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Tropospheric Ozone Effects on the Productivity of Some Crops in Central Saudi Arabia

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Abstract: This study was conducted to evaluate damaging degree of ambient ozone (O_3) levels in certain economically important crops in typical areas of the central KSA (Riyadh). Daily mean ozone concentrations were recorded by portable O_3 analyzers in the center of Batha, Naseem, Oleya and Industrial City, from the beginning of October, 2006 to middle of June, 2007. Maseef area was used as control because it is receiving fewer pollutants (O_3 levels less than 40 nL L^{-1}). Selected crops grown in pots were exposed to short-term of pollution at defined localities. These crops include *Triticum aestivum* L. cv. Giza 68 (wheat), *Vicia faba* L. cv. Lara, (broad bean), *Phaseolus vulgaris* L. cv. Giza 3 (kidney bean) and *Pisum sativum* L. cv. Perfection (pea). The exposure indicators of them are length, injury symptoms, biomass and yield. The maximum values of daily O_3 were 125 nL L^{-1}, 77 nL L^{-1}, 95 nL L^{-1} and 166 nL L^{-1}, in all the four studied areas, respectively in mid June, 2007. Results showed that the estimated yield losses varied in all four studied areas, being 35, 9, 39 and 46%, respectively for wheat; being 16, 13, 21 and 33%, respectively for broad bean; being 22, 20, 28 and 45%, respectively for kidney bean and being 5, 3, 14 and 30%, respectively for pea. This research recommended that these plant species can be used to give bio-indicator significance to assess ambient ozone impacts of different examined areas in KSA.

Key words: O_3-Pollution, short-term exposure, crops, growth, reduction

INTRODUCTION

The climatic record of the Middle East region for the past five years showed that there were fluctuations in the temperature and a decrease in rainfall over large portions [1]. Human activities in Saudi Arabia such as burning fossil fuels and changes in land use that modify the global climate with temperature rise projected for the next 100 years could affect the human welfare and the environment. In the 21st century, warming trend and changes in precipitation patterns are expected to continue along with a rise in sea level and increased frequency of extreme weather events [26].

The O_3 concentration in the normal range is 10-30 nL L^{-1} [25]. By rising temperature, its levels could reach above the natural ones. KSA has high levels of this gas during hot and sunny days when poor circulation occurs in the atmospheric boundary layer. In the mid-latitudes, such conditions are typical of the summer season and are associated with anticyclonic weather [22, 28]. However, the O_3 pollution in Saudi Arabia is a matter of concern to all environmentalists of this region.

Ozone potentiality to injure vegetation has been known for over 50 years [16]. It is clear that ambient O_3 can cause visible leaf injury, growth and yield reductions and alter sensitivity to biotic and abiotic stresses [15]. O_3 is indicated as the main culprit for economic crop damage caused by air pollution in the USA and probably causes more damage to vegetation than all other pollutants combined [21]. Economic involvement of these effects may be important [20, 28]. An understanding of exposure/response requires three types of information: a measure of plant response [21]; an index describing pollutant exposure [19]; and a

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mathematical function that relates plant response to exposure [34].

The accurate estimation of crop yield loss is essential for producing useful measures of the economic effect of pollutants [37]. A number of experimental approaches have been used to assess the effects of chronic exposure of O_3 and crop response [27]. Ground surveys of vegetation in the vicinities of the monitoring sites have been done and candidates for bioindicators for ozone have been identified [28, 29]. The open top chamber (OTC) method is the most widely used [1, 2, 3, 4, 30] to evaluate the degree of damage by O_3. On the other hand, Nali, *et al.* [32] studied its effect on some economic crops productivity in ambient plots. Forty-eight experts from several European countries participated in the exercises and assessed visible symptoms of ozone injury both in OTC (Lattecaldo) and under open field (Moggio) conditions [10]. The most comprehensive series of experiments on the relationship between O_3 exposure and crop yield began in 1980, when the National Crop Assessment Network (NCLAN) was established in the USA [20]. Muzikaa *et al.* [31] also studied many variable representing the combined effect of O_3, SO_2 and NO_2 and was negatively correlated with both *Picea abies* and *Fagus sylvatica* growth.

Short-term O_3 exposure is demonstrated to be appropriate for several economically important agricultural species and also for trees and natural vegetation [23]. While, cultivated plants and mid-daylight hours were the best living organisms and time respectively to evaluate the biomass responses to all critical levels [23]. Research has shown that considerable inter- and intra-species variation exists, some of which may result from different environmental conditions under which the experiments were performed, such as O_3 concentration [13].

This study focuses on 1) monthly monitoring of the concentrations of O_3, SO_2, NO_2 in five areas (Maseef, Batha, Naseem, Oleya and Industrial City) of the SA; 2) O_3 effects on studied crops (wheat, broad bean, kidney bean, pea) biomass and morphology; 3) assessing yield reductions of these crops in response to O_3.

MATERIALS AND METHODS

Collecting climate data: Climate monitored at five localities in Riyadh: Maseef, Batha, Naseem, Olaea and Industrial City. Data were collected from the beginning of October 2006 to the end of June 2007. Monthly air temperature, rain fall, relative humidity and wind speed were recorded. Concentrations of studied gases were measured daily at 10AM and 5 PM using O_3, SO_2, NO_2 meters, Graywolf Sensing Solutions, Sweden. These instruments have barometric compensation and internal calibration systems, which perform daily zero/span checks. The means of 7 hours daily (applied to the solar time) and of 30 days monthly were calculated and expressed in ppb (nL L^{-1}). All O_3, SO_2, NO_2 concentrations were stored in special files in a PC.

Plantation, treatments and measurements: Seeds of *Triticum aestivum* L. cv. Giza 68 (wheat), *Vicia faba* L. cv. Lara, (broad bean), *Phaseolus vulgaris* L. cv. Giza 3 (kidney bean) and *Pisum sativum* L. cv. Perfection (pea) were planted in pots at the Botany and Microbiology Department, Faculty of Science, King Saud University during the last week of November 2007 under controlled conditions from suitable soil and irrigation. These plants were left until reaching good vegetative growth (20-25 cm length) then, total number of plants reduced to be 10 in each pot. All pots were transferred to test polluted localities (Maseef, Batha, Naseem, Olaea and Industrial City). Maseef area used as a control.

The biomass was determined when green harvest done. The fresh weights of total leaves, stems and roots were weighed at the end of the growing season, April 2007. At this time the individual plant length was measured with a plastic ruler at the end of growing season. Individual leaf area per plant was measured. A week after seed formation, green harvest was performed. The leaves were divided into the following categories; health; (green), senescent (yellowing) and injured. Subsequently, the proportion of leaves in each of the three categories was calculated per pot. A dry harvest was carried out in April 2007 when seeds were brown and plants carried loosely seeds, then seeds characters were determined.

Statistical analysis: Statistical analyses were carried out using the SPSS BASE 10.0 (SPSS Inc., Chicago, IL) packages. Data were tested by ANOVA. LSD at $p \leq 0.05$ was applied to detect the effect of O_3 short-term critical level on some economic crops. Mean and variance separation between different localities were calculated by using the means of individual measurements.

RESULTS AND DISCUSSION

Climatic distribution: Mean values of meteorological parameters in Riyadh city, KSA (2006/2007) were recorded in Table 1. They 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, Batha 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 [8]. When the behavior of the localities is compared, it was observed that monthly values captured at Industrial City were significantly high (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 $NO+O_3 = NO_2+O_2$ [8]. 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 accumulation of photochemical products, which is common in all big cities [14]. This value is above the threshold for public warning (ca. 184 ppb). Saturday recorded the highest ozone levels due to the heavy traffic (Table 3).

All studied localities of the Riyadh city showed higher values of O_3, SO_2 and NO_2 levels except Maseef. The data in Table 3 ensured that weekend-work days had less effect as reported in other cities such as Rome [11] and the metropolitan area of New Jersey, New York City [8].

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

Months	Air temperature (°C)	Humidity (%)	Wind velocity (km h^{-1})	Rain-fall (mm)
October 2006	39	30	6	0
November 2006	30	33	9	0
December 2006	22	35	8	3.12
January 2007	18	36	7	18.8
February 2007	20	35	8	12.6
March 2007	32	30	7	13.6
April 2007	36	30	8	1.78
May 2007	41	28	6	0.55
June 2007	42	22	6	0

Table 2: Monthly mean values of gases concentration (nL L^{-1}) in Riyadh city, KSA during the growth period of studied crops (2006/2007)

Localities /Months	O_3 concentrations	SO_2 concentrations	NO_2 concentrations
Maseef			
October 2006	38	13	12
November 2006	33	13	12
December 2006	29	13	12
January 2007	25	11	11
February 2007	26	10	11
March 2007	34	11	12
April 2007	35	13	11
May 2007	36	12	13
June 2007	39	12	12
Batha			
October 2006	95	23	22
November 2006	82	21	20
December 2006	57	15	16
January 2007	55	14	15
February 2007	66	10	14
March 2007	87	10	15
April 2007	94	21	16
May 2007	95	21	18
June 2007	125	22	19
Naseem			
October 2006	64	18	22
November 2006	64	18	22
December 2006	46	18	15
January 2007	33	17	15
February 2007	33	10	13
March 2007	46	12	14
April 2007	58	13	16
May 2007	62	14	19
June 2007	77	15	20
Olea			
October 2006	82	24	26
November 2006	60	23	25
December 2006	44	23	22
January 2007	45	16	15
February 2007	55	16	17
March 2007	79	16	18
April 2007	93	18	19
May 2007	95	19	23
June 2007	95	29	27
Industrial city			
October 2006	115	29	26
November 2006	85	24	23
December 2006	55	20	22
January 2007	50	15	21
February 2007	52	20	24
March 2007	77	25	25
April 2007	89	33	35
May 2007	120	35	33
June 2007	166	41	32

Table 3: Daily mean values of gases concentration (nL L^{-1}) in Riyadh city, KSA during the growth period of studied crops (2006/2007)

Localities /Days	O_3 concentrations	SO_2 concentrations	NO_2 concentrations
Saturday	178	43	40
Sunday	135	33	32
Monday	131	33	33
Tuesday	129	32	31
Wednesday	130	30	33
Thursday	86	17	11
Friday	54	11	10

1979). The concentrations of O_3 during the work days were very similar except Saturday. Some of the results are not shown, as no statistically significant differences. According to the literature [23], the O_3 levels observed in Riyadh city can also affect plants. Industrial city often showed continuous exceedances for the entire hot month, in May, June and October [32]. Ozone in high levels during these three summer months are quite common in many Mediterranean countries, with frequent values up to 200 nLL^{-1} h [17]. Concentrations of SO_2 and NO_2 in Maseef recorded close values during months of the study, while in other localities recorded high variations ranged between 10 - 41 nLL^{-1} and between 13 -35 nLL^{-1} for SO_2 and NO_2, respectively (Table 2). Daily concentrations of SO_2 and NO_2 often showing maximum values above 43 and 40 nLL^{-1}, respectively during Saturday (Table 3).

Effect of ozone on studied crops: Short-term ozone impacts on some characters of wheat, broad bean, kidney bean and pea plants are shown in Tables 4-8. In order to evaluate the production losses of the most important crops in Riyadh, the authors considered their distribution and a set of exposure on morphology, biomass, yield response relationships of four economic crops as proposed by UNECE (United Nation Economic Commission for Europe) and US-NCLAN. Reduction in length of wheat plants subjected to climatic changes at Industrial city reached to 28%, while it is 13, 9 and 15 at Batha, Naseem and Oleya respectively (Table 4). Kidney bean and pea lengths were reduced in highly polluted localities but non-significant. The localities chosen at Batha and Naseem recorded non-significant reduction in length of broad bean. In addition, the probable economic loss of broad bean for Oleya and Industrial city was estimated. Naseem station recorded no significant difference in leaf area of wheat, while other stations were significant in comparison with Maseef Station (Table 5). Significant decreases were recorded in the leaf area of broad bean, kidney bean and pea plants grown in pots at

Table 4: Effect of O_3 on final lengths (cm) of wheat, broad bean, kidney bean and pea plants grown in pots at five localities, Riyadh, KSA (2006/2007)

Localities	Wheat length/pot	Broad bean length/pot	Kidney bean length/pot	Pea length/pot
Maseef	139.1	89.1	64.1	44.0
Batha	121.2	77.5	56.2	36.2
Naseem	128.4	75.9	52.1	35.3
Olaea	123.2	66.0	45.6	33.2
Industrial City	108.6	57.9	43.9	32.2
LSD ($p\leq0.05$)	11.1	14.8	12.3	21.2

Table 5: Effect of O_3 on final leaf areas (cm^2) of wheat, broad bean, kidney bean and pea plants grown in pots at five localities, Riyadh, KSA (2006/2007)

Localities	Wheat leaf area/plant	Broad bean leaf area/plant	Kidney bean leaf area/plant	Pea leaf area/plant
Maseef	7.2	4.7	4.1	3.6
Batha	4.4	3.1	3.1	3.2
Naseem	6.2	3.5	3.3	3.3
Olaea	4.6	2.8	3.0	3.4
Industrial city	3.5	2.4	2.5	2.5
LSD ($p\leq0.05$)	2.1	1.1	1.2	0.5

Oleya and Industrial city, Industrial city and Industrial city respectively. Evaluation of O_3 short-term damage to biomass of the studied economic crops for the Riyadh Region, recorded a little variation between examined localities (Table 6). The O_3 concentrations caused quantitative biomass losses of wheat total biomass varying from 6% for Batha, 5% for Naseem, 13% for Oleya and 16% for Industrial city. The estimated of high biomass loss varied from 6% for broad bean to 7% for pea, while reached 4% for kidney bean. Effect of O_3 on a number of leaf categories such as healthy (He), senescence (Se), injury (In) of wheat, broad bean, kidney bean and pea plants grown in pots at five localities (2006/2007)are summarized in Table 7.

At the end of growing season of wheat and broad bean, number of injured leaves of wheat was increased by 27% at Batha, by 20% at Naseem, by 11% at Oleya and by 43% at Industrial city, while this number for broad bean was 33% at Batha, 22% at Naseem, 42% at Oleya and 33% at Industrial city. On the other hand, number of healthy leaves of kidney bean was decreased at Batha by 6%, at Naseem by 6%, at Oleya by 33% and at Industrial city by 50%, while this number for pea was 8% at Batha, 13% at Naseem, 50% at Oleya and length 59% at Industrial city. Generally, quantitative yield loss of studied economic crops was exceeded at all the localities except Maseef (Table 8). Due to the highest levels of O_3 in all studied areas, the big loss reached to 46% 5n case of wheat in Industrial city, followed by Oleya (39%). Wheat showed that varied yield losses in all studied areas being 35, 9, 39 and 46% in Batha, Naseem, Olea and Industrial city, respectively. In Maseef, the number of wheat seeds

Table 6: Effect of O_3 on biomass (gm) of wheat, broad bean, kidney bean and pea plants grown in pots at five localities, Riyadh, KSA (2006/2007)

Localities	Wheat biomass/pot shoot	root	total	Broad bean biomass/pot shoot	root	total	Kidney bean biomass/pot shoot	root	total	Pea biomass/pot shoot	root	total
Maseef	23.9	4.1	28.0	65.8	13.5	79.3	54.4	11.0	65.4	44.5	12.2	56.7
Batha	22.6	3.7	26.3	64.2	11.7	75.9	54.1	10.1	64.2	43.5	10.1	53.6
Naseem	23.2	3.5	26.7	64.5	12.2	76.7	54.1	10.2	64.3	43.7	11.2	54.9
Olaea	22.2	2.6	24.8	64.3	11.3	75.6	54.0	9.8	63.8	43.8	10.1	53.9
Industrial City	22.1	2.1	24.2	63.7	10.6	74.3	53.4	9.0	62.4	43.0	10.0	53.0
LSD ($p\leq0.05$)	1.1	1.2	0.6	0.8	0.7	0.5	0.3	0.9	1.7	4.5	0.5	1.8

Table 7: Effect of O_3 on number of leaf categories: healthy (He), senescence (Se), injury (In) of wheat, broad bean, kidney bean and pea plants grown in pots at five localities, Riyadh, KSA (2006/2007)

Localities	Wheat Leaf categories Number/pot He	Se	In	Broad bean Leaf categories Number/pot He	Se	In	Kidney bean Leaf categories Number/pot He	Se	In	Pea Leaf categories Number/pot He	Se	In
Maseef	24.0	5.0	8.0	35.0	3.0	7.0	36.0	6.0	6.0	27.0	3.0	7.0
Batha	20.0	7.0	11.0	31.0	4.0	10.0	34.0	7.0	8.0	25.0	3.0	10.0
Naseem	23.0	4.0	10.0	33.0	3.0	9.0	34.0	5.0	9.0	24.0	4.0	10.0
Olaea	21.0	7.0	9.0	27.0	6.0	12.0	27.0	8.0	13.0	18.0	5.0	15.0
Industrial City	16.0	7.0	14.0	23.0	7.0	15.0	24.0	12.0	12.0	17.0	5.0	18.0
LSD ($p\leq0.05$)	6.6	2.7	3.2	4.1	2.5	3.7	4.3	5.7	2.4	4.5	1.1	4.1

Table 8: Effect of O_3 on seeds number and seeds yield (gm) of wheat, broad bean, kidney bean and pea plants grown in pots at five localities, Riyadh, KSA (2006/2007).

Localities	Wheat Seeds/pot number	yield	Broad bean seeds/pot number	yield	Kidney bean seeds/pot number	yield	Pea seeds/pot number	yield
Maseef	3502	77.5	657	88.5	365	54.3	575	59.9
Batha	3011	57.3	417	76.5	284	44.4	444	57.3
Naseem	3123	71.2	409	78.5	314	45.3	477	58.4
Olaea	2811	55.6	403	73.2	247	42.5	428	52.5
Industrial City	2802	53.1	333	66.4	219	37.4	361	46.1
LSD ($p\leq0.05$)	75.5	13.2	88.9	11.3	66.3	12.2	23.6	15.5

exceeded by 491, 379, 691 and 700, for Batha, Naseem, Olea and Industrial city, respectively. Yield of broad bean being 16, 13, 21 and 33% in the four studied areas, respectively, while for kidney bean being 22, 20, 28 and 45% in the four studied areas, respectively and being 5, 3, 14 and 30% in the four studied areas, respectively for pea. This reduction in yield is because Maseef was the only locality where the O_3 is not exceeded the normal levels but the other ones showed high levels with variable climatic conditions. The results obtained from the present study, which is first of its kind in the region, can be compared with the results obtained from similar studies conducted elsewhere in the world. A study conducted by Posch *et al.* [33] in the Madrid Area during May-July obtained similar results. In summer 1997, in the Parnish National Park, in the northern outskirts of the Athens Basin, the exceeded damage referred to the critical level of O_3 effect on forest trees [36]. Above results suggest that the effect of O_3 on vegetation is more significant in the Mediterranean area in comparison with northern European sites. The Mediterranean basin is known to have a climate with different characteristics from those of northern and central Europe [18]. In spite of this, mapping of the critical level for O_3 in Germany shows up to more than 280 nL L^{-1} and the damage was exceeded in 93.7% of the agricultural area during the period 1991-1995 [6].

In England, cumulative O_3 dose for the period of May-July 1989 showed loss exceeding 50% only on the southwest coast [9]. In Toscana (Italy), the long-term critical level of O_3 for agricultural crops' cumulative loss is reached to 45% in almost every year [32].. Previous air filtration experiments conducted in northern Italy and Egypt [1, 3, 29, 35], based on the open-top exposure technique, showed the beneficial effect of filtering ambient air on the productivity of several crops (kidney bean, soybean, barley, bean, radish, pumpkin and wheat). The picture must be regarded as largely incomplete, as dose/response functions for important Italian crops (such as grapevine and vegetables) are not available. Results should be used only as a preliminary indication, considering that the relationships are closely connected to specific climatic and agronomic conditions; furthermore the species sensitivity is relative, there being differences in the yield response of cultivars and sometimes of clones [24]. In addition, differences may exist in responses of plants under different climatic conditions. Crops in northern Europe may be exposed to O_3 under conditions of lower temperatures and higher humidity. This could make them more susceptible to O_3 effects than crops growing in the Mediterranean area under higher temperatures and lower humidity which could cause more stomatal closure and make crops less susceptible to O_3. The economic effects on crops can not be easily derived from equations obtained from OTC experiments because plant response depends on the modifying factors, indicated in level II approach and which are especially important in the Mediterranean area. As the data base for the critical level for crops is based on experiments performed in north Europe, there are many uncertainties about the sensitivity of the Mediterranean species [7]. In this area, the proposed long-term critical levels are largely exceeded, but the magnitude of the effects predictable by the dose/response relationship adopted by the UNECE are not reached, suggesting some mitigation mechanisms operating at these latitudes [17]. Assigning a value to economic losses from to atmospheric pollution is not an easy question. The main obstacle is the variability of the market price (linked to the elasticity of the demand price) for agricultural products. Furthermore, there are few data relating to losses due to effects of O_3 on crop quality [5].

The authors concluded that ozone concentrations over large areas of Riyadh Region have exceeded many times than normal levels and pea is the highly resistant one in such environment than other studied crops. In this region, natural vegetation, agricultural crops and forest trees are likely to be at risk because of the recurrent ambient O_3 values. It is difficult to derive the real effects on crops growing in urban/rural sites. More research is needed to understand the way in which the environmental factors may modify that response.

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