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Full Length Research Paper

Uptake of nutrients and heavy metals in cultivated and non-cultivated plant under atmospheric air pollution of Al-jubail Industrial City, Saudi Arabia

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The current paper deals with effects of ambient O_3, SO_2 and NO_2 air pollution on major and minor elements uptake of cultivated and non-cultivated plants of near and far from Al-jubail Industrial City. The results of chemical analysis revealed that the heavy metals in soils decreased with distance from the source, controlled mainly by water movement and topography. All cultivated and non-cultivated plants of near to the city exhibited maximum content of major and minor elements as compared to far from the city. These results indicate that all plants were efficient in uptake of elements and tolerant to ambient O_3, SO_2 and NO_2 air pollution. This study suggest to resolve different environmental problems in mining areas, where metal contamination may adversely influence plants, animal and human health.

Key words: Ambient O_3, cultivated and non-cultivated plants, responses, resistance.

INTRODUCTION

Air pollution by toxic metals is one of the serious problems of the environment. Plants have been frequently used as indicators in the search for metal pollution or accumulation of ores, or as accumulators for soil remediation which is called phyto-remediation (Baker et al., 1994). Many researchers reported that gaseous air pollutants such as ozone (O_3), sulphur dioxide (SO_2) and nitrogen oxide (NO_2) are the main cause of recent forest decline in many countries. The adverse effects of O_3 and SO_2 on vegetation around urban and industrial areas are well recognized (Bennett and Loppert, 1979). These gases are known to disturb metabolic process with subsequent reductions of growth and development of plant (Tingey et al., 1971; Barnes and Pfirrmann, 1992; Srivastava, 1999). Effects of ozone may occur at various levels of organization, that is from the cellular level through the level of individual organs and plants to the level of plant communities and ecosystems. As described earlier, exposure to elevated ozone concentrations causes effects on individual crop and tree species, and on species mixtures, leading to losses in economic values, quality traits, and ecological and genetic resources. During the last decades, as urban centers and consequent highway traffic have continued to grow in the world, so have the ground level O_3 concentrations. The National Research Council published an authoritative document in 1992 called "Rethinking the ozone problem in urban and regional air pollution" (Krupa et al., 2001). Most recently, a number of state-of-the-science papers have been published (NARSTO, 2000).

Alternative transportation strategies such as mass transit and the use of fuel other than gasoline (a major source of O_3 precursor pollutants) in automobiles may provide some relief in the United States and other developed countries, perhaps some 20 years hence (Sawyer et al., 2000), nevertheless, O_3 is and will continue to be a growing problem in developing countries. Already, Mexico City, New Delhi India and Beijing are

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Table 1. Mean monthly values of average meteorological data for 2006 in Aljubail Industrial City.

Month	ATM			MWS10			PRE			PRS			RH		
	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.
Jan.	5.7	28.3	16.2	0.6	9.9	4.1	0	1.6	0	1010	1026	1018.5	6.4	97.6	60.4
Feb.	9.5	33.7	18.5	0.3	11.4	4.5	0	0.8	0	1007	1023	1016.1	5.3	99.1	63
March	11.7	36.2	21.1	0.4	10.8	3.9	0	0.2	0	1006	1019	1012.7	3.9	97.7	50.6
April							0	0.6	0	998.3	1017	1009.4			
May	25.9	47	36.1	0.6	10.4	3.9	0	0	0	994.4	1007	1000.1	3.4	93.7	24.3
June	29.4	46.5	37.5	0.6	13	4.7	0	0	0	991.3	1002	997.1	5.5	88.7	26.8
July	28.3	48.3	36.6	0.4	9.8	3.1	0	0	0	993.8	1004	997.9	4.4	95.4	46
August	21.3	45.2	33	0.5	10.1	3.3	0	0	0	997.1	1011	1004.6	4.9	97.4	47.6
Sept.	22.4	41.5	30.8	0.5	10	3.4	0	0	0	1007	1018	1011.6	7.8	96.5	49.3
Oct.	11.3	37.5	22.8	0.7	10.1	3.7	0	6.2	0.1	1009	1021	1015.5	16.3	97.7	58.6
Nov.	4.4	23.3	14	0.4	13.2	4.5	0	13.6	0.1	1010	1029	1019.6	21.2	97.7	65.3
Dec.	4.4	23.3	14	0.4	13.2	4.5	0	13.6	0.1	1010	1029	1019.6	21.2	97.7	65.3

among urban centers generating significant ground level of O_3 concentrations. Forest fires are creating hemispheric O_3 problems and burning clear-cut for land reclamation in Central and South America and Southeast Asia. Forest fires and biomass burning result in emissions of the precursor compounds for O_3 formation. Penetration of O_3 into soil is believed to be limited essentially to the soil surface. The negative effects of O_3 on soybean nodulation have thus been suggested to be due to plant mediated responses to O_3 (Blum and Tingey, 1977). Increased O_3 levels across a natural gradient of ambient polluted air have been reported to result in increased fungal diversity, higher nitrogen content and lower calcium content in Jeffrey pine (*Pinus jeffreyi*) litter (Fenn and Dunn, 1989). Nevertheless, the mine dump with enhanced metal contents has been discharged downstream which may adversely influence plants growing on the surrounding land. As local residents consume these plants continuously, this may possibly have adverse impacts on human health.

Numerous studies regarding metal contamination in metalliferous mining and smelting areas have been carried out in the United Kingdom (Fuge et al., 1989), in the United States (Levy et al., 1992) and in other countries. Although there is a long history of ambient O_3, SO_2 and NO_2 air pollution in the Kingdom of Saudi Arabia, no such reference exist to deal with heavy metal contamination from industries.

The present study was, therefore, undertaken to determine on the effect of ambient air pollution on the uptake of nutrients and heavy metals in plants that is *Bougainvillea* spp., *Nerium oleander*, *Tevetia neralfoia*, *Moltkiopsis ciliate*, *Heliotropium bacciferum* and *Zygophyllum album*. This study will substantially contribute to the knowledge required to resolve practically environmental problems in mining areas, where metal contamination may adversely influence crops, animal and human health.

MATERIALS AND METHODS

Study area description

The study area is characterized by a succession of small sand dunes and rocky surface dissected by several wadis toward the Arabian Gulf. The chain of sand dunes is composed of solid oolitic limestone. Between each sand dune and others, there are salty lagoons and sometimes there is cultivable land. The surface of Aljubail area is covered by a salty crust of very white color. The coastal area of Aljubail habitat is characterized by alternate appearance and disappearance of sand dunes and by the lines of saline lagoons. In both the two habitats, the major plant communities are distributed above the sand dunes and in some wadis between them. Also, there are a large numbers of decorative plants around the high way. The sites were named after the dominant species: a) *Z. album*, b) *M. ciliata*, c) *H. bacciferum*, d) *Bougainvillea spp.*, e) *N. oleander* and f) *T. neralfoia*. Samples were separated into assimilatory organs (leaves or stems) and leaves, cleaned, air dried then ground into fine powder and subjected to analysis.

The main meteorological data of this study area are shown in Table 1.

Soil analysis

Soil samples were collected from study sites. Soils were collected at depth from 0 to 30 cm. The collected samples were put in plastic bags and kept in ice tank till it was transported to the laboratory. Each sample was divided into two portions; one for fresh soil parameter analysis, and the other air-dried for proper analysis. Large stones and other similar objects were removed and the soils were ground to break up aggregates and crumbs, without breaking the actual soil particles. Prior analysis soils were sieved in 2 mm mesh. Soil mechanical analysis was carried out by the pipette method and soil moisture was determined using the method described by Richards (1954). The pH was measured in 1: 5 soil-water suspensions by using Wheaton pH-meter. The electrical conductivity was determined by Jenway conductivity meter model 4310. Total soluble salts (TSS) soluble anions were determined as described by Richards (1954). Estimation of soil organic carbon was determined by color method using spectrophotometer model Spectronic 20 Milton Roy Company, USA.

Table 2. Mean monthly values for air quality (O_3, SO_2 and NO_2) in highly polluted and less-polluted localities of Aljubail Industrial City.

Month	Air quality in different locality					
	O_3 (nL/L)		SO_2 (nL/L)		NO_2 (nL/L)	
	Highly polluted areas	Less- polluted areas	Highly polluted areas	Less- polluted areas	Highly polluted areas	Less- polluted areas
August	125	55	35	25	30	25
September	130	55	35	25	25	20
October	110	50	30	20	25	20
November	100	45	20	20	20	15
December	90	45	20	15	15	15
January	60	35	15	10	10	10
February	70	35	15	10	10	10
March	75	45	15	15	20	15
April	85	45	25	15	25	20
May	100	50	25	15	30	25

PLANTS AND THEIR SOILS ELEMENTAL ANALYSIS

Nitrogen content was determined using Kildahl Phosphorus in plants and soils were determined as available phosphorus in 0.002 NH_2SO_4 extracts using Spectro Master model 410, Taiwan. Sodium, calcium, magnesium and potassium were determined in ammonium acetate leachate by Jenway flamephotometer PFP7, England. The remaining elements (Cd, Pb, Fe, Mn, Zn, Cu) were determined using Perkin Elmer atomic absorption 300, USA using 2 g of plants and soils which digested by 1:1 conc. HCl and HNO_3 (Tables 5 and 6).

Statistical analyses

Statistical analyses were carried out using the t-test. Mean standard deviations and variance separation between different plants in each site was calculated by using the means of individual measurements.

RESULTS

Status of ambient air

Monthly changes in mean concentrations (nl l^{-1}) of O_3, SO_2 and NO_2 during 2006 and 2007 growing seasons at Aljubail Industry City, KSA are listed in Table 2.

Major and minor elements of plants

The concentrations for major and minor elements that is Mg, K, Ca, P, Na, N, C, Cd, Cu, Fe, Mn, Pb and Zn in plants (cultivated and non cultivted of far and near from the industerial city) were studied. Tables 3 and 4 revealed that concnetration of major and minor elements was found significantly almost higher in all cultivate-plants that is *Bougainvillea spp*., *N. oleander* and *T. neralfoia* and non-cultivated that is, *M. ciliata, H. bacciferum* and *Z. album* near the city than cultvited and non-cultivated far from the city. However, maximum content of P, Na and N was recorded in cultivated plant *Bougainvillea spp.* of near the city as compared to cultivated plants far from the city. Similarly, *N. oleander* gave the maximum value for leaf- K and Na content and also P and Na content was recorded maxmum in cultivtaed plant (*T. neralfoia*) of near the city as compared to cultivated far from the city. Morever, conent of C in all cultivated and non-cultivate plants of near and far from the industterial city was found non-significant (Table 3). As far as non-cultivated plants is concern, the maximum concentration of Mg (*M. ciliata*), K (*H. bacciferum*), P (*M. ciliata, H. bacciferum* and *Z. album*), P, Na and N (*M. ciliata*, *H. bacciferum* and *Z. album*) was recorded in plants near the city as compared to plant far from the city. Among the plants cultivated, *T. neralfoia* showed non-significant for Mg content in leaf. Similarly, all non-cultivated plants of near and far from the industerial city exhibited statitically non-significant for leaf-Mg content (Table 3).

Table 4 revealed that concentration of minor elements in cultivated and no-cultivated plants of near and far from the industerial city was found almost statistically significant. However, contcentration of Cu and Zn in *Bougainvillea spp*., Cd, Cu and Pb in *N. oleander* and Cd, Cu, Mn and Pb in *T. neralfoia* was found non-significant in cultivated plants (Table 4). Similarly, in non-cultuvated plants, content of Cd and Mn in *M. ciliata*, Cu and Zn in *H. bacciferum* and Cd, Cu and Zn in *Z. album* was found non-significant (Table 4). The results also showed non leaves illustration in Tables 3 and 4. No significant responses were noted for C with respect to cultivated and non-cultivated in Table 5. With respect to air quality treatment effects on major element concentrations, levels of O_3 stimulated the uptake of all elements for cultivated except few cases. The reduction in K contents in response to elevated O_3 appeared in *T. neralfoia*. An increase in Ca uptake of farest locailties

Table 3. Mean values for leaves major element contents of plants grown in high polluted and less-polluted localities of Aljubail Industry City under atmospheric O_3, SO_2 and NO_2 enrichments regimes, 2006 and 2007.

Treatment	Major element						
Plant	Mg_T (ppm)	K_T (ppm)	Ca_T (ppm)	P_T (ppm)	Na_T (ppm)	N_T (%)	C_T (%)
Cultivated							
1) *Bougainvillea* spp.							
Far from industry city	7.46	24.04	81.69	60.70	71.83	2.67	43.7
Close to industry city	7.15	27.59	74.59	71.99	72.17	2.92	43.7
Statistical sign	*	*	*	**	*	**	NS
2) *Nerium oleander*							
Far from industry city	6.39	39.45	58.21	45.94	16.76	1.29	43.5
Close to industry city	6.83	42.49	49.59	6.98	39.29	1.60	43.7
Statistical sign	*	*	*	**	**	**	NS
3) *Tevetia neralfoia*							
Far from industry city	7.03	35.09	68.22	38.19	54.54	1.41	43.5
Close to industry city	7.02	28.01	60.49	50.53	58.63	1.47	43.7
Statistical sign	NS	*	*	**	**	**	NS
Non-cultivated							
1) *Moltkiopsis ciliate*							
Far from industry city	6.11	53.44	71.01	29.61	18.11	1.01	43.7
Close to industry city	6.72	45.38	53.53	48.12	37.54	1.37	43.4
Statistical sign	NS	*	*	**	**	**	NS
2) *Heliotropium bacciferum*							
Far from industry city	7.36	47.63	74.53	58.57	39.93	1.27	43.2
Close to industry city	7.25	56.97	5.28	60.84	44.70	1.33	43.8
Statistical sign	NS	**	**	*	**	**	NS
3) *Zygophyllum album*							
Far from industry city	8.04	41.36	37.85	49.28	85.33	1.21	43.7
Close to industry city	7.99	35.28	45.57	51.64	85.63	1.29	44.1
Statistical sign	NS	**	**	*	NS	**	NS

Far from industry city (less polluted) means samples collected from the 10th kilometer around the industry city, close to industry city (highly polluted) means samples collected from the first kilometer around the industry city, and NS = non-significant. Statistical significant: (*) = $P \leq 0.1$, (**) = $P \leq 0.05$ and (***) = $P \leq 0.01$ respectively.

from pollution area in response to O_3 were observed. Also, lower Ca uptake to leaves of *Z. album* in response to O_3 in farest locailties from pollution area was found. *Bougainvillea spp.* Mg, P, Na, N and C in leaf samples were slightly affected by pollution. With respect to air quality effects on minor element contents, there were significant changes in concentrations of Fe while non-significant for Cd, Cu, Mn, Pb and Zn concentration in leaves (Table 6).

An increase in O_3 increased element contents in *M. ciliata* leaves except for Cd. The foliar Fe, Mn and Pb concentrations in *Bougainvillea spp.* leaves were increased by elevated O_3 exposure. The resultts present in the study are revealed that the uptake of major or minor elemets was higher in both cultivated and non-cultivated plant of far from the city under atmospheric air pollution of Al-jubail Industrial City (Table 2).

DISCUSSION

The results of the present study showed that metal uptake by plants can be affected by several factors including metal concentrations in soils, soil pH, cation

Table 4. Mean values for leaves minor element contents (ppm) of plants grown in high polluted and less-polluted localities of Aljubail Industry City under atmospheric O_3, SO_2 and NO_2 enrichments regimes, 2006 and 2007.

Plant	Treatment	Major element					
		Cd_T (ppm)	Cu_T (ppm)	Fe_T (ppm)	Mn_T (ppm)	Pb_T (ppm)	Zn_T (ppm)
Cultivated							
***Bougainvillea* spp.**							
Far from industry city		0.19	0.26	8.15	0.35	4.87	0.41
Close to industry city		0.20	0.25	11.76	0.43	5.08	0.43
Statistical sign		*	NS	*	*	*	NS
Nerium oleander							
Far from industry city		0.15	0.18	4.26	0.31	3.57	0.33
Close to industry city		0.15	0.16	9.20	0.59	3.81	0.47
Statistical sign		NS	NS	**	*	NS	*
Tevetia neralfoia							
Far from industry city		0.17	0.17	7.87	0.25	4.23	0.38
Close to industry city		0.16	0.19	8.17	0.21	4.16	0.57
Statistical sign		NS	NS	*	NS	NS	**
Non-cultivated							
Moltkiopsis ciliate							
Far from industry city		0.11	8.37	5.68	0.23	2.61	0.21
Close to industry city		0.11	0.19	14.88	0.32	2.83	0.49
Statistical sign		NS	*	**	NS	*	**
Heliotropium bacciferum							
Far from industry city		0.12	0.22	11.59	0.17	3.07	0.45
Close to industry city		0.13	0.19	16.43	0.48	3.37	0.50
Statistical sign		*	NS	*	*	*	NS
Zygophyllum album							
Far from industry city		0.18	0.22	8.59	0.31	4.36	0.39
Close to industry city		0.18	0.21	11.67	0.24	4.61	0.45
Statistical sign		NS	NS	**	*	*	NS

Far from industry city (less polluted) means samples collected from the tenth kilometer around the industry city, close to industry city (highly polluted) means samples collected from the first kilometer around the industry city, and NS = non-significant. Statistical significant: (*) = $P \leq 0.1$, (**) = $P \leq 0.05$ and (***) = $P \leq 0.01$ respectively.

exchange capacity, organic matter content, types and varieties of plants and plant age. It revealed that uptake of major elements in all plants could be due to ascribed variation in the genetic make-up of plants. Plants exhibit a great magnitude of interspecific variation (Ashraf and McNeilly, 1990) and physiological changes occur (Huang et al., 2006; Siddiqui et al., 2009) for stresses. Barnes and Pfirrman (1992) indicated that O_3 increased the P and K concentration in shoot tissue but with no effect on N, S, Mg and Ca levels. Elevated atmospheric O_3 concentration can not only alter C and N cycling in soil but may affect plant nutrition. Urat and Schaub (2007) and Ashraf and McNeilly (1990) reported that uptake rates of calcium, magnesium, potassium and nitrate from the nutrient solutions were altered in dependence on fumigation, time of exposure and stage of plant development. Uptake rates of all ions by the seedlings fumigated with SO_2 first increased, but later on decreased as compared to the control and fumigation with O_3 or O_3 in combination with SO_2 affected uptake of the various nutrients differently.

The study generally observed that the driving force for movement of an ion across a membrane has two components, one chemical and one electrical established by differences of activity and charge across the membrane. Similar results were also reported by Rubio et al. (2003) and Jin et al. (2010) who reported that plants have evolved various mechanisms to adapt to salt stress

Table 5. Mean values for some selected physical properties of soil supporting plants grown in high polluted and less-polluted localities of Aljubail Industry City under atmospheric O_3, SO_2 and NO_2 enrichments regimes, 2006 and 2007.

Treatment	Physical property				Texture	Moisture (%)
Plant	OM (%)	Sand (%)	Silt (%)	Clay (%)		
Cultivated soil						
Far from industry city	1.2	84	6	10	Loamy sand	35.4
Close to industry city	1.2	85	8	7	Loamy sand	24.1
Statistical sign	NS	NS	NS	*		*
Non-cultivated soil						
Far from industry city	0.78	92	6	6	Sand	4.5
Close to industry city	0.77	84	8	8	Loamy sand	2.4
Statistical sign	NS	*	NS	NS		**

Far from industry city (less polluted) means samples collected from the tenth kilometer around the industry city, close to industry city (highly polluted) means samples collected from the first kilometer around the industry city, and NS = non-significant. Statistical significant: (*) = $P \le 0.1$, (**) = $P \le 0.05$ and (***) = $P \le 0.01$ respectively.

Table 6. Mean values for some selected chemical properties of soil supporting plants grown in high polluted and less-polluted localities of Aljubail Industry City under atmospheric O_3, SO_2 and NO_2 enrichments regimes, 2006 and 2007.

Treatment	Chemical property						
Plant	pH	EC (mmos/cm)	TSS (%)	Cl^- (%)	SO_4^{--} (%)	CO_3^{--} (%)	HCO_3^- (%)
Cultivated soil							
Far from industry city	10.06	122.0	2.11	0.11	32.5	nil	2.01
Close to industry city	10.05	108.1	2.23	0.11	35.4	nil	1.99
Statistical sign	NS	*	NS	NS	*		NS
Non-cultivated soil							
Far from industry city	10.00	69.4	3.11	8.88	35.2	nil	1.85
Close to industry city	10.15	178.3	3.36	9.16	36.2	nil	1.99
Statistical sign	NS	***	NS	NS	NS		NS

Far from industry city (less polluted) means samples collected from the tenth kilometer around the industry city, close to industry city (highly polluted) means samples collected from the first kilometer around the industry city, EC = electro-conductivity, TSS = total soluble salts and NS = non-significant. Statistical significant: (*) = $P \le 0.1$, (**) = $P \le 0.05$ and (***) = $P \le 0.01$ respectively.

including control of Na+ uptake and Na+ xylem loading, Na++ retrieval from the xylem, Na+ extrusion from the root, intracellular compartmentation of Na+ into the vacuoles and Na+ excretion. However, reducing Na++ uptake should be the most efficient approach to control Na++ accumulation in most crop plants, and hence to improve their salt resistance, since if uptake is reduced, the range of other mechanisms for dealing with excess Na+ do not need to be invoked. Another mechanism responsible for the retention and relative availability of nutrients is physical association of minerals with the organic components of the soil. However, further detail study is required on the molecular features of the heavy metals transport mechanism in both cultivated and uncultivated plants of Saudi Arabia.

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