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Dust collection potential and air pollution tolerance indices in some young plant species in arid regions of Iran

Zeinab Javanmard [(1)],
Masoud Tabari Kouchaksaraei [(1)],
Hosseinali Bahrami [(2)],
Seyed Mohsen Hosseini [(1)],
Seyed Ali M Modarres Sanavi [(3)],
Daniel Struve [(4)]

Dust is one of the main environmental challenges in most arid zone cities of Iran. Tree plantation and forest belts can provide a cost-effective and eco-friendly solution to mitigate dust pollution. Air pollution tolerance index (APTI) based on a combination of total chlorophyll (TChl), relative water content (RWC), ascorbic acid (AsA), and leaf pH is considered as one of the most important means for determining sensitive and tolerant plant species for greening. The present study aimed to evaluate the dust capturing efficiency and APTI of *Fraxinus rotundifolia* Mill., *Morus alba* L., *Celtis caucasica* Willd., and *Melia azedarach* L., four tree species commonly used in urban green areas of most cities in Iran. As a completely randomized design, 256 saplings were grown in four plastic sheets (64 saplings of four species in each chamber) and the dust was applied at concentrations of 0, 300, 750, and 1500 µg m^{-3} once a week for 70 days. The results revealed that dust accumulation was greatest in the 750 and 1500 µg m^{-3} treatment in the following order: *M. alba* > *C. caucasica* > *F. rotundifolia* > *M. azedarach*. In all species, pH, RWC, AsA, and TChl diminished with increasing dust concentration. A decline in APTI of 0 to 1500 µg m^{-3} was observed in all species. At 750 µg m^{-3}, only *M. alba* was tolerant to dust and the other species were intermediate. At 1500 µg m^{-3}, *M. alba* and *M. azedarach* showed to be intermediate while two other species were sensitive. The greatest relationship was found between APTI and RWC (R^2= 0.85), followed by APTI and AsA (R^2 = 0.82). Although *C. caucasica* showed a high capacity for dust accumulation at 1500 µg m^{-3}, it was found to be sensitive and can, therefore, be used as a dust pollution bioindicator. *F. rotundifolia* and *C. caucasica* are not suitable for plantation in urban green spaces where dust concentration is 1500 µg m^{-3}. *M. alba* appeared to be a tolerant species adaptable to arid urban environments with a potential for reducing dust levels by sinking its particles.

Keywords: APTI, Ascorbic Acid, Dust Pollution, Persian Lilac, White Mulberry

Introduction

Considered as a common air pollutant, dust is defined as a collection of fine solid particles of natural or anthropogenic origins which is usually formed by disintegration processes (Arslan & BoyBay 1990). Dust pollution is harmful for human health and environment, causing major problems and incurring staggering costs in various socio-economic sectors (Samoli et al. 2011, Hatami et al. 2018). A set of atmospheric, geomorphic, and ecological processes and human activities are involved in the mechanism of production, transfer, and deposition of dust particles (Reheis & Urban 2011). An estimated amount of 2 × 10^{12} tons of dust is emitted into the atmosphere annually (Shao et al. 2011), where dust particles originating from wind (aeolian) erosion claim about 40% of aerosols in the troposphere (Terradellas et al. 2015). The major sources of soil dust include arid and semi-arid regions, particularly subtropical latitudes where the great deserts are located, including Africa, Middle East, Southwest Asia, the central Australia, Mongolia, and parts of Europe and the Americas (Goudie 2014).

Plants are the primary recipients of deposited dust and endure it more than other living organisms, because of their immobility and continuous exposure to dust (González et al. 2014). Dust particles directly affect plants *via* deposition on aerial parts or indirectly through altering the chemical characteristics of soil (Maletsika et al. 2015). Dust deposition on plants usually affects the quantity and quality of the light that reaches plant surfaces and elevates leaf temperature (Hirano et al. 1995). Furthermore, accumulation of dust particles on leaves may lead to stomata blocking which interferes with gas exchange (Taheri Analojeh et al. 2016). All of the above

(1) Department of Forestry, Faculty of Natural Resources, Tarbiat Modares University, P. O. Box 14115-111 (Iran); (2) Department of Soil Science, Faculty of Agriculture, Tarbiat Modares University, P. O. Box 14115-111 (Iran); (3) Department of Agronomy, Faculty of Agriculture, Tarbiat Modares University, P. O. Box 14115-111 (Iran); (4) Department of Horticulture and Crop Science, The Ohio State University, 386 E Torrence Road, Columbus, OH 43214 614-313-5975 (USA)

@ Masoud Tabari Kouchaksaraei (mtabari@modares.ac.ir)

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changes can adversely affect leaf physiological and biochemical traits and negatively impact the plant growth and productivity (Maletsika et al. 2015). The intensity of the dust pollution on plants depends on its chemical and physical properties, duration and frequency of occurrence of dust events as well as leaf morphology and species tolerance to such stress. Also, climatic characteristics such as temperature, relative humidity, wind speed, and precipitation events influence the intensity of dust stress on plants (Siqueira-Silva et al. 2016).

To mitigate the impact of dust pollution in the air, environmentalists emphasize benefiting from perennial green belts in and around urban areas (Rao et al. 2004). Urban vegetation improves air quality by absorbing and accumulating dust pollutants on leaves (Kaur & Nagpal 2017). The dust accumulation potential on plants' leaves depends on leaf structure, leaf geometry, leaf epidermal and cuticular features, leaf phyllotaxy, as well as height and canopy of trees (Prusty et al. 2005). The key to maximizing the benefits of urban green zones is the proper selection of tree species for a proposed dust reduction and dust tolerance. Leaves constitute the most sensitive plant organ which are highly exposed to dust stress (Siqueira-Silva et al. 2016), making them as bioindicators for air quality in several studies (Achakzai et al. 2017, Maity et al. 2017, Bharti et al. 2018).

Tab. 1 - Some of the physical and chemical properties of soil dust samples (0-10 cm depth).

Soil Dust Property	Value
Texture	Clay-loam
Sand (%)	44
Clay (%)	48.66
Silt (%)	7.33
EC (ds m^{-1})	7.29
pH	6.65
N (%)	0.04
P (ppm)	13
K (ppm)	292
O.M (%)	0.68
SiO_2 (%)	30.42
Al_2O_3 (%)	6.2
TiO_2 (%)	0.41
Fe_2O_3 (%)	4.21
Na_2O (%)	2.25
CaO (%)	24.15
MnO (%)	5.11
K_2O (%)	0.35
P_2O_2 (%)	0.12
V_2O_2 (%)	0.01
NiO (%)	0.01
Cr_2O_3 (%)	0.03
MgO (%)	15.01
CuO (%)	0.01
ZrO_2 (%)	0.02
P_2O_5 (%)	0.12
CdO (%)	0.0002
Sb_2O_3 (%)	0.00001

When exposed to dust, the leaves experience physiological changes before exhibiting visible damage symptoms (Hayat et al. 2012). On the other hand, tolerance to dust pollution can be conferred through physiological and biochemical adjustments of the leaf, such as pH, relative water content (RWC), total chlorophyll (TChl), and ascorbic acid (AsA or Vitamin C – Rai & Panda 2014). Therefore, these four parameters are utilized to calculate "air pollution tolerance index- APTI" in plants (Achakzai et al. 2017). Sensitive species can act as biological indicators or biomonitors for air quality where tolerant species as sink can be used to combat dust pollutant in green belt development plans (Maity et al. 2017). Although most studies on APTI are related to industrial activities and vehicles (Rai & Panda 2014, Achakzai et al. 2017, Kaur & Nagpal 2017, Bharti et al. 2018), there are very few reports on APTI with natural dust (Gholami et al. 2016, Ranjbar-Fordoei 2018, Mohammadi et al. 2018).

Recent climatic changes in Iran and subsequent droughts combined with indiscriminate use of water resources have led to intensification and frequency of dust storms represented by formation of new dust centers and increased intensity, durability, and transition distance from the source region. For these reasons, more than half of the Iranian provinces are suffering from critical aerosol dust pollution (Amiraslani & Dragovich 2011, Rashki et al. 2014), among which some places are ranked as first to third in the world in terms of dust pollution (World Health Organization Report 2016). For instance, the daily maximum dust concentration reaches up to 5337 µg m^{-3} in Ahvaz (Shahsavani et al. 2012) and 3094 µg m^{-3} in Zabol (Rashki et al. 2012). The maximum number of dusty days in Zabool and Dezful is about 166 and 188 days per year, respectively. Also, the data provided by the Iranian Meteorological Organization (IMO) revealed that during the period 2001-2005, the average number of dusty days for Dezful, Kermanshah, and Abadan cities were 87.8, 73, and 58.2 days, respectively. Based on the United Nations Environment (UNE), the *per capita* urban green space (UGS) in Iran (7-12 m^2) is far lower than either the standard index (20-25 m^2) or the ideal global index (50 m^2) by World Health Organization (2010), highlighting the importance of additional green space in urban and suburban areas.

Fraxinus rotundifolia Mill., *Morus alba* L., *Celtis caucasica* Willd. and *Melia azedarach* L. are commonly used in urban green spaces of central Iran, as well as in arid and semi-arid regions, particularly where the dust pollution is high. Accordingly, this investigation aimed to assess the collection potential and estimation of APTI of the mentioned tree species under dusty air pollution and to introduce the most suitable species for planting in urban green space of dusty regions.

Materials and methods

The experiment was conducted at a research greenhouse at the Faculty of Agriculture, Tarbiat Modares University, Tehran, Iran (35° 44′ N, 51° 10′ E; elevation: 1215 m a.s.l.). The climate of the area is arid and semi-arid, with average annual relative humidity of 34% and average annual rainfall of 161 mm.

Plant materials

The four target species (*F. rotundifolia, M. alba, C. caucasica* and *M. azedarach*) were initially grown for two years in polypropylene pots containing soil mixture (sand, clay, animal manure and cocopeat in 2:1:1:1 proportion) in a nursery (35° 44′ N, 51° 10′ E; 1312 m a.s.l.). Sixty-four uniform saplings (in terms of collar diameter and height) from each species were selected and transferred to the greenhouse. Twenty days later, the saplings were transplanted to a 5L plastic pot containing the same soil used at nursery and irrigated daily at constant parameters (temperature 26 ± 2 °C; 14 hours photoperiod; relative humidity 54 ± 5% and photosynthetically active radiation-PAR 1000 µmol m^{-2} s^{-1}).

Preparation of soil dust

Soil samples for dust preparation were collected at depths of 0-10 cm from the largest source of dust generation in the southern province of Khuzestan, Iran (Heidarian et al. 2017). The blended soil was passed through a 106 µm sieve and oven dried at 80 °C for 48 hours. A detailed soil analysis is provided in Tab. 1.

Application of dust

The selected dust concentrations (300, 750 and 1500 µg m^{-3}) were based on the typical concentrations recorded in suspended particles (TSP) in Khuzestan Province (Shahsavani et al. 2012, Hatami et al. 2018), taking 0 µg m^{-3} as control. Four plastic covered chambers (5 × 2 × 3 m) for the four dust concentrations were made based on an earlier work (Siqueira-Silva et al. 2016) with some modification. Each chamber contained 64 saplings (Fig. 1). Dust was applied on plants over 10 weeks with one-week intervals (from 09:00 to 12:00) using a dust simulator. Each treatment was carried in four replicates (with four saplings per replicate). The saplings were irrigated as needed. Calibration of dust chambers for the concentration and method of particle size distribution in the air was conducted by the dust monitor (model 176000A Microdust Pro Dust Monitoring®, Casella, Buffalo, NY, USA).

Dust collection potential

At the end of the experiment, five fully expanded leaves from selected saplings per treatment (from each dust level-each tree species) were severed, placed individually in plastic bags and transferred to the laboratory. The leaf samples were weighed using an electric digital balance. Individual leaves were then cleaned using a fine brush to remove dust and then reweighed. The area of each leaf was measured using a Leaf Area Meter (Model LI-3000®, Li-Cor, Lincoln, NE, USA). The amount of dust accumulation was calculated following Prusty et al. (2005) as (eqn. 1):

$$W=\frac{W_2-W_1}{a} \qquad (1)$$

where W is the dust accumulation amount (mg cm^{-2}), W_1 is the weight of leaf without dust (mg), W_2 is the weight of leaf with dust (mg), and a is the total area of leaf in cm^2.

Leaf extract pH

The leaf extract pH was determined by the protocol of Rai & Panda (2014). For each treatment, four samples of 0.5 g of the fresh leaves were crushed and homogenized in 50 ml deionized water, after which the mixture was centrifuged at 7000×g for 10 minutes. The pH of the supernatant was measured using a digital pH meter (model µ pH system 361, Systronics AG, Baden-Dättwil, Switzerland).

Relative water content (RWC)

The RWC of leaf was determined according to Karami et al. (2017). Four samples of fully matured leaves for each treatment were collected and immediately taken to the laboratory. These leaves were washed completely, and the excess was removed by a filter paper. The fresh leaves were weighed to obtain the fresh weight (*FW*), and then placed in a water-filled Petri plate overnight (24 hours). The samples were weighed again to achieve the turgid weight (*TW*). Then, the turgid leaves were oven dried at 70 °C for 48 hours, and the dry weight (*DW*) was recorded. The RWC was calculated as follows (eqn. 2):

$$RWC=\frac{FW-DW}{TW-DW}\cdot 100 \qquad (2)$$

Total chlorophyll (TChl)

For measuring TChl content, sapling leaves from each treatment were collected at the end of the experiment and their surface was cleared off dust particles by a soft brush (Siqueira-Silva et al. 2016). About 0.1 g of fresh leaves (four samples for each treatment) was extracted in 10 ml of chilled 80% acetone. The liquid portion was decanted into another test tube and centrifuged at 4 °C in the dark at 6000×g for 15 minutes. The supernatant was collected with the absorbance being captured at 645 and 663 nm using a spectrophotometer (FCC Compliance, Epoch, Biotek Instrument, USA). The contents of chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*), and total chlorophyll (TChl – mg g^{-1} FW) were determined as follows (Arnon 1949 - eqn. 3 to eqn. 5):

$$\text{Chl}\,a=0.0127\cdot A663-0.00269\cdot A645 \qquad (3)$$

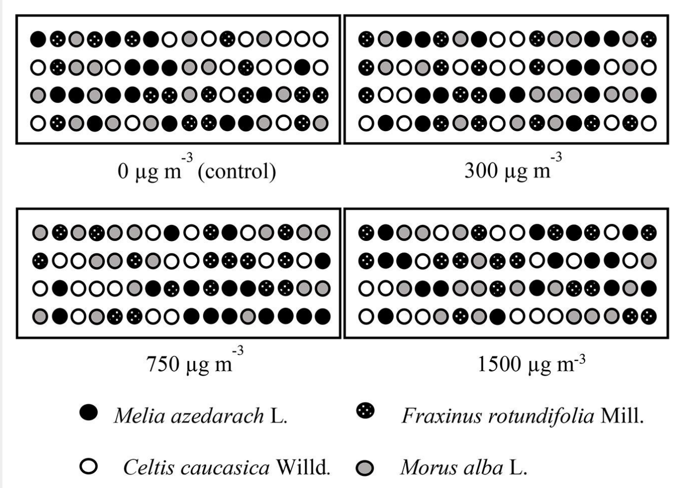


Fig. 1 - Experimental design map (a randomized complete design with four replicates of four saplings per species at each dust concentration).

$$\text{Chl}\,b=0.0229\cdot A645-0.00468\cdot A663 \qquad (4)$$

$$TChl=0.0202\cdot A645+0.00784\cdot A663= =\text{Chl}\,a+\text{Chl}\,b \qquad (5)$$

Ascorbic acid (AsA)

The spectrophotometric method was used to determine the AsA of the leaves (Keller & Schwager 1977). About 1 g of fresh leaf (four samples for each treatment) was homogenized with 20 ml oxalic acid-EDTA solution (5 g oxalic acid + 0.75 g EDTA in 1 ml of distilled water), and then centrifuged at 6000×g for 15 minutes at room temperature where the liquid supernatant was separated. The supernatant (1 ml) was mixed with 5 ml of 2,6-dichlorophenol indophenol (DCPIP). The optical density (OD) of the solution (*Es*) was read at 520 nm. One drop of AsA solution was added in order to bleach the supernatant sample where optical density was measured at the same wavelength (*Et*). The optical density of DCPIP solution was also taken at 520 nm (*Eo*). The standard curve was prepared using 1% aqueous solution of AsA. The concentration of AsA (mg g^{-1}) was calculated by the following equation (eqn. 6):

$$AsA=[Eo-(Es-Et)]\cdot\frac{V}{W}\cdot V\,1\cdot 1000 \qquad (6)$$

where W is the weight of the fresh leaf taken, $V1$ is the volume of the supernatant taken, V is the total volume of the mixture. The value of [*Eo*-(*Es*-*Et*)] is estimated by the standard curve.

Air pollution tolerance index (APTI)

APTI was calculated by measuring the leaf extract pH, RWC, TChl and AsA content. APTI is formulated as follows (Ogunkunle et al. 2015 - eqn. 7):

$$APTI=\frac{[AsA(P+TChl)+RWC]}{10} \qquad (7)$$

where AsA is expressed in mg g^{-1}, TChl in mg g^{-1}, P is the pH of leaf extract and RWC is expressed as percentage.

Based on the computed APTI values, the plant species were classified as sensitive (≤11), intermediate (12 to 16), and tolerant (≥17), according to Ogunkunle et al. (2015).

Statistical analysis

The effects of dust concentration and tree species were analyzed using a GLM procedure. The means were declared significantly different using the Duncan's multiple range test. All statistical analyses were performed using SPSS® version 23.0 (SPSS Inc., Chicago, IL, USA). Linear regression (R^2) analysis was carried out to assess changes in APTI (dependent variable) governed by leaf pH, RWC, TChl, and AsA (independent variables) of plant species, using Microsoft Excel 2013®.

Results

The two-way analysis of variance revealed that dust concentration significantly affected the extract pH in all tested tree species, while the effect of dust concentration and tree species was significant on RWC and TChl. There was a significant interaction between dust concentration and tree species on dust potential collection as well as AsA content (Tab. 2).

Increased dust concentration enhanced foliar dust accumulation capacity in all species. High dust collection potential at 750 and 1500 µg m^{-3} in the tested plants was noted in the sequence of *M. alba* > *C. caucasica* > *F. rotundifolia* > *M. azedarach*. At 1500 µg m^{-3}, the maximum dust load was noticed on leaves of *M. alba* (2.88 mg cm^{-2}), followed by *C. caucasica* (2.41 mg cm^{-2}), *F. rotundifolia* (1.61 mg cm^{-2}) and *M. azedarach* (1.23 mg cm^{-2}); similar trends were observed at 750 µg m^{-3}, where dust load was 2.18, 1.59, 1.11, and 0.94 mg cm^{-2} for the same species, respectively (Fig. 2).

The pH of leaf extract of all species diminished when subjected to increased dust concentrations (Fig. 3), which ranged within 7.57-6.35 in *M. alba*, 7.29-6.28 in *M. azedarach*, 7.69-6.46 in *F. rotundifolia*, and 7.4-6.0 in *C. caucasica*. Rising soil dusting was

Tab. 2 - The effect of dust application on dust collection potential and many physiological and biochemical traits of four trees species. (*): $p < 0.05$; (**): $p < 0.01$

Parameter measured	Factors (*F*-values)		
	Dust concentration (D)	Tree species (T)	D × T
Dust collection potential	59.879**	12.624**	2.964*
Leaf extract pH	5.220**	0.722	0.067
Ascorbic acid content	150.265**	45.042**	10.696**
Relative water content	76.988**	4.747**	1.218
Total chlorophyll content	27.289**	3.652*	0.297

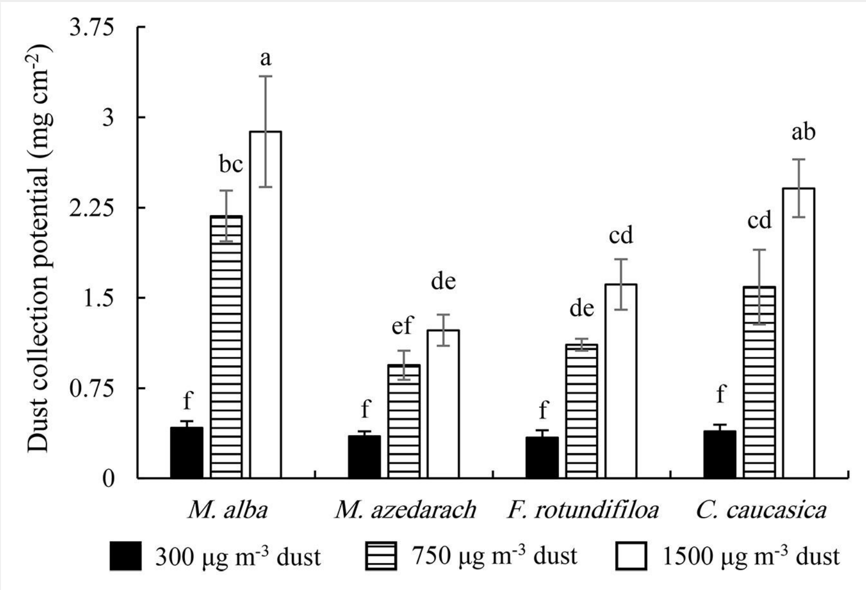


Fig. 2 - Dust collection potential during the 70 days dust exposure treatment for four common Iranian urban trees species. Different letters indicate significant differences among 12 treatment combinations (interaction of dust level × tree species) after Duncan's test (p<0.05). Values are mean ± SE. n=4 saplings from each treatment (dust level-tree species).

associated with reduction in AsA of all species; from 0 to 1500 µg m^{-3}, the AsA of *M. alba, M. azedarach, F. rotundifolia*, and *C. caucasica* dropped by 21%, 16%, 36%, and 42%, respectively (Fig. 3).

Increase in dust concentration induced a significant decrease in the RWC and TChl concentrations in all plant species (Fig. 3). For instance, at 1500 µg m^{-3}, the relative water content (RWC) in leaves was reduced by 33%, 33%, 37%, and 46% for *M. alba, C. caucasica, F. rotundifolia* and *M. azedarach*, respectively, while TChl declined by 35%, 46%, 44%, and 51% for the same species, respectively. Irrespective of dust concentrations, the highest RWC was found in *M. alba* and *M. azedarach*. Further, the maximum TChl value was observed in *M. alba*, while the lowest RWC and TChl values were found in *C. caucasica* (Fig. 3).

The APTI value diminished with increase in dust levels in all plant species (Fig. 4), which varied from 19.8 to 9.05. In 0 µg m^{-3}, the APTI value was found as the following order: *M. alba* > *C. caucasica* > *M. azedarach* and *F. rotundifolia*; at 300 µg m^{-3}, the trend of APTI score was *M. alba* > *C. caucasica* > *M. azedarach* and *F. rotundifolia*; at 750 µg m^{-3}, the order was: *M. alba* (17.25) > *M. azedarach* (15.69) > *F. rotundifolia* (13.34) > *C. caucasica* (12.48); at 1500 µg m^{-3}, the ATPI scores were 12.70, 12.19, 10.45, and 9.05 in *M. alba, M. azedarach, F. rotundifolia* and *C. caucasica*, respectively (Fig. 4).

All plant species were found to be tolerant at 0 and 300 µg m^{-3}. On the other hand, at 750 µg m^{-3}, *M. alba* was tolerant, while the other three species were intermediate. At 1500 µg m^{-3}, *M. alba* and *M. azedarach* responded like intermediate-tolerant species, but *C. caucasica* and *F. rotundifolia* were found to be sensitive (Fig. 4).

A high positive correlation was found be-

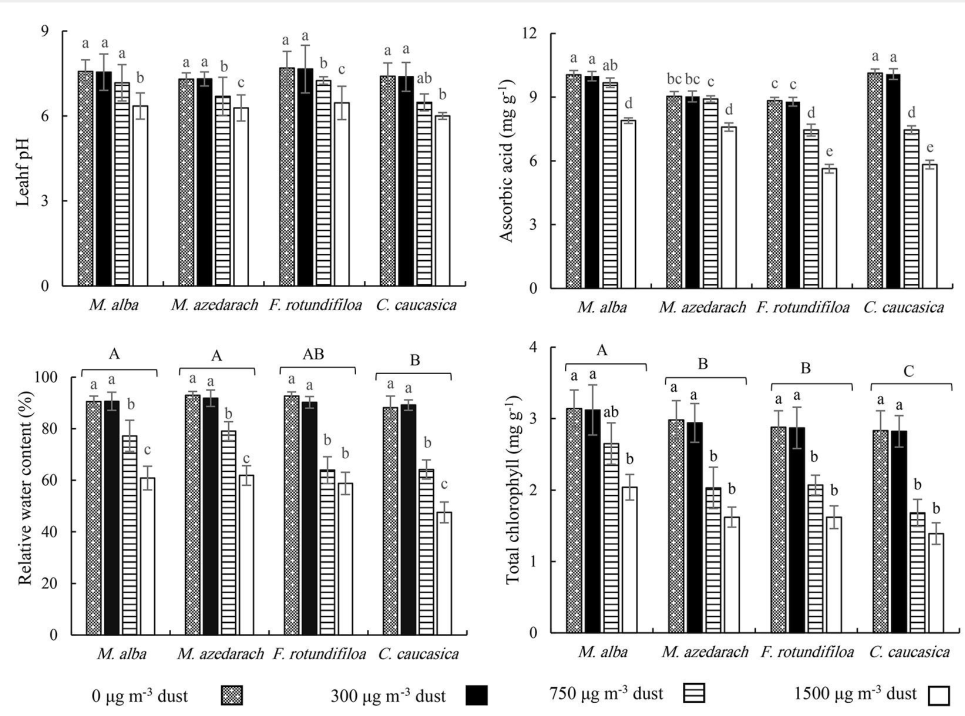


Fig. 3 - Leaf pH, Ascorbic acid (AsA), relative water content (RWC) and total chlorophyll (TChl) during the 70 days dust exposure treatment for four common Iranian urban trees species. Different letters indicate significant difference among four dust levels (in leaf pH), and interaction of dust level × tree species (in AsA). In RWC and TChl, lowercase letters indicate significant differences among four dust levels in each plant species, and capital letters indicate significant differences among four plants species after Duncan's test (p<0.05). Values are the mean ± SE. n=4 saplings from each treatment (dust level-tree species).

tween APTI and RWC (R^2 = 0.85), and between APTI and AsA (R^2 = 0.82). On the other hand, a low and moderate positive correlation was found between APTI and pH (R^2= 0.45) and between APTI and TChl (R^2 = 0.72), (Fig. 5).

Discussion

In the present study, increase in dust concentration promoted dust accumulation potential in all species. At 750 and 1500 µg m^{-3}, the trend of dust accumulation among the species was *M. alba* > *C. caucasica* > *F. rotundifolia* > *M. azedarach*. The high dust accumulation in *M. alba* can be explained by the ovate shape of the leaves with depressions in the middle, uneven surface, and high area of leaves. However, in *C. caucasica*, this may be due to the relatively high, rough and uneven surface of the leaves and presence of tiny hairs on the abaxial surface. Principally, greatest dust deposition is found in species with leaves of thick, rough and hairy surfaces; consequently, such species are suitable for the accumulation of dust (Prusty et al. 2005). In our findings, low dust removal capacity in *F. rotundifolia* was probably because of smooth surface and low area of leaves. The low dust-retention amount of *M. azedarach* might be due to small area, thin lamina, as well as flat and smooth surface of leave. Indeed, these two species display a low dust accumulation potential since dust is shed by air movement.

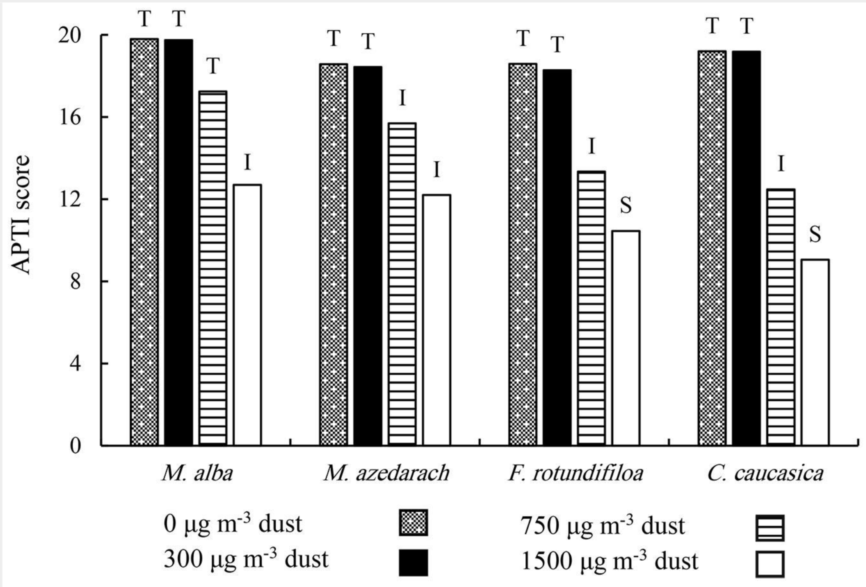
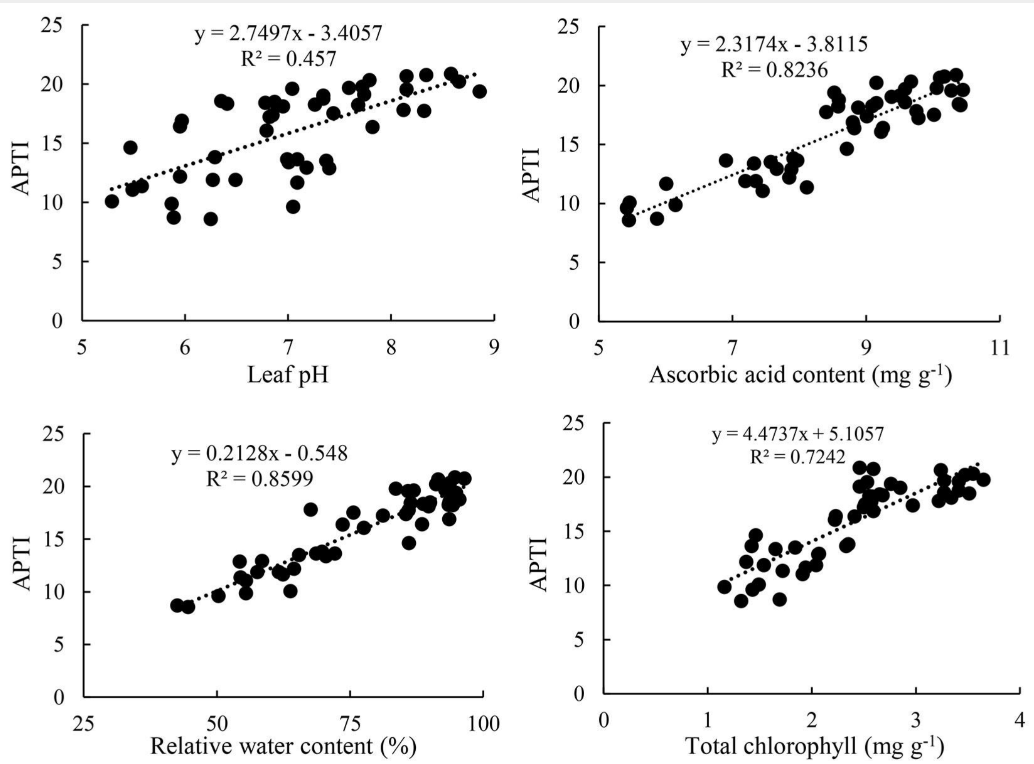


Fig. 4 - APTI score and plant species response under different dust concentrations during the 70 days dust exposure treatment for four common Iranian urban trees species. (T): Tolerant, (I): Intermediate, (S): Sensitive.

In the current study, increase in dust stress led to a significant reduction in pH of leaves across all tested plant species, which was in line with the results in *Pistacia vera* L. (Ranjbar-Fordoei 2018). The leaf pH is an index of detoxification mechanism in plants for improving tolerance capacity against air pollution (Ninave et al. 2001). The penetration of chemical dust particles with an acidic nature into the cell sap and their conversion to acidic radicals cause reduction of leaf extract pH, where the decline is greater in sensitive plants than in tolerant plants (Das & Prasad 2010). Low leaf pH reduces the efficiency of the conversion from hexose to ascorbic acid (Uka et al. 2017). In the current study, it seems that more probable penetration of acidic dust particles (pH 6.65) into the leaf tissues along with growing dust accumulation on the leaf surface caused diminished pH of leaf extracts.

The elevated dust concentration resulted in reduced AsA content, which was in correspondence with another study employing the marble crushing-caused dust deposition on the leaf surface of some tree species (Noor et al. 2015). AsA concentration is directly proportional to the pH value of the leaf. Likewise, acidic pH of dust deposited on leaf surface alters cell sap pH towards acidic and declines the efficiency of the

Fig. 5 - Linear regression analysis of individual variables (physiological and biochemical variables) with APTI.



conversion of hexose sugar to AsA formation (Uka et al. 2017). The descending trend in AsA content as well as leaf extract pH with increase in dust concentration may be attributed to the positive relationship between these two parameters. Another reason for reduction of AsA under dust stress may be its consumption for scavenging reactive oxygen species (ROSs) produced in chain reactions following the penetration of pollutant particles into foliar tissues (Noor et al. 2015).

Increase in dust concentration resulted in a descending trend of RWC across the examined species, which is in line with earlier studies in sweet potato (Yao et al. 1998), peach (Maletsika et al. 2015), grapevine (Karami et al. 2017), and pistachio (Ranjbar-Fordoei 2018). RWC is a useful indicator of plant's water status whose high value is considered as a resistance index against stresses (Tounekti et al. 2011, Gholami et al. 2016). In our findings, the maximum RWC was detected in *M. alba* and *M. azedarach*, while the lowest was found in *C. caucasica*. Under dust stress, low RWC may be due to the effect of dust pollutant on leaf transpiration, since the crust formed by dust deposition on the leaf can lead to the blockage of the stomata and reduced transpiration (Zia-Khan et al. 2015, Javanmard et al. 2019). Also, the reaction of dust particles with the cell membrane results in foliar injury and higher membrane permeability in dusted leaves which may be another reason for the low RWC value (Prajapati & Tripathi 2008).

Increase in dust concentration was associated with a marked reduction of TChl across all tested species; the highest and the lowest values were recorded in *M. alba* and *C. caucasica*, respectively. Similar trend of reduced TChl in response to dust pollution has also been reported on *Haloxylon aphyllum* Bunge (Heydarnezhad & Ranjbar-Fordoie 2014), *Vigna radiata* L. (Alavi & Sharifi 2015), *P. persica* (Maletsika et al. 2015) and on *P. vera* (Ranjbar-Fordoei 2018). Dust deposition on the leaf surface may reduce the synthesis of chlorophyll due to shading effects. Another reason may be related to pigment degradation and the inhibition of enzymes essential for biosynthesis of pigments due to the incorporation of dust particles into the leaf tissue (Lepeduš et al. 2003).

Increase in the dust level was associated with a decline in the APTI value. At high dust concentrations (750 and 1500 μg m^{-3}), the APTI value was found to be in the order of: *M. alba* > *M. azedarach* > *F. rotundifolia* > *C. caucasica.* It can be stated that plant species respond differently to different dust concentrations. Higher accumulation of dust particles changes the physiological and biochemical variables of the leaf which can be measured by the APTI (Achakzai et al. 2017). Hence, different APTI values represent the ability of a plant to combat against air dust pollution (Rai & Panda 2014).

Plant species are classified in terms of their tolerance level to the air pollution as (Ogunkunle et al. 2015): sensitive (≤11 APTI), intermediate (12-16 APTI), and tolerant (≥17 APTI). In the present study, at 750 μg m^{-3} of dust, only *M. alba* fell under tolerant category; at 1500 μg m^{-3}, *M. alba* and *M. azedarach* were classified as intermediate, while the other two species were sensitive. Species with higher APTI values show greater tolerance to air pollution and can act as a dust sink (Maity et al. 2017). It can, therefore, be stated that *M. alba* is a potential species to be planted in polluted sites and for reducing air dust pollution, while *C. caucasica* and *F. rotundifolia* are suitable for biomonitoring of air dust pollution. In our study, the highest correlation existed between APTI and RWC (R^2= 0.85), followed by between APTI and AsA (R^2 = 0.82), indicating that RWC and AsA of the leaf are important variables in the estimation of APTI.

Conclusion

The trend of dust accumulation capacity among the four tested tree species at 750 and 1500 μg m^{-3} of dust levels was *Morus alba* > *Celtis caucasica* > *Fraxinus rotundifolia* > *Melia azedarach*. Growing concentrations of soil dust caused a significant reduction in the leaf extract pH, RWC, AsA, and TChl for all species examined. A decline in APTI score of 0 to 1500 μg m^{-3} was observed in all species. Among the four species, *M. alba* was only tolerant to 750 μg m^{-3} of dust. At 1500 μg m^{-3}, *M. alba* and *M. azedarach* were classified as intermediate, while the other two species were sensitive. RWC and AsA were the most crucial factors promoting tolerance to dust stress in the plants. Despite the high capacity of dust accumulation at 1500 μg m^{-3}, *C. caucasica* was sensitive and could be used only as a bioindicator for dusty air. *M. azedarach* showed to be an intermediate species and was more resistant than *F. rotundifolia* and *C. caucasica;* therefore, the two latter species cannot be introduced for urban plantation in arid regions with dusty air of 1500 μg m^{-3}. Overall, due to the maximum potential for dust accumulation and the higher tolerance than the other three species (at 750 and 1500 μg m^{-3}), *M. alba* can be suitable for plantation in arid urban environments and serves as a sink for dust particles.

List of abbreviations

(APTI): Air Pollution Tolerance Index; (RWC): Relative Water Content; (TChl): Total Chlorophyll; (AsA): Ascorbic Acid; (IMO): Iranian Meteorological Organization; (UNE): United Nations Environment; (UGS): Urban Green Space; (WHO): World Health Organization; (ROS): Reactive Oxygen Species.

Authors' contributions statement

The study was conducted by contributions from all authors. ZJ and MTK shaped the structure of the scientific design. ZJ, HAB and SAMMS performed greenhouse and laboratory works. ZJ and MTK carried out data analysis. The text was written by ZJ and MTK. It also was improved from view point of technical and English language by DS.

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References

Achakzai K, Khalid S, Adrees M, Bibi A, Ali S, Nawaz R, Rizwan M (2017). Air pollution tolerance index of plants around brick kilns in Rawalpindi. Pakistan. Journal of Environmental Management 190: 252-258. - doi: 10.1016/j.jenvman.2016.12.072

Alavi M, Sharifi M (2015). Experimental effects of sand-dust storm on tolerance index, percentage phototoxicity and chlorophyll a fluorescence of *Vigna radiata* L. Proceedings of the International Academy of Ecology and Environmental Sciences 5: 16-24.

Amiraslani F, Dragovich D (2011). Combating desertification in Iran over the last 50 years: an overview of changing approaches. Journal of Environmental Management 92: 1-13. - doi: 10.1016/j.jenvman.2010.08.012

Arnon DI (1949). Copper enzymes in isolated chloroplasts: polyphenoloxidase in beta vulgaris. Plant Physiology 24: 1-15. - doi: 10.1104/pp.24.1.1

Arslan M, BoyBay M (1990). A study on the characterization of dust fall. Atmospheric Environment 24: 2667-2671. - doi: 10.1016/0960-1686(90)90146-E

Bharti SK, Trivedi A, Kumar N (2018). Air pollution tolerance index of plants growing near an industrial site. Urban Climate 24: 820-829. - doi: 10.1016/j.uclim.2017.10.007

Das S, Prasad P (2010). Seasonal variation in air pollution tolerance indices and selection of plant species for industrial areas of Rourkela. Indian Journal of Environmental Protection 30: 978-988. [online] URL: http://www.environmentportal.in/files/airpollutiontolerance.pdf

Gholami A, Mojiri A, Amini H (2016). Investigation of the air pollution tolerance index (APTI) using some plant species in Ahvaz region. Journal of Animal and Plant Sciences 26: 475-480. [online] URL: http://www.thejaps.org.pk/docs/v-26-02/24.pdf

González JA, Prado FE, Piacentini RD (2014). Atmospheric dust accumulation on native and non-native species: effects on gas exchange parameters. Journal of Environmental Quality 43: 801-808. - doi: 10.2134/jeq2013.08.0308

Goudie AS (2014). Desert dust and human health disorders. Environment International 63: 101-113. - doi: 10.1016/j.envint.2013.10.011

Hatami Z, Rezvani Moghaddam P, Rashki A, Nasiri Mahallati M, Habibi Khaniani B (2018). Effects of desert dust on yield and yield components of cowpea (*Vigna unguiculata* L.). Archives of Agronomy and Soil Science 64: 1446-

1458. - doi: 10.1080/03650340.2018.1440081

Heidarian P, Joudaki M, Darvishi Khatoni J, Shahbazi R (2017). Recognized dust sources in Khuzestan province. Geosciences 27: 33-46. [in Persian with English abstract]

Heydarnezhad S, Ranjbar-Fordoie A (2014). Impact of aeolian dust accumulation on some biochemical parameters in black saxaul (*Haloxylon aphyllum* Bunge.) leaves: a case study for the Aran-Bidgol region, Iran. International Journal of Forest, Soil and Erosion 4: 11-15. - doi: 10.22069/ijerr.2016.3871

Hirano T, Kiyota M, Aiga I (1995). Physical effects of dust on leaf physiology of cucumber and kidney bean plants. Environmental Pollution 89: 255-261. - doi: 10.1016/0269-7491(94)00075-O

Hayat S, Khalique G, Irfan M, Wani AS, Tripathi BN, Ahmad A (2012). Physiological changes induced by chromium stress in plants: an overview. Protoplasma 249: 599-611. - doi: 10.1007/s00709-011-0331-0

Javanmard Z, Tabari Kouchaksaraei M, Bahrami HA, Hosseini SM, Modares Sanavi, SAM (2019). Effects of dust on morpho-physiological response of *Fraxinus rotundifolia* Mill. seedling, Iranian Journal of Forest. [in press] [in Persian with abstract in English]

Karami L, Ghaderi N, Javadi T (2017). Morphological and physiological responses of grapevine (*Vitis vinifera* L.) to drought stress and dust pollution. Folia Horticulturae 29: 231-240. - doi: 10.1515/fhort-2017-0021

Kaur M, Nagpal A (2017). Evaluation of air pollution tolerance index and anticipated performance index of plants and their application in development of green space along the urban areas. Environmental Science and Pollution Research 24: 18881-18895. - doi: 10.1007/s11356-017-9500-9

Keller T, Schwager H (1977). Air pollution and ascorbic acid. European Journal of Plant Physiology 7: 338-350. - doi: 10.1111/j.1439-0329.1977.tb00603.x

Lepeduš H, Cesar V, Suver M (2003). The annual changes of chloroplast pigments content in current-and previous-year needles of Norway spruce (*Picea abies* L. Karast.) exposed to cement dust pollution. Acta Botanica Croatica 62: 27-35. [online] URL: http://hrcak.srce.hr/3538?lang=en

Maity S, Mondal I, Das B, Mondal AK, Bandyopadhyay J (2017). Pollution tolerance performance index for plant species using geospatial technology: evidence from Kolaghat Thermal Plant area, West Bengal, India. Spatial Information Research 25: 57-66. - doi: 10.1007/s41324-016-0075-1

Maletsika PA, Nanos GD, Stavroulakis GG (2015). Peach leaf responses to soil and cement dust pollution. Environmental Science and Pollution Research 22: 15952-15960. - doi: 10.1007/s11356-015-4821-z

Mohammadi A, Mokhtari M, Mosleh Arani A, Taghipour H, Hajizadeh Y, Fallahzadeh H (2018). Biomonitoring levels of airborne metals around Urmia Lake using deciduous trees and evaluation of their tolerance for greenbelt development. Environmental Science and Pollution Research 25: 21138-21148. - doi: 10.1007/s11356-018-1899-0

Ninave SY, Chaudhari PR, Gajghate DG, Tarar JT (2001). Foliar biochemical features of plants as indicators of air pollution. Bulletin of Environmental Contamination and Toxicology 67: 133-140. - doi: 10.1007/s00128-001-0101-3

Noor MJ, Sultana S, Fatima S, Ahmad M, Zafar M, Sarfraz M, Balkhyour MA, Saif SZ, Ashraf MA (2015). Estimation of anticipated performance index and air pollution tolerance index and of vegetation around the marble industrial areas of Potwar region: bioindicators of plant pollution response. Environmental Geochemistry and Health 37: 441-445. - doi: 10.1007/s10653-014-9657-9

Ogunkunle CO, Suleiman LB, Oyedeji S, Awotoye OO, Fatoba PO (2015). Assessing the air pollution tolerance index and anticipated performance index of some tree species for biomonitoring environmental health. Agroforestry Systems 89: 447-454. - doi: 10.1007/s10457-014-9781-7

Prajapati SK, Tripathi B (2008). Seasonal variation of leaf dust accumulation and pigment content in plant species exposed to urban particulates pollution. Journal of Environmental Quality 37: 865-870. - doi: 10.2134/jeq2006.0511

Prusty BAKP, Mishra C, Azeez PA (2005). Dust accumulation and leaf pigment content in vegetation near the national highway at Sambalpur, Orissa, India. Ecotoxicology and Environmental Safety 60: 228-235. - doi: 10.1016/j.ecoenv.2003.12.013

Rai PK, Panda LLS (2014). Dust capturing potential and air pollution tolerance index (APTI) of some road side tree vegetation in Aizawl, Mizoram, India: an Indo-Burma hot spot region. Air Quality Atmosphere and Health 7: 93-101. - doi: 10.1007/s11869-013-0217-8

Ranjbar-Fordoei A (2018). Impact of aeolian dust on leaf biochemical and biophysical attributes of Pistachio (*Pistacia vera* L.): a case study for the Kashan (central Iran) Pistachio orchards. Journal of Crop Production and Processing 8: 1-10. [in Persian with English abstract] - doi: 10.29252/jcpp.8.3.1

Rao PS, Gavane AG, Ankam SS, Ansari MF, Pandit VI, Nema P (2004). Performance evaluation of a green belt in a petroleum refinery: a case study. Ecological Engineering 23: 77-84. - doi: 10.1016/j.ecoleng.2004.06.013

Rashki A, Kaskaoutis DG, Rautenbach CJD, Eriksson PG, Qiang M, Gupta P (2012). Dust storms and their horizontal dust loading in the Sistan region, Iran. Aeolian Research 5: 51-62. - doi: 10.1016/j.aeolia.2011.12.001

Rashki A, Kaskaoutis DG, Eriksson PG, Rautenbach CJDW, Flamant C, Abdi Vishkaee F (2014). Spatial-temporal variability of dust aerosols over the Sistan region in Iran based on satellite observations. Natural Hazard 71: 563-585. - doi: 10.1007/s11069-013-0927-0

Reheis MC, Urban FE (2011). Regional and climatic controls on seasonal dust deposition in the southwestern US. Aeolian Research 3: 3-21. - doi: 10.1016/j.aeolia.2011.03.008

Samoli E, Kougea E, Kassomenos P, Analitis A, Katsouyanni K (2011). Does the presence of desert dust modify the effect of PM_{10} on mortality in Athens, Greece? Science of the Total Environment 409: 2049-2054. - doi: 10.1016/j.scitotenv.2011.02.031

Shahsavani A, Naddafi K, Jafarzade Haghighifard N, Mesdaghinia A, Yunesian M, Nabizadeh R, Goudarzi G (2012). The evaluation of PM_{10}, $PM_{2.5}$ and PM_1 concentrations during the Middle Eastern Dust (MED) events in Ahvaz, Iran, from April through September. Journal of Arid Environments 77: 72-83. - doi: 10.1016/j.jaridenv.2011.09.007

Shao Y, Wyrwoll KH, Chappell A, Huang Lin Z, McTainsh GH (2011). Dust cycle: an emerging core theme in Earth system science. Aeolian Research 2: 181-204. - doi: 10.1016/j.aeolia.2011.02.001

Siqueira-Silva AI, Pereira EG, Modolo LV, Lemos-Filho JP, Paiva EA (2016). Leaf structural traits of tropical woody species resistant to cement dust. Environmental Science and Pollution Research 23: 16104-16114. - doi: 10.1007/s11356-016-6793-z

Taheri Analojeh A, Azimzadeh HR, Mosleh Arani A, Sodaiezadeh H (2016). Investigating and comparing short period impact of dust on physiological characteristics of three species of *Pinus eldarica*, *Cupressus sempervirens*, and *Ligustrum ovalifolium*. Arabian Journal of Geosciences 9: 1-12. - doi: 10.1007/s12517-015-2241

Terradellas E, Nickovic S, Zhang X (2015). Airborne dust: a hazard to human health, environment and society. World Meteorological Organization Bulletin 64: 42-46. [online] URL: http://dialnet.unirioja.es/servlet/articulo?codigo=5849729

Tounekti T, Vadel A, Oñate M, Khemira H, Munné-Bosch S (2011). Salt- induced oxidative stress in rosemary plants: damage or protection? Environmental and Experimental Botany 71: 298-305. - doi: 10.1016/j.envexpbot.2010.12.016

Uka UN, Hogarh J, Belford EJD (2017). Physiological responses of some plant species as a bio-indicator of roadside automobile pollution stress using the air pollution tolerance index approach. International Journal of Plant Research 3: 9-16. - doi: 10.5923/j.plant.20130302.01

World Health Organization (2010). Urban planning, environment and health: from evidence to policy action. In: "Urban Planning, Environment and Health: from Evidence to Policy Action". WHO Regional Office for Europe, Copenhagen, Denmark, pp. 119. [online] URL: http://www.euro.who.int/__data/assets/pdf_file/0004/114448/E93987.pdf

World Health Organization (2016). Ambient air pollution: a global assessment of exposure and burden of disease. Pub. no. 978-92-4-151135–3, Geneva, Switzerland. pp. 121. [online] URL: http://apps.who.int/iris/bitstream/handle/10665/250141/9789241511353-eng.pdf

Yao MH, Tsai JC, Chi KS (1998). The influence of dust on photosynthesis responses of sweet potato (*Ipomoea batatas*) leaves. Chinese Journal of Agrometeorology 5: 105-112.

Zia-Khan S, Spreer W, Othmanli H, Müller J (2015). Effect of dust deposition on stomatal conductance and leaf temperature of cotton in northwest China. Water 7: 116-131. - doi: 10.3390/w7010116