African Journal of Agricultural Research Vol. 7(47), pp. 6305-6312, 13 November, 2012
Available online at http://www.academicjournals.org/AJAR
DOI: 10.5897/AJAR12.828
ISSN 1991-637X ©2012 Academic Journals

Full Length Research Paper

Short-term effects of dust storm on physiological performance of some wild plants in Riyadh, Saudi Arabia

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Accepted 14 September, 2012

The effects of dust storm were investigated in three wild plants named *Ficus nitida, Datura stramonium* and *Plumeria acutifolia* by means of chlorophyll fluorescence measurements, as well as, net photosynthetic rate and stomatal conductance after progressive dust deposition extended for 6 days. In the two months leading up to the storm, severe drought conditions in Riyadh, plus above average maximum temperatures resulted in high potential evapo-transpiration rates, producing severe soil moisture deficits. Exposure to dust resulted in a drastic effect on some physiological parameters including the loss of chlorophyll a and b contents, inhibition of net photosynthetic rate (P_N) and significant decrease of stomatal conductance (g_s). Carotenoids content and carotenoids/total chlorophyll ratio of dust stressed plants were significantly increased parallel with the progressive deposition of the dust in comparison with control plants. The maximum efficiency of photosystem II photochemistry (Fv/Fm, PSII efficiency) varied among plants collected from the same site. Our results evidenced that dust deposition decreased overall plant performance through its severe effect on photosynthesis and resulted in a significant inhibition of PSII efficiency throughout this study period.

Key words: Chlorophyll fluorescence, dust storm, photosynthesis, Saudi Arabia.

INTRODUCTION

The Sahara and dry lands around the Arabian Peninsula are the main source of airborne dust, with some contributions from Iran, Pakistan and India into the Arabian Sea, and China's storms deposit dust in the Pacific (Kukal and Saadallah, 1973). The Arabian Peninsula is one of the five major regions where dust originates, and dust storm or sandstorm is a meteorological phenomenon common in arid and semi-arid regions (Idso, 1976). Dust storms arise when a gust front blows loose sand and dust from a dry surface;thereafter, particles are transported by saltation and suspension, causing soil erosion from one place and deposition in another place. The tendency of dust load resulted from dust storm was increased due to the impact of Gulf war activities, which caused soil disturbance in most countries of Arabian Peninsula (UNEP, 1991).

The frequency of dust storms in the Arabian Peninsula has been reported by many researchers (Goudie, 1978; El-Desouky and Al-shalal, 1979; Safar, 1980). Khalaf and Al-Hashash (1993) reported that dust storms are usually caused by the action of strong persistent winds on dry, fine-grained, and loose soil. Several studies reported the frequency of dust storms in the Arabian Peninsula and found that the average quantity of dust falling on Kuwait and Riyadh were 191and 392 tons km^{-2} $year^{-1}$, respectively (Al-Tayeb and Jarrar, 1993). Basahy (1987)

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estimated the dust deposition rate in some areas of Saudi Arabia to be 196 to 220 tons km^{-2} $year^{-1}$.

Dust deposition has been found to affect many physiological processes on plants including photosynthesis, stomatal functioning and productivity by covering and plugging stomata, shading and removing cuticular wax (Luis et al., 2008). Chlorophyll fluorescence, an indication of the fate of excitation energy in the photosynthetic apparatus, has been used as an early, *in vivo*, response of plant response toward different stresses (Maxwell and Johnson, 2000; Ibrahim and Bafeel, 2008).

Photo inhibition has been documented through the measured reduction in the quantum yield of photosystem II (PSII) and a decrease in variable chlorophyll (Chl a) fluorescence (Demmig and Adams, 1993). The decreasing efficiency of PSII photochemistry under stress may reflect not only on the inhibition of PSII function, but may also resulted in a change increase in the dissipation of thermal energy that is often considered as a photoprotective mechanism (Demmig and Adams, 1993). Takashi (1994) studied the photosynthetic rate of *Cucumis sativus* and *Phaseolus vulgaris* leaves covered by several kinds of volcanic ash from Mt. Sekurajima and Mt. Unzen-Fugendake, in addition to chemically inert dust (Loam powder and carbon black, JIS Z 8901) under various conditions. In another study concerning the effect of dust from the military activities, *Astragalus jaegerianus* plants were dusted bimonthly at canopy-level dust concentrations ranging from 0 to 32 g/m^2, and physiology and growth were monitored until plants senesced (Wijayratne et al., 2009). Riyadh city, the capital of Saudi Arabia, situated at an altitude of 600 m, is surrounded by desert areas and is therefore exposed to dust storms most of the year. The aim of this study was to investigate the effects of natural dust storm accumulation on plants such as shading and plugging stomata and their effect on some physiological performance of some plants in Riyadh, Saudi Arabia.

MATERIALS AND METHODS

Dust storm and study area

This study areas were chosen at two replicates locations that are about 5 km far apart and down-wind of the dust storm; ten plants were collected from each site every measurement. The data presented in our results were the mean of the total plants collected from the two sites. Our study area located in the west area of Riyadh near Daraia; at campus of the king Saud; (25 Km from city center). The climatic conditions were extremely dry with a day/night temperature of 39/25°C. The experimental sites defined by 5 plots that were 12.5 m^2 (4 × 3.5 m) each. The species considered in our experiment were *Ficus nitida, Datura stramonium* and *Plumeria acutifolia* (Collenette, 1999).

Leaves were collected on the first day of the dust storm of 10 March 2009 and every day thereafter until the sixth day after the beginning of the storm. The dust storm of 10 March 2009 covered most of Riyadh city in KSA and carried one of the largest recorded dust loads in Riyadh for the two last decades. (http://www.youtube.com/watch?v=BFj6bdA35lI&feature=player_detailpage#t=17s http://www.youtube.com/watch?v=gj0vNUJmtA0&feature=player_detailpage#t=59s).

Washing dust off leaves as a control were collected at the same time from plants repeatedly washed by distilled water every day and considered as undusted plants in the same study area. Ten leaves for each time per plant were weighed carefully for fresh weight determination (FW), and then dried in a hot-air oven at 70°C until a constant weight to obtain dry weight (DW).

Dust analysis

The elemental composition of dust samples were performed by using the x-ray fluorescence technique (XRF) as described by Eshaikh and Kadach (2005). X-ray fluorescence spectrometer (EDXRF) unit, JSX-3202-M used in this study was manufactured by JEOL Company in Japan. The qualitative analysis is the identification of all elements present in the X-ray fluorescence spectra, which is based on the determination of the correct top position of each peak (centroid). This technique is known as the best non-destructive and multi-elements analysis method used with success in many activities including environmental studies. The dust samples were simply collected by wiping from different places at different regions of Riyadh city.

Pigment analyses

Photosynthetic pigments, viz, chlorophyll *a*, chlorophyll *b* and carotenoids were extracted and determined from expanded young leaves according to Inskeep and Bloom (1985). A portion of leaves (0.1 g fresh weight) were immersed in 10 ml N, N-dimethylformamide (DMF) and kept overnight at 4°C. The extract-containing pigments were decanted, and the absorbance was measured at three wavelengths 647, 665 and 453 nm using spectrophotometer (JENWAY, 6305, UK). Formula and extinction coefficients used for determination of photosynthetic pigments were in mg g^{-1} FW as described by Inskeep and Bloom (1985):

Chl. a = 12.70 Absorbance 665 – 2.79 Absorbance 647
Chl. b = 20.70 Absorbance 647 – 4.62 Absorbance 665
Carotenoids = 4.2 Absorbance 453 – (0.0264 Chl. a + 0.426 Chl. b)

Measurement of photosynthetic rate (P_N) and stomatal conductance (g_s)

Net photosynthetic rate (P_N) and stomatal conductance (g_s) were measured in at least ten attached leaves per plant every day for 30 s day^{-1}, using an IR gas analyzer (CIRAS-1, PP Systems, Hitchin, UK) under 56 to 60 % relative humidity with 14/10 h day/night cycle. Light intensity was 320 µmol m^{-2} s^{-1} and day and night temperatures were 25/20°C. Measurements of both net photosynthetic rate as well as the stomatal conductance were made between 11 am and 4 pm. The adaxial and abaxial leaf conductance was measured in situ at approximately midday for 30 s. Standard calculations were used to determine photosynthetic rate and stomatal conductance according to Farquhar and Sharkey (1982).

Measurement of chlorophyll fluorescence

In vivo chlorophyll fluorescence measurements were monitored in fully-expanded and young leaves according to Branquinho et al.(1997) using a PAM 101 modulated fluorometer (Chlorophyll Fluorometer, Watz, Effelrich, Germany). Fluorescence was excited

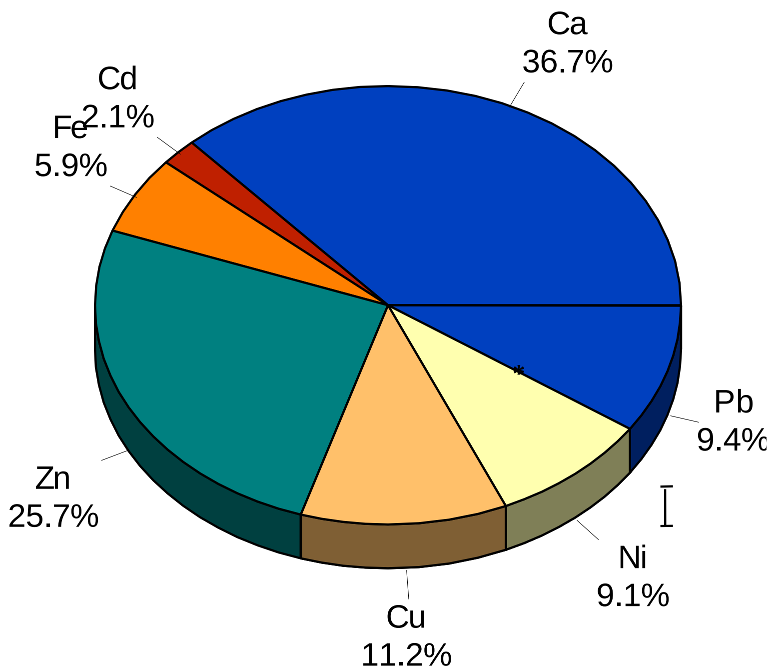

Figure 1. Elemental composition of desert dust collected from different localities of Riyadh City (Saudi Arabia).

by illuminating leaves with a clips emitting red pulsed light intensity (< 0.1 μmol $m^{-2}s^{-1}$) with a wavelength 650 nm. Prior to measurement of fluorescence, plants were covered by black bags with small holes to keep the plant leaves in darkness at 22 ± 2°C for at least 30 min. Dark adaptation was performed to ensure that the primary quinine acceptor (Q_A) was maximally oxidized. The basal non-variable chlorophyll fluorescence level with open PSII reaction centers (F_0) and the maximal fluorescence intensity indicator (F_m) level with closed PSII were determined at room temperature on intact leaves of 10 replicate plants from all treatments. The F_o (as initial fluorescence level) was measured by a weak red measuring beam, followed by a saturation light pulse to measure the maximum Fm level. Variable fluorescence (F_v) was calculated as the difference between F_m and F_0 (Maxwell and Johnson, 2000). The efficiency of PSII (F_v/F_m) was estimated from the ratio of variable ($F_v = F_m - F_0$) to maximum fluorescence (F_m) measured for each plant on 30 min dark-adapted plants (Maxwell and Johnson, 2000).

Statistical analysis

All data presented are the means of ten replicates. A significance difference of samples was calculated by Student's t-test. Results of testing were considered significant if calculated P-values were ≤ 0.05.

RESULTS

Analysis of collected dust sediments revealed that most samples were rich in calcium and zinc in addition to highly considerable amounts of other elements including Cu, Ni and Pb. Conversely, small quantities of Cd and Fe were found in the collected dust (Figure 1).

The general appearances of the studied plants were distinguishable between the dust exposed plants and control plants in their size and color appearance. Fresh and dry weights of dust stressed plants were markedly decreased in response to dust accumulation after 5 and 6 days from the beginning of the storm (Figure 2). The largest reduction in fresh and dry weight was observed in *D. Stramonium* plants hat attained only 28 and 13% of mass relative to controls (Figure 2). The corresponding values for *P. acutifolia* were 38 and 22%, respectively.

Progressive decrease in photosynthetic pigments including chlorophyll a and chlorophyll b was associated with dust accumulation in all studied plants throughout the study period. In comparison with control, the greatest reduction in chl a (86%) and b (73%) was observed in *F. nitida.* (Table 1). Simultaneously, significant differences between dust-stressed and control plants were found in chl a/b ratio (Table 1). Compared with control plants, all studied plants had less chl a/b ratio. The most pronounced decrease in chl a/b ratio was observed in *F. nitida* and reached to 81% reduction at the end of this study period. Conversely, significant increases in total carotenoids were detected in *F. nitida* by 1.9 fold; *Datura Stramonium* (3.1x) and *P. acutifolia* (3.9x) relative to control plants. Moreover, at the end of the study period a highly significant increase in carotenoids/ total chlorophyll ratio by 2-fold was observed in *F. nitida*a and *D. stramonium*, and by 3-fold for *P. acutifolia* (Table 1).

Significant increase of initial fluorescence (F_0) was detected during the prolonged dust exposure in *D.*

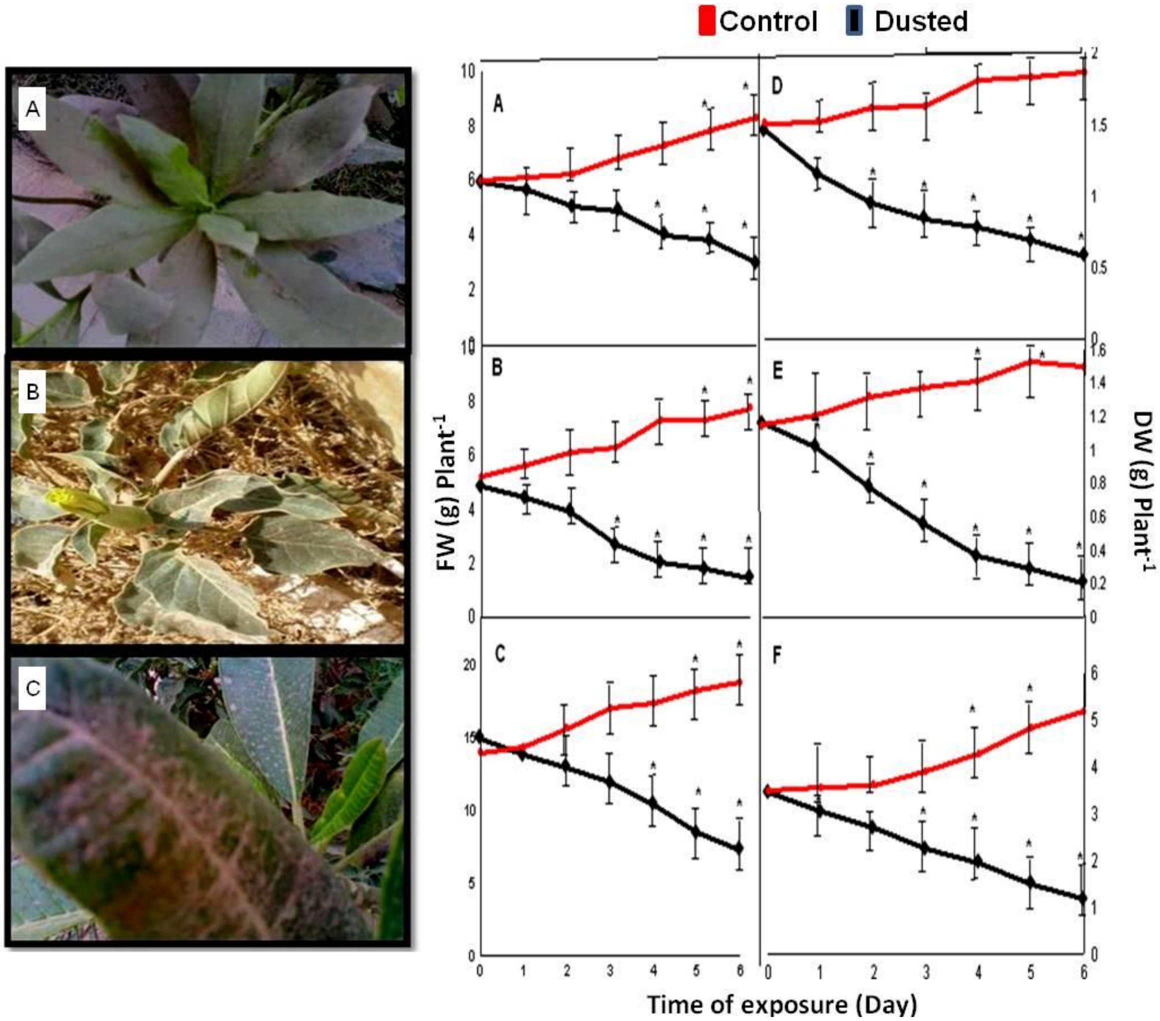

Figure 2. Morphometric symptoms after 6 days of the dust storm, and respective changes in fresh and dry weight for leaves of *F. nitida,* (A, D); *D. Stramonium*, (B, E) and *P. acutifolia* (C, F) plants after 6 days of the dust storm. Each value is an average of ten replicates for each measurement. Significant differences for the same species (after correction of the significance level P = 0.05) are indicated by asterisks

stramonium and *P. acutifolia* relative to control. On the other hand variable fluorescence (F_v) was significantly decreased in response to dust accumulation and exposure time. For instance, Fv of *F. nitida, D. Stramonium* and *P. acutifolia* were reduced to about 59, 75, and 74% less than the control plants at the end of our study (data not shown). Maximum photochemical efficiency of PSII, expressed as Fv/Fm, was slightly decreased by 10, 11 and 7.5% in *F. nitida, D. Stramonium,* and *P. acutifolia,* respectively, on the second day of the dust storm, in comparison with control (Figure 3). Prolonged exposure to dust accumulation resulted in a significant inhibition of the photochemical efficiency of photosystem II, particularly at the fifth and sixth days of the storm. For example, after 6 days of the dust storm Fv/Fm values were decreased by 62, 61, and 5% in *F. nitida, D. Stramonium,* and *P. acutifolia,* respectively and relative to the control (Figure 3).

Net photosynthetic rate (P_N) was significantly decreased from the beginning of the dust storm. After two days of the storm, P_N values for *F. nitida, D. Stramonium* and *P. acutifolia* were decreased by 19, 32 and 29 %, respectively and relative to the control plants (Figure 4). The prolonged exposure of plants to the six-day dust storm resulted in a highly significant decrease in the net photosynthetic rate (P_N) of all studied plants that ranged between 70 to 85% less than the control plants.

After completion of stress period, stomatal conductance was also inhibited significantly and decreased, ultimately to levels 16, 10 and 8%, respectively less than the control plants (Figure 5). In addition, the intrinsic water-use efficiency (P_N/g_s) showed the same trend of inhibition in all studied plants and throughout our study period (data not shown).

Table 1. Effect of desert dust storm on photosynthetic pigments chlorophyll a, b and carotenoids (mg g-1 DW) of *Ficus nitida*, *Datura Stramonium* and *Plumeria acutifolia* species after different time intervals.

Photosynthetic pigment (mg g^{-1} DW)	*Ficus nitida*													
	Time (Days)													
	C0	S0	C1	S1	C2	S2	C3	S3	C4	S4	C5	S5	C6	S6
Chl *a*	11.09±0.59	10.48±0.62	11.17±0.63	8.08±0.45	11.74±0.67	7.44±0.42	12.09±0.97	5.45±0.36	12.15±1.02	3.73±0.22	12.32±1.03	3.05±0.16	12.25±1.09	2.10±0.16
Chl *b*	2.81±0.19	2.72±0.21	2.87±0.28	2.31±0.22	2.88±0.23	2.15±0.14	2.90±0.15	1.94±0.11	2.93±0.15	1.22±0.09	3.04±0.17	1.08±0.08	3.10±0.19	0.85±0.07
Chl *a* + Chl *b*	13.90±1.09	13.20±0.99	14.04±1.14	10.39±0.87	14.62±1.21	9.59±0.82	14.99±1.09	7.39±0.70	15.08±0.81	4.95±0.63	15.36±0.91	4.13±0.41	15.35±0.44	2.95±0.29
Chl *a* / *b*	3.95	3.85	3.9	3.5	4.10	3.46	4.17	2.8	4.15	3.1	3.72	2.82	3.95	2.47
Carotenoids	2.90±0.25	2.88±0.22	2.85±0.26	3.24±0.32	2.94±0.31	3.85±0.21	2.93±0.29	4.12±0.11	2.95±0.32	4.72±0.20	2.94±0.33	5.02±0.12	2.96±0.31	5.49±0.12
Carotenoids/Chl a+b	0.21	0.20	0.20	0.31	0.20	0.40	0.195	0.6	0.196	1.00	0.191	1.22	0.193	1.9

Photosynthetic pigment (mg g^{-1} DW)	*Datura stramonium*													
	Time (Days)													
	C0	S0	C1	S1	C2	S2	C3	S3	C4	S4	C5	S5	C6	S6
Chl *a*	12.04±0.91	11.78±0.82	12.13±1.03	10,11±0.92	12.22±1.26	8.40±0.74	12.41±1.32	7.29±0.98	12.47±0.12	6.33±0.65	12.88±1.42	4.20±0.43	12.93±1.55	3.15±0.06
Chl *b*	3.88±0.13	3.92±0.14	3.94±0.16	3.44±0.14	3.89±0.18	3.13±0.13	3.92±0.18	2.81±0.11	3.89±0.18	2.60±0.09	4.98±0.17	2.02±0.08	4.78±0.19	1.68±0.06
Chl *a*+Chl *b*	15.92±1.03	15.7±0.98	16.07±1.22	13.55±1.08	16.11±1.54	11.53±0.94	16.33±1.44	10.10±1.12	16.36±1.72	8.93±0.91	17.86±1.65	6.22±0.87	17.71±1.89	4.83±0.75
Chl *a* / *b*	3.10	3.00	3.08	2.90	3.14	2.70	3.17	2.60	3.21	2.40	2.6	2.1	2.71	1.9
Carotenoids	2.97±0.11	3.08±0.12	3.92±0.13	5.14±0.14	3.94±0.13	5.92±0.16	4.01±0.15	6.72±0.22	4.12±0.16	8.02±0.22	4.18±0.14	8.98±0.22	4.51±0.22	9.42±0.24
Carotenoids/Chl a+b	0.186	0.20	0.24	0.4	0.24	0.51	0.25	0.67	0.25	0.90	0.23	1.44	0.25	1.95

Photosynthetic pigment (mg g^{-1} DW)	*Plumeria acutifolia*													
	Time (Days)													
	C0	S0	C1	S1	C2	S2	C3	S3	C4	S4	C5	S5	C6	S6
Chl *a*	7.89±0.72	8.58±0.86	8.18±0.79	7.51±0.74	8.33±0.81	5.40±0.59	8.76±0.49	4.29±0.37	9.11±0.36	3.63±0.15	9.04±0.35	2.70±0.35	9.19±0.38	1.85±0.10
Chl *b*	2.88±0.19	2.92±0.17	2.82±0.16	2.64±0.14	3.03±0.15	2.10±0.13	3.14±0.19	1.85±0.11	3.23±0.15	1.62±0.10	3.44±0.16	1.27±0.09	3.51±0.17	0.96±0.03
Chl *a*+Chl *b*	10.77±0.93	11.50±1.02	11.10±0.88	10.15±0.89	11.33±1.03	7.57±0.65	11.90±0.63	6.14±0.48	12.34±0.59	5.25±0.38	12.48±0.68	3.97±0.22	12.70±0.52	2.81±0.19
Chl *a*/*b*	2.74	2.94	2.90	2.84	2.75	2.57	2.79	2.32	3.54	2.24	2.63	2.13	2.62	1.93
Carotenoids	2.22±0.19	2.16±0.12	2.33±0.17	3.24±0.20	2.21±0.14	4.52±0.26	2.56±0.18	5.72±0.26	2.55±0.18	7.02±0.21	3.01±0.15	7.98±0.23	3.22±0.18	8.52±0.24
Carotenoids/Chl a+b	0.21	0.19	0.21	0.32	0.22	0.60	0.22	0.93	0.21	1.34	0.24	2.01	0.25	3.03

Values are means ± SD (n=5). 0 time, the day of the storm; 1-6 days after the storm; C, control; S, Stressed.

DISCUSSION

The fallout sediments resulted from the dust storm are mainly represented by two textural classes, loam and silt loam, of which silt is the dominant fraction (Modaihsh, 1997). The dust was found to contain fine particles of sand and seemed to be from mineral origin. According to our results the collected dust contained high Ca content; averaging 37% as well as considerable amounts of other elements such as Cd, Fe, Zn, Cu and Ni were detected in the dust. Therefore, it could be concluded that the drastic effect resulted from the dust accumulation on studied plants could be resulted from the presence of such trace elements. According to the results obtained by Modaihsh (1997) trace elements cause inhibition of various physiological species, including photosynthesis and the main sources of these trace elements are automobile emission and atmospheric transportation. A quantitative estimation

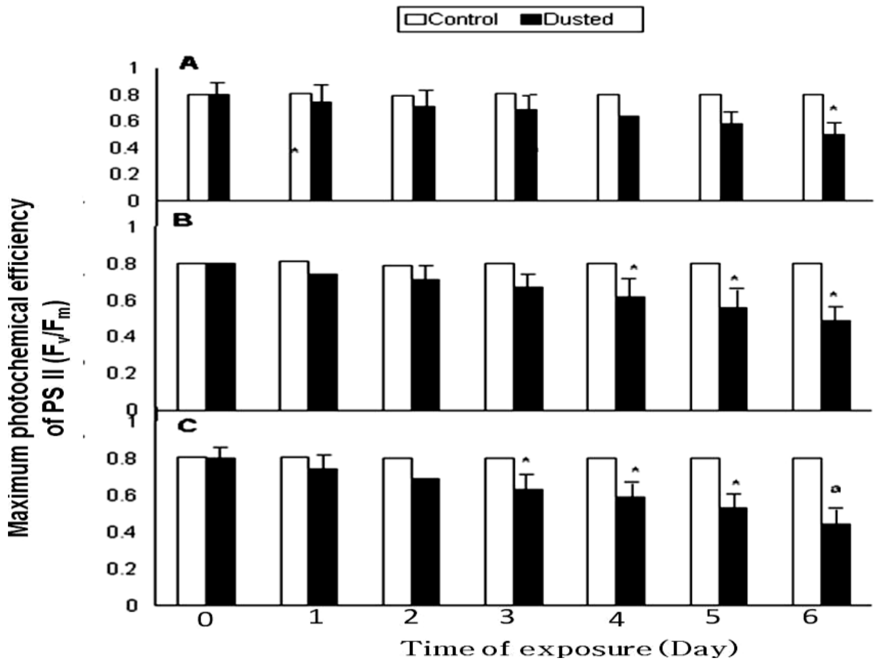

Figure 3. Variations of maximum photochemical efficiency of PS II (F_v/F_m) in *F. nitida*, *A; D. Stramonium, B;* and *P. acutifolia*, C after exposure to desert dust storm for six days. Values are means ± SE (n =10). Asterisks mean significantly different within the same species during the exposure time (P < 0.05). 0, the beginning of the storm; 1 to 6 days after the beginning of the storm.

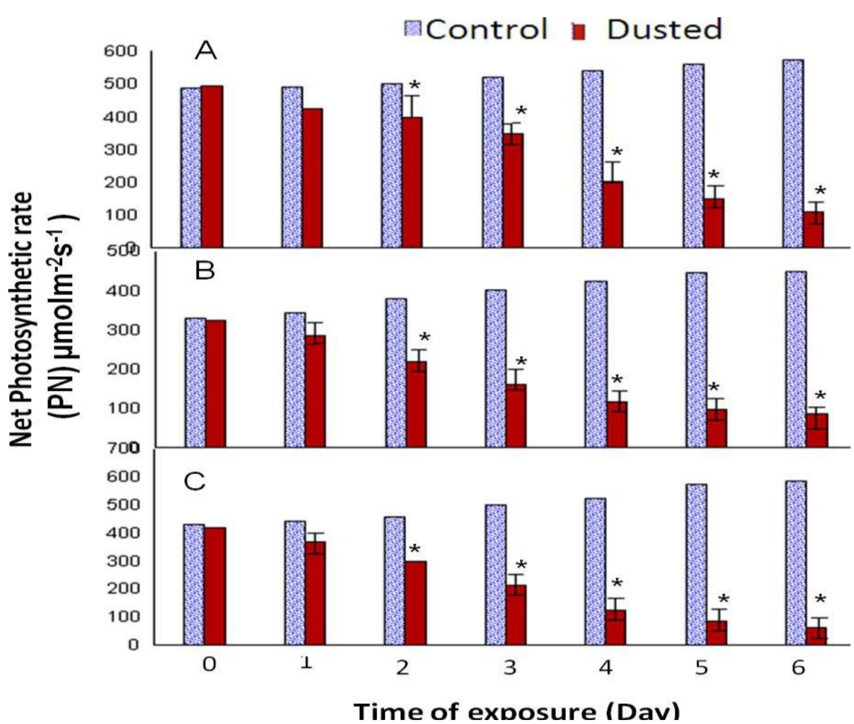

Figure 4. Effect of desert dust storm on net photosynthetic rate in *F. nitida*, *A; D. Stramonium, B;* and *P. acutifolia*, C plants after exposure to desert dust storm for 6 days. Values are means ± SE (n=10). Asterisks mean significantly different within the same species during the exposure time (P < 0.05). 0, the beginning of the storm; 1 to 6 days after the beginning of the storm.

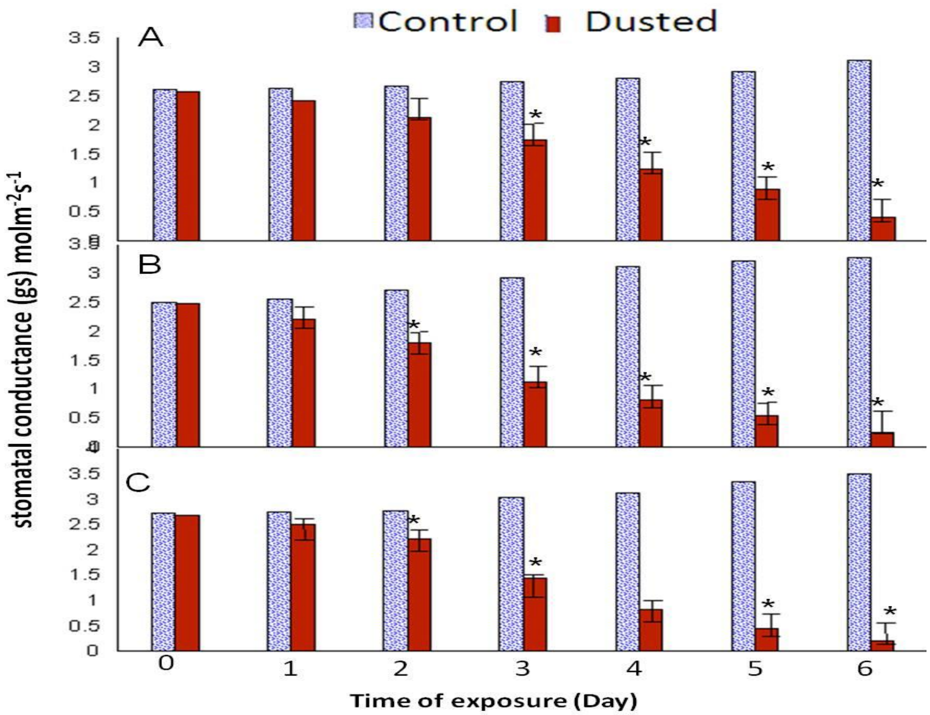

Figure 5. Effect of desert dust storm on stomatal conductance in *F. nitida*, *A; D. Stramonium, B;* and *P. acutifolia*, C after exposure to desert dust storm for 6 days. Values are means ± SE (n=10). Asterisks mean significantly different within the same species during the exposure time ($P < 0.05$). 0, the beginning of the storm; 1 to 6 days after the beginning of the storm.

along with dust analysis confirms the visual ill effects of the dust on the plant growth especially the morphometric symptoms, as well as fresh and dry weights. Wijayratne et al. (2009) reported that dust accumulation could decrease the vigor and fitness of *A. jaegerianus* through reduced growth and the average shoot growth declined with increasing dust accumulation, but seasonal net photosynthesis increased.

Highly content of Ca element may be originated from soils rich in limestone and dolomite which is abundant in Saudi Arabia. Our results are consistent with the observation of Ashraf (1991) and similar findings were reported in Iraq by Kukal and Saadallah (1973) who found that $CaCO_3$ was as high as 69% in Iraqi dust storms. Also, Khalaf and Al-Hashash (1983). Date found that calcareous silt was an abundant constituent in Kuwait dust fall-out. The decrease of total chlorophyll and the increase of carotenoids/total chlorophyll ratio in dust stressed plants suggested that these relationships could be used as an indicator of tolerance and physiological status of the plant under these stress conditions (Maxwell and Johnson, 2000; Ibrahim and Bafeel, 2008). The significant increase in the carotenoids content suggests carotenoids have a photo-protective response to dust deposition by increased production of active oxygen species. Therefore, leaves of our studied plants appeared to be more capable of avoiding and/or scavenging the production of active oxygen species (AOS) generated during dust stress. These results are certainly in agreement with larger carotenoids pool in the plants grown under different stresses. The maximum efficiency of PSII photochemistry (F_v/F_m) varied from one plant to another, even though they shared the same site. Our results confirmed that PSII activity was drastically affected by dust deposition indicated by the great reduction in the maximum photochemical efficiency of PSII, expressed as Fv/Fm. The progressive decrease of Fv/Fm ratio indicated damage to most of the PSII reaction centre and structural modifications on PSII, especially in DI-protein (Maxwell and Johnson, 2000). Nevertheless, sustained reduction of Fv/Fm values may also result from accumulation of non-functional PSII.

About half of the PSII complex must be inactivated before photosynthetic capacity becomes limited (Oquist and Malmber, 1989). However, previous reports documented that a slight inactivation of the PSI and PSII were closely correlated with the changes in net photosynthetic rate (PN) (Maxwell and Johnson, 2000).

According to a previous study, it changes in net photosynthetic rate reflect alteration in both stomatal conductance and/or mesophyll capacity for photosynthesis (Allen and Ort, 2001). In our results, significant decrease in net photosynthesis (PN) was observed in all stressed plants that we attribute to stomatal conductance limitation caused by dust deposition. The significant decrease of stomatal conductance associated with dust accumulation indicated that net photosynthetic rate was reduced due to the plugging of stomata by dust during daylight. These results are consistent with the results by Starck et al. (2000), who concluded that the depressive effect of dust was mainly associated with larger dust load and/or the smaller particle size of the dust.

Conclusion

Dust storms cause soil loss from the dry lands, and worse, they preferentially remove organic matter and the nutrient-rich lightest particles, thereby reducing agricultural productivity. Also the abrasive effect of the storm damages most plants by inhibiting the physiological performance of plants including photosynthesis by shading the leaf surface because the finer particles of dust.

ACKNOWLEDGEMENTS

The author would like to thank the program Research center at college of Teachers, Deanship of scientific research, King Saud University, Riyadh- Saudi Arabia for funding and supporting this research.

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