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RESEARCH ARTICLE

Assessment of anticipated performance index of some deciduous plant species under dust air pollution

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Abstract

Green vegetation improvement is an economical strategy to mitigate dust air pollution. The anticipated performance index (API) is considered a main criterion to select the suitable plants of urban forests. API is calculated by taking air pollution tolerance index (APTI) and socio-economic and biological aspects into account. In the present work, API of four current deciduous tree species in urban areas of Iran was evaluated. The seedlings were soil-dusted by a dust simulator in plastic chambers at levels of 0, 300, 750, and 1500 μg/m^3 at intervals of 1 week for 70 days. At 750 and 1500 μg/m^3 dust concentrations (DCs), greatest dust collection capacity was observed with *Morus alba* and the lowest one with *Melia azedarach*. Increasing DC declined APTI of all species. At 750 μg/m^3 DC, only *Morus* was tolerant, but at 1500 μg/m^3 DC, this species and *Melia* were categorized as intermediate, and *Celtis caucasica* and *Fraxinus rotundifolia* as sensitive. *Morus* was assessed as a good performer under two higher DC. *Celtis* was recognized as a moderate under 750 μg/m^3 DC and poor performer under 1500 μg/m^3 DC. Thus, *Celtis* can be considered as a biomonitor for air quality or as sink for dust in high dusty areas because of its high capacity of dust deposition. At two higher DCs, *Fraxinus* and *Melia* showed very poor and poor performance; planting these species in high dust areas is not recommended. In contrast, *Morus* is the most suitable tree species for urban green spaces in dusty regions, due to its high dust collection capacity and high APTI and API values.

Keywords API · APTI · Dust concentration · Dust-tolerant species · Green belt · Urban forests

Introduction

Atmospheric dust consists of a complex mixture of fine solid matters suspended in air (Grantz et al. 2003). It is taken into consideration as one of the main widespread air pollutants, especially in arid zones (Drack and Vázquez 2018). The emissions of dust particles into the atmosphere have been estimated nearly 2000 million tons per year (Shao et al. 2011). Dust pollution is primarily a result of climate change, natural disasters, unplanned development, and unregulated man's activities (Naidoo and Chirkoot 2004). The occurrence of dust pollution has far-reaching implications on many aspects of human life, for example health and well-being, ambient air quality, soil fertility, and socio-economic activities.

Plants as initial receptors of pollutants are effective in air cleaning (Kaur and Nagpal 2017; Nowak et al. 2018). They have a great potential to absorption, adsorption and accumulation of pollutants on their leaf surface (Kaur and Nagpal 2017). For this, the development of green cover and creating a greenbelt is an ecologically and economical solution to improve air quality (Pandey et al. 2015; Singh et al. 2020). A suitable green belt consists of a collection of pollutant-resistant trees for mitigating the air pollution (Prajapati and Tripathi 2008). Thus, choice of appropriate tolerant plant species is of major importance when developing green spaces (Kwak et al. 2020).

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Extensive works have been done on different choice indices for tree species which are employed in urban green spaces (Ng et al. 2015; Kashyap et al. 2018). In view of global problems related to dust pollution, assessing the dust accumulation potential of tree species is a main necessity (Liu et al. 2012). The air pollution tolerance index (APTI) is being applied broadly to estimate the tolerance of vegetation against air pollutants and to select species for urban greening and diminution of pollutants (Rai and Panda 2014; Molnár et al. 2020). The adaptation of growth, gas exchanges, and biochemical characteristics of tolerant plant species can encounter pollution stress efficiently for their survival (Banerjee et al. 2018).

APTI assesses the resistance of plants against air pollution (e.g., Pandey et al. 2015; Kaur and Nagpal 2017). Sensitive plants serve as air pollution bio-indicator, while tolerant ones are known acting as sinks and can be employed to air pollution mitigation (Roy et al. 2020). Since the APTI assesses the impact of pollutants only according to biochemical parameters (total chlorophyll, ascorbic acid, leaf extract pH, and relative water content), selection of tree species based only on APTI may not reflect the correct idea (Govindaraju et al. 2012), and to this reason, many studies have used the anticipated performance index (API) in addition to the APTI (Rai and Panda 2014; Noor et al. 2015; Pandey et al. 2015; Kashyap et al. 2018; Patel and Kumar 2018; Leghari et al. 2019). In contrast to APTI, API uses biological and socio-economic aspects of tree species considered for being planted in polluted areas. Therefore, this index can be more reliable for creating the green spaces in air-polluted areas (Bora and Joshi 2014; Karmakar and Padhy 2019).

In the last two decades, more than half of Iran's provinces have been exposed to dust phenomenon, due to climate change and human interference, as well as proximity to the deserts of Saudi Arabia, Iraq, and Syria (Rashki et al. 2014). Given that according to World Health Organization (2006), air dust concentration (DC) of higher than 425 has been reported as "critical condition"; Ahvaz and Zabol, two southern cities of Iran, showed a daily maximum DC of 5337 and 3094 μg/m^3, respectively (Shahsavani et al. 2012; Rashki et al. 2012).

Unfortunately, the area of green spaces in Iran is very small so that plantation development with trees and shrubs is necessary. Thus, choice of plants species suitable to develop urban and rural green spaces is urgently needed. Because of little knowledge on response of tree species to dust pollution, some tree species common in Iran (especially in the central regions with arid to semi-arid climate) were considered in the current investigation. The chief target of the current investigation was to derive propositions of proper plant species for urban greening in dust-affected areas. More specifically, we tested which of the four species performed best under different dust levels and ranked them by using API assessment.

Material and methods

Plant materials

Two-year-old uniform deciduous tree seedlings of *Melia azedarach*, *Morus alba*, *Celtis caucasica*, and *Fraxinus rotundifolia* (64 seedling of each species) were prepared from research greenhouse of Karaj Nursery, close to Tehran, Iran (35° 44′ N, 51° 10′ E and 1312 m a.s.l.). The climate of the area is semi-arid, with average relative humidity of 34% and average annual rainfall of 251 mm. The seedlings were exposed to the following conditions: temperature of 26.2 ± 2.1 °C, photoperiod of 14 h, relative humidity of 54.3 ± 5.2% and photosynthetic active radiation (PAR) of 1000 μmol/m^2/s. They were transplanted into 5-L plastic pots, watered every second day to 90% field capacity, and examined as randomized complete block design replicated four times. The levels of DC were 0, 300, 750, and 1500 μg/m^3. Four levels of DC and four tree species resulted in 16 different treatments.

Application of dust

For producing dust, like Manoochehri et al. (2016), soil samples smaller than 106 μm were taken from an upper layer of soil (with characteristics displayed in Table 1) at the south and south-east of Ahvaz city, where it was exposed to wind erosion.

Based on a previous work (Hatami et al. 2018), DC of 0, 300, 750, and 1500 μg/m^3 were selected for experiment. For dust simulation, three chambers were constructed using transparent plastic sheets, based on an earlier research (Siqueira-Silva et al. 2017). Dusting was done using a dust simulator in three chambers at intervals of 1 week for 70 days. Dust was not applied in the fourth chamber. In reality, 64 seedlings (16 seedlings from each tree species) were located in a similar chamber. During dust application, all seedlings were watered every 2 days at 90% field capacity.

The particle counter (176,000 A Microdust Pro Dust Monitor) was utilized to find out the dust concentration (DC) and distribution of particle sizes in the air inside the chambers (Hatami et al. 2018).

Dust collection potential

After 70 days of the dusting, in each treatment (dust concentration-tree species), five mature and healthy leaves from a representative seedling (Prusty et al. 2005) were weighted (W_1) and then reweighed (W_2) after removing the dust from the leaves by a fine brush. The leaf area (A) measurement performed by a leaf area meter (Delta-T Devices, England) and the capacity of accumulated dust was determined using the below equation (Prusty et al. 2005):

Table 1 Some analytical characteristics of soil used for dust simulation (0 to 10 cm layer)

Texture	Clay-loam	MnO (%)	5.11	SiO_2 (%)	30.42
Electrical conductance (ds/m)	7.29	NiO (%)	0.01	Na_2O (%)	2.25
pH	6.65	Fe_2O_3 (%)	4.21	P_2O_2 (%)	0.12
Organic matter (%)	0.68	K_2O (%)	0.35	MgO (%)	15.01
K (ppm)	292	Cr_2O_3 (%)	0.03	CaO (%)	24.15
TiO_2 (%)	0.41	P_2O_5 (%)	0.12	P (ppm)	13
ZrO_2 (%)	0.02	N (%)	0.04	Al_2O_3 (%)	6.2

$$\text{Dust collection potential (mg/cm}^2) = \frac{W_1 - W_2}{A.}$$

Air pollution tolerance index

To APTI assessment, four biochemical traits, i.e., ascorbic acid, total chlorophyll, leaf extract pH, and relative water content (Lohe et al. 2015), were measured. Ascorbic acid and total chlorophyll were determined spectrophotometrically. To calculate leaf extract pH using protocol of Pandey et al. (2016), 0.5-g fresh leaf was homogenized in 50-mL deionized water and centrifuged at 7000*g* for 10 min. The pH of supernatant was measured using a digital pH meter (Systronics; model μ pH system 361). Relative water content was measured using the following variables: the fresh weight of leaves (FW), the turgid weight (TW) which was measured after the leaves were immersed in a water-filled Petri plate overnight (24 h), and lastly the dry weight of the leaves (DW) after letting them dry in an oven at 70 °C for 48 h. Relative water content was calculated as the following equation:

$$\text{Relative water content} \ \ (\%) = \frac{(\text{FW}-\text{DW})}{(\text{TW}-\text{DW})} \times 100$$

After measuring the ascorbic acid, total chlorophyll, leaf extract pH, and relative water content, APTI was calculated according to below equation (Ogunkunle et al. 2015).

$\text{APTI} = [\text{A} \ (\text{T} + \text{P})] \frac{+\text{R}]}{10}$ where A is the ascorbic acid (mg/g FW), T is total chlorophyll (mg/g FW), P is leaf extract pH, and R is relative water content (%).

After the calculation of APTI values, the bio-indicator response of each tree species was classified as sensitive, intermediate, and tolerant with ATPI values of ≤ 11, 12–16, and ≥ 17, respectively (Ogunkunle et al. 2015).

Anticipated performance index

The API values were computed via APTI grades and different biological and socio-economic attributes such as plant type, crown shape and density, plant habitat, structure of laminar, and economic values referred (Table 2). According to these properties, different grades (+ or −) were given to different plant species (Prajapati and Tripathi 2008). These were scored with respect to their grades; beside that, the plant species classification was provided according to API score, considered by the following equation (Pandey et al. 2015; Kaur and Nagpal 2017). In reality, API of zero is equal to score (S) ≤ 30 and evaluation class (EC) of "With not suggestion for plantation," API of 1 is equal to S = 31–40 and EC of "very poor," API of 2 is equal to S = 41–50 and EC of "Poor," API of 3 is equal to S = 51–60 and EC of "moderate," API of 4 is equal to S = 61–70 and EC of "good," API of 5 is equal to S = 71–80 and EC of "very good," API of 6 is equal S = 81–90 and EC of "excellent," and API of 7 is equal to S = 91–100 and EC of "best." The scoring percentage for API grade calculation is given as:

$$\text{API} \ (\%) = \frac{\text{Number of } \ \}+\}\text{obtained by any tree species}}{\text{Maximum possible number of}\}+\}\text{any tree species}} \times 100$$

Statistical analysis

SPSS software (ver. 23.0) was used for statistical analysis of data. The influence of dust concentration (DC) and tree species on dust collection potential, ascorbic acid, total chlorophyll, leaf extract pH, and relative water content was assessed using a general linear model (GLM) procedure. The means (± SE) were statistically compared using Duncan's multiple range test ($p = 0.05$).

Results

Dust collection potential of all tree species elevated with rising DC. The trend of dust collection potential among species at DCs of 750 and 1500 μg/m^3 was *Morus* > *Celtis* > *Fraxinus*> *Melia*. Dust collection potential of plant leaves ranged from 0.94 to 2.18 mg/cm^2 at 750 μg/m^3 DC and from 1.23 to 2.88 mg/cm^2 at 1500 μg/m^3 DC. *Morus* exhibited highest dust accumulation ability (2.88 mg/cm^2), whereas *Melia* showed the lowest dust accumulation capacity (1.23 mg/cm^2) (Table 3).

APTI value at 750 and 1500 μg/m^3 DCs was greater compared with low DCs (control and 300 μg/m^3). The value of APTI among species varied from 19.80 to 9.05, with a maximum value of APTI in *Morus* (19.80). At a concentrations of

Table 2 Gradation of tree species regarding to air pollution tolerance index (APTI), biological traits, and socio-economic uses for determination of the anticipated performance index (API)

Grading property		Evaluation class	Grade allotment*
Tolerance	APTI	2.0 to 6.0	+
		6.1 to 10.0	++
		10.1 to 14.0	+++
		14.1 to 18.0	++++
		18.1 to 22.0	+++++
Socio-economic and biological	Plant habit	Small	–
		Medium	+
		Large	++
	Crown structure	Sparse/irregular/globular	–
		Spreading crown/open/semi-dense	+
		Spreading dense	++
	Plant type	Deciduous	–
		Evergreen	+
Structure of laminar	Size	Small	–
		Medium	+
		Large	++
	Texture	Smooth	–
		Coriaceous	+
	Hardiness	Soft	–
		Hard	+
	Economic importance	Uses < 3	–
		3 or 4 uses	+
		Uses ≥ 5	++

* Maximum grades scored by any plant species can be = 16

Sources: Prajapati and Tripathi (2008) and Kashyap et al. (2018)

0 and of 300 μg/m^3, APTI value of tree species was as the following order: *Morus* > *Celtis* > *Melia* > *Fraxinus*. At 750 μg/m^3 DC, the trend was different (*Morus* > *Melia* > *Fraxinus* and *Celtis*) but it did not differ at 1500 μg/m^3 DC (Table 4).

Table 3 Comparison of dust collection potential of tree species at different levels of dust concentration (DC)*

Plant name	DC (μg/m^3)		
	300	750	1500
Morus alba	0.42 ± 0.03^f	2.18 ± 0.12^b	2.88 ± 0.18^a
Melia azedarach	0.35 ± 0.02^f	0.94 ± 0.04^e	1.23 ± 0.05^d
Fraxinus rotundifolia	0.34 ± 0.02^f	1.11 ± 0.04^{de}	1.61 ± 0.08^c
Celtis caucasica	0.39 ± 0.02^f	1.59 ± 0.10^c	2.41 ± 0.16^b

Different letters indicate significant differences under the interaction of dust concentration (DC) × tree species, using Duncan test ($p \leq 0.05$). Values are mean ± SE, and $n = 4$ seedlings per treatment (dust concentration × tree species)

* There was no need for analysis of zero level of DC (control)

Table 4 Comparison of air pollution tolerance index (APTI) and bio-indicator responses of tree species studied at different DCs

Plant name	Parameter	DC (μg/m^3)			
		0	300	750	1500
Morus alba	APTI score	19.80	19.75	17.25	12.70
	Plant response	T	T	T	I
Celtis caucasica	APTI score	19.20	19.20	12.50	9.05
	Plant response	T	T	I	S
Fraxinus rotundifolia	APTI score	18.55	18.30	13.35	10.45
	Plant response	T	T	I	S
Melia azedarach	APTI score	18.60	18.45	15.70	12.20
	Plant response	T	T	I	I

T tolerant (APTI score ≥ 17), *I* intermediate (APTI score = 12–16), *S* sensitive (ATPI score ≤ 11)

All investigated plants at 0 and 300 μg/m^3 DCs have been ranked as tolerant, while in level of 750 μg/m^3 DC, only *Morus* classified as tolerant to dust. The other three species would be classified as intermediately tolerant. At the highest level of dust pollution, *Morus* and *Melia* would be categorized as intermediately tolerant, whereas *Celtis* and *Fraxinus* would fall into the class of sensitive species (Table 4).

Grading of plants species related to the APTI score and socio-economic and biological aspects treated at different DC (to determine API) has been shown in Table 5. Under 0 and 300 μg/m^3 DCs, *Morus* (75.00%), *Melia* (56.25%), and *Fraxinus* (43.75%) performed very good, moderate, and poor, respectively. Under two high DC status, *Morus*, *Melia*, and *Fraxinus* were evaluated as good, poor, and very poor performer, respectively. Along the increasing DC from control to highest level, performance of *Celtis* dropped from good (68.75%) to poor (50.00%) (Table 6).

Discussion

In the present study, in all plant species the dust accumulation potential increased with DC. At 750 and 1500 μg/m^3 DCs, the dust accumulation rank order was *Morus* > *Celtis* > *Fraxinus* > *Melia*. The high dust-retention capacity of *Morus* may be owing to the uneven, large surface, and ovate shape with depressions in the middle part of the leaf. The tiny hairs on the dorsal side of the leaf as well as the big, rough, and rugged leaf area may be the reason for high dust collection potential in *Celtis*. In general, thick leaves with rough and hairy surfaces accumulate the highest amount of dust (Prusty et al. 2005). Smooth surface and small leaves in case of *Fraxinus* and *Melia* as well as thin lamina in case of the latter are probably the causes for the weak dust-retention capacity of these two species.

Plants with bigger APTI score have higher tolerance against pollutants and act as a dust sink, but those with small APTI represent the sensitive nature and are utilized as bio-indicator of air pollution (Roy et al. 2020). For all tested species, increasing dust concentration caused a drop in APTI score. At higher DCs, APTI values are highest for *Morus*, followed by *Melia*, *Fraxinus*, and finally *Celtis*. APTI is according to leaf pH, AsA, TChl, and RWC variables; hence, variation in APTI value among plants is related to these variables. Higher accumulation of dust particles on leaves affects the above-listed variables (Achakzai et al. 2017).

According to biomonitor response category of plant species (Ogunkunle et al. 2015) (see the "Material and methods" section of APTI), in our experiment, at 750 μg/m^3 DC, *Morus* was tolerant (APTI score, 17.25). At highest level of dust, *Morus* and *Melia* were categorized as intermediate (APTI scores, 12.70 and 12.11, respectively), but *Fraxinus* and *Celtis* were rated as sensitive (APTI scores, 10.45 and 9.05 for *Fraxinus* and *Celtis*, respectively). In reports of Esfahani et al. (2013) and Leghari et al. (2019), the high tolerance level of *Morus* towards air pollution is well-documented. In contrast, Bhardwaj and Singh (2015) classified *Morus* as an intermediate, and *Melia* as a tolerant plant species under air pollution. Based on our results, *Morus* is a species to be considered for plantations at dust-polluted sites, whereas *Celtis* and *Fraxinus* seem to be proper for monitoring dust-polluted air.

Urban forests have much prominent influence in decline of atmospheric pollution (Vailshery et al. 2013). APTI is utilized to select trees resistant to air pollution for urban green spaces and green belt development (Singh et al. 1991; Alotaibi et al. 2020). However, the assessment through API is a proper method to choose tree species for developing urban forests in polluted regions (Bora and Joshi 2014). Generally, the plants species belonging to the API categories consisting "moderate, good, very good and excellent" are advised for planting in parks as well as in rural and urban green spaces (Govindaraju et al. 2012; Karmakar and Padhy 2019). Moderately performing plants may be also suggested for green belt and urban forest, due to their esthetic, economical, and medicinal values (Pathak et al. 2011; Kayani et al. 2014).

Table 5 Assessment of the tree species studied regarding to air pollution tolerance index (APTI) score and biological and socio-economic characteristics to estimate the anticipated performance index (API) at different DCs*

Plant name	Obtained APTI grades				Plant habit	Crown structure	Tree type	Laminar structure			Economic importance
	DC (μg/m^3)							Size	Texture	Hardiness	
	0	300	750	1500							
Morus alba	+++++	+++++	++++	+++	+	++	–	++	–	–	++
Melia azedarach	+++++	+++++	++++	+++	+	+	–	–	–	–	++
Fraxinus rotundifolia	+++++	+++++	+++	+++	+	+	–	–	–	–	–
Celtis caucasica	+++++	+++++	+++	++	–		+	+	+	+	++

* Socio-economic importance of tree species was provided from available literature and experts

Table 6 Anticipated performance index (API) and evaluation class of tree species studied at different DC levels

Plant name	DC (μg/m³)	Grade allotment		API	Evaluation class
		Total plus	% Score		
Morus alba	0	12	75.00	5	Very good
	300	12	75.00	5	Very good
	750	11	68.75	4	Good
	1500	10	62.50	4	Good
Melia azedarach	0	9	56.25	3	Moderate
	300	9	56.25	3	Moderate
	750	8	50.00	2	Poor
	1500	7	50.00	2	Poor
Fraxinus rotundifolia	0	7	43.75	2	Poor
	300	7	43.75	2	Poor
	750	5	31.25	1	Very poor
	1500	5	31.25	1	Very poor
Celtis caucasica	0	11	68.75	4	Good
	300	11	68.75	4	Good
	750	9	56.25	3	Moderate
	1500	8	50.00	2	Poor

Other properties of plants such as dust-capturing efficiency are important criteria for selecting suitable plant species in urban environments (Pandey et al. 2015).

In our investigation, *Morus* proved to be a good or very good performer at all dust levels (API grade = 5 at two low DCs, and API grade = 4 at two high DCs). In reality, *Morus* species having large leaves and a dense crown structure minimizes the dissemination of dust particles. In addition, it has a high socio-economic value (Gupta et al. 2016; Saikim et al. 2017). Therefore, *Morus* can be introduced as a favorable tree to develop urban green spaces of dust-polluted regions (even in severely polluted areas). Similarly, Gupta et al. (2016) and Leghari et al. (2019) classified *Morus* as a very good and excellent performer, respectively, in such conditions and recommended its use for green spaces development.

Generally, the performance of a tree species differs regarding to amount of pollutants deposition. For example, *Celtis* was recognized as good performer (API grade = 4) under 0 and 300 μg/m³ DC, while as moderate performer (API grade = 3) at 750 μg/m³ DC only. Thus, in areas with 750 μg/m³ DC, *Celtis* and *Morus* are preferred for planting. At highest level of dust stress, *Celtis* reached a low APTI value only (APTI = 9.5) and showed poor performance (API grade = 2); hence, it is not suitable for green belt improvement. However, it has high dust collection efficiency so it may be proposed as a sink when planted in programs with aims of trapping dust particles.

Kashyap et al. (2018) found that the performance of *Melia* changed from moderate to poor when increased the dust pollution. Similarly, in our investigation at high DC, *Melia* and *Fraxinus* showed poor performance and very poor performance, respectively; therefore, these two species should not be considered for planting in areas with dusty air pollution. Likewise, since the both species show low dust collection ability, they cannot be recommended as a dust accumulating species in polluted environments.

Conclusion

From the results of the investigation, it can be concluded that the order of dust collection potential among the four tested tree species at 750 and 1500 μg/m³ DC was *Morus alba* > *Celtis caucasica* > *Fraxinus rotundifolia* > *Melia azedarach*. With increasing DC, the APTI of all species declined. At 750 μg/m³ DC, only *Morus* was tolerant (APTI score, 17.25), at 1500 μg/m³ DC, *Morus* and *Melia* were categorized as intermediate (APTI values, 12.70 and 12.19, respectively), and *Celtis* and *Fraxinus* as sensitive (APTI values, 10.45 and 9.05, respectively).

Morus was assessed as a good performer (API grade = 4) under 750 and 1500 μg/m³ DCs. *Celtis* was recognized as a moderate performer (API grade = 3) under 750 μg/m³ DC and as a poor performer (API grade = 2) at 1500 μg/m³ DC. *Celtis* can also be considered for monitoring dusty air quality, or as sink of dust particles in high dusty air regions, due to the high dust accumulation. At 750 and 1500 μg/m³, *Fraxinus* and *Melia* showed very poor and poor performance (API grade ≤ 2); therefore, where the DC is high (≥ 750 μg/m³), plantation development of this two species is not recommended. *Morus* is a most suitable species for development of green belts in dusty regions, due to highest dust collection potential and high APTI and API.

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Author contributions Zeinab Javanmard and Masoud Tabari Kouchaksaraei planned the methodology of the research and performed the tests and statistical analysis. All authors contributed to writing and reading the initial draft. Ashutosh Kumar Pandey contributed to reviewing and editing the final manuscript.

Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

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