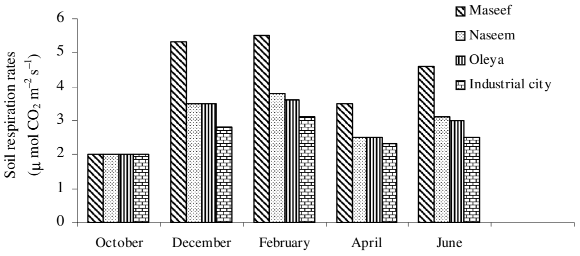

Fig. 3: *In situ* soil respiration rates (μ mol CO_2 m^{-2} sec^{-1}) for soils of kidney bean grown in pots under four air quality localities treatments at Riyadh city, KSA

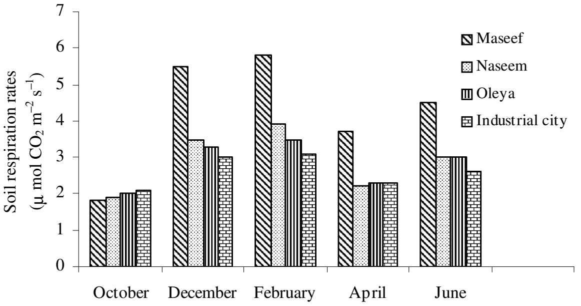

Fig. 4: *In situ* soil respiration rates (μ mol CO_2 m^{-2} sec^{-1}) for soils of pea grown in pots under four air quality localities treatments at Riyadh city, KSA

Respiration rates levels in soils of kidney bean plants before seed germination were exactly similar (Fig. 3). In all growth stages, no significant differences between Rs rates of Naseem and Oleya localities. The Rs rates were lowered to low levels at the time of harvesting under air quality treatments of Industril City locality. Exposure of kidney bean plants to low O_3 significantly deceases the levels of respiration. The highest respiration rates for all growth stages were observed during grainfill development (Fig. 3).

With respect to the combination of elevated NO_2, SO_2 and O_3, respiration levels of pea soils were not only higher before the mid of the day, but also afternoon (Fig. 4). In term of air quality treatment effects, the results were typically significantly different between all studied localities except the times of grainfill and pre-harvesting. During grainfill and pre-harvesting times, only significant decreases were recorded between all sites and Maseef site (Fig. 4).

Typically, Rs rates found in soils with a recent input of easily degradable substrate. Such substrates would induce a microflora that usually respired more CO_2 per unit degradable C[13]. Close relationship were found between the effects of air quality treatments and CO_2 fluxes, however, Rs rates as reflecting the activity of whole microbial activity[14]. The relationships between Rs rates were found to be linked to climatic conditions. Part of the climatic effect may be explained by an altered quantity of metabolizable substrates due to an influence on primary production or substrate allocation to the roots and decomposition as such in response to climatic conditions[15]. The translocation of photosynthetic compounds below-ground made high linking between CO_2-fluxes and the stimulation of microbial activity[16].

The flux of CO_2 from soil can be a significant component of the carbon budget in an ecosystem. In a prairie environment, soil surface CO_2 fluxes were comparable to daily gross photosynthetic rates when averaged over 24 hours[17]. Yim *et al.* [18] found that up to 20% of net CO_2 uptake by a crop could originate in soil. There were strong positive responses to increased soil respiration under atmospheric CO_2 concentrations [Fig. 30, 31, 32 and 33 (from 15-17)]. Elevated tropospheric gases decreased the CO_2 fluxes for all studied crops. These results agree with that obtained by Stott *et al.* [19]. The respiration of roots, decay of organic matter, and activity of microbes primarily produce soil CO_2[20]. Soil respiration is very dependent on soil temperature, organic content, moisture content and precipitation [21]. High in *situ* soil respiration rates due to more C mineralized as CO_2 and transferred to the atmosphere; therefore, such soils acted as net sources of CO_2[22]. However, the negative effects resulting from tropospheric O_3 treatments on organic C fractions and respiration appear to have been balanced by the positive effects of higher inputs of decomposable C below-ground. A relatively low Rs in soils under localities treatments is an indication of environmental stress that to repair damages under stress requires soil microbes to divert an increasing amount of energy from growth and reproduction for maintenance and survival[23].

CONCLUSION

Increases in global climate will not only directly affect the growth of plants, but might also alter the living conditions for soil biota. Part of the climatic effect may be explained by an altered quantity of metabolizable substrates due to an influence on primary production or substrate allocation to the roots and decomposition as such in response to climatic conditions. Significant relationships between CO_2-fluxes and the stimulation of microbial activity may be attributed to the translocation of photosynthetic compounds under ground. The suitable time for detecting Rs is the period after 12pm because higher temperatures correlate with soil surface CO_2 fluxes and accelerate the development of a soil

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