

Impact of Dust Deposition on Photosynthesis, Gas Exchange, and Yield of Date Palm (*Phoenix dactylifera* L.) cv. 'Sayer'

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ABSTRACT

This experiment was conducted to determine the effects of dust, rain, and pollination on photosynthesis activity and crop yield of commercial date palm (*Phoenix dactylifera* L.) cultivar 'Sayer'. Mature trees were used for dust treatments application and assessments under Ahvaz, Iran, during the 2016-2017 growing seasons. The dust blew on the trees canopy using a blower and the leaf gas exchange was evaluated using an infrared gas analyzer on the intact leaves. After treatments, photosynthesis rate, transpiration rate, and stomatal conductance were measured. The leaf gas exchange results showed significant differences between the applied combined treatments on photosynthesis rate (from 9.18 to 0.64 $\mu\text{mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$), stomatal conductance (from 39.9 to 6.67 $\text{mmol m}^{-2}\text{s}^{-1}$), and transpiration rate (from 2.78 to 1.49 $\text{mmol H}_2\text{O m}^{-2}\text{s}^{-1}$). Deposition manner of dust particles, the number of stomata in the abaxial and adaxial surfaces of leaflets, and the minimum dust-carrying capacity (MDCC) were determined using scanning electron microscopy (SEM). Stomata study using SEM showed that date palm leaflet surfaces are almost wavy and the stomata are situated in the concave surfaces in a linear arrangement on both abaxial and adaxial leaf surfaces. Although, there were no significant differences in stomatal density at the abaxial (299 mm^{-2}) and adaxial (300 mm^{-2}) leaf surfaces, the leaflet position within the leaf showed a significant influence on MDCC. The base positioned leaflets in the leaf showed the highest (2.5 mg cm^{-2}) and the upper positioned top leaflets showed the lowest MDCC (1.7 mg cm^{-2}), respectively. Also, SEM showed a sign of covering or entering dust particles into the stomata with possible stomata clog and blockage lead to the significant reduction of photosynthesis and crop yield. Besides, pollinated trees showed the maximum crop yield (59.17 Kg tree^{-1}), so the minimum yield was recorded on un-pollinated palm trees (1.90 Kg tree^{-1}).

Keywords: Minimum dust-carrying capacity, Stomata blockage, Stomatal conductance, leaf abaxial and adaxial surface, Scanning electron microscopy.

INTRODUCTION

Date palm (*Phoenix dactylifera* L.) is an important crop and majestic plant that plays a great role in people rural life, as much as they call it "tree of life" and it can develop very well in the harsh environmental conditions that other plants even cannot survive (Jain, Al-Kheyri and Johnson, 2011; Hodel and Johnson, 2007).

During recent years, one of the most important hazardous conditions that have

had negative impacts on date production in Iran is air pollution with dust storm. The negative impact of dust on plants depends on the physical and chemical properties of dust; therefore, based on the absolute level of deposition, dust may physically cover the leaves (Farmer, 1993). Akhzari and Haghghi (2015) mentioned that vegetation area has great effect on occurrence of dust storms over several western cities of Iran. They concluded that dust storms are more frequent during spring and summer when

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vegetation percentage value shows reductions in the source of dust. Vegetation reduces wind speed at the soil surface and prevents much of the wind force from contacting soil particles, thus causing wind erosion reduction.

Ahmed, *et al.* (2015) reported more stomata closure in *Pyrus malus* than *Prunus domestica* under dust storm. They found that dust reduces fruit production in apple trees grown at the edges of an orchard that was 15 kg. Dust deposition on plants' leaves can negatively affect photosynthesis and plant growth (Sharifi *et al.*, 1997). Some physiological responses of plant leaf-like photosynthesis are very sensitive to environmental changes such as air pollution (Cloutis, 1996; Bhattarai and Midmore, 2009, Sun *et al.*, 2012). Mamat, *et al.* (2014) reported that dust stress led to decreases in net photosynthetic rate (Pn) and stomatal conductance (gs). They concluded that Pn and gs decreased more under severe dust treatment than mild dust treatment. Xue and Bake (2019) investigated that the Net photosynthetic rate, transpiration rate, and stomatal conductance, and water use efficiency decreased with longer dust and shading exposure time. They mentioned that the stomatal factors in the early stage of sand exposure and shading combined treatment are the main limiting factors for the photosynthesis of prune. In date palm, leaves last for about 5 years leading to more dust accumulation on leaflets. Cornish *et al.* (1991) reported that when leaves are covered with dust, they will receive less light for photosynthesis, this can interfere with the gas exchange between the leaf and air. The reduction of leaf stomatal conductance influences final plant yield. Also, Shukla *et al.* (1990) reported that cement dust can reduce photosynthesis, due to reduced leaf area, stomata blocking and an interception in the radiation due to cement coating on the leaf surface. Thompson *et al.* (1984) stated that photosynthesis was reduced enormously when the leaves' surfaces were covered with dust. Besides, Farmer (1993) showed that

fine particles in dust can affect the plant gas exchange. Air pollution was thought to penetrate the leaf tissue through the stomata (Watanabe, 2015).

Indirect evidence suggests that mesophilic cells are severely damaged by acid spray near the intercellular spaces located below the stomatal in pine needles (Zobel and Nighswander, 1991). Some laboratory investigations verified that dust particles suspended in water could intrude the leaf tissue through the stomata due to the formation of persistent water films from stomatal walls to leaf surfaces (Burkhardt *et al.*, 2012; Eichert *et al.*, 2008). An important factor that could affect aerosol deposition on leaf surfaces is the stomata position and its form in the epidermis (Eichert *et al.*, 2008; Evert, 2006). Most dicots have more stomata on the abaxial side of the leaf, but monocots have the almost same number of stomata on both adaxial and abaxial leaf surfaces (Watanabe, 2015). It was reported that stomatal diameter range between 8 up to 12 μm (Krajickova and Mejstrik, 1984) while dust particles size is smaller and varies between 20 to 50 μm (Zarasvandi, 2009). It should be stated that some environmental conditions such as temperature and water stress affect the number and size of stomata, as reported by Arzani *et al.*, (2013) on pistachio rootstocks.

The response to dust of many plant species including citrus (Delgado Saborit, 2009), apple (Cook, 1981; Ahmed *et al.*, 2015), pear (Ahmed *et al.*, 2015), mango (Rai, 2014), lime (Delgado Saborit, 2009; Parish, 1910), populus (Fluckinger *et al.*, 1979), and guava (Sulistijorini *et al.*, 2008; Rai, 2014) have been studied. Farmer (1993) noted that dust can physically injure the trees' leaves and bark, reduce fruit setting, and cause a general reduction in growth. Faisal (2010) studied the effects of roads dust on some quantitative and qualitative traits of date palm. It was concluded that dust decreases chlorophyll content of the palm leaves closest to the road compared with the farthest ones. Zia-Khan *et al.* (2015) reported 28% reduction in yield and

30% reduction in stomatal conductance of the dust treated plants compared with the control, due to stomata blockage by the dust.

In the present research, our hypothesis was that the increase in dust storms frequency in the region and the increase in dust intensity effects on commercial date palms have led to the negative impact on date palm photosynthesis and yield. The negative impact of air polluted dust on flowering and fruit set of date palm has been reported previously by Torahi and Arzani (2017) and Torahi *et al.* (2017). The aim of the present research was to examine the effects of dust deposition on date palm leaves and their response to leaf photosynthesis (A), gas exchange, and yield of commercial date palm cultivar 'Sayer', which is growing under the harsh dust air polluted areas of Iran in the Mediterranean region.

MATERIALS AND METHODS

Plant Material and Growth Conditions

The experiments were carried out during

2016 and 2017 growing seasons at the date palm research orchard of the Date Palm and Tropical Fruits Research Center of Iran (31° 12' N, 48° 33' E), in Ahwaz, Khuzestan Province, Iran (Figure 1). This is a subtropical region where temperature in summer exceeds 52°C and in winter it falls to -2°C. Air humidity in this region ranges from 25 to 90% in hot dry summer, humid summer, and rainy winter days.

Soil sample analysis of the experimental site was performed from 0-30, 30-60, 60-90, 90-120, and 120-150 cm of soil depth before starting the experiments. The soil texture was sandy loam with an average of 12.2, 63.4, and 24.4% clay, sand, and silt, respectively. The average pH of the soil in all depths was 7.24 with 2.93 dSm⁻¹ EC and 0.03, 4.42, and 19.75% nitrogen (N), Gypsum, and CaCO₃, respectively. The amount of potassium (K) in the orchard soil was 280 ppm.

Two field experiments were carried out. The first experiment, to study the effects of dust and rain in a short period of exposure time (Figure 1 A, B, and C) and other related treatments on the photosynthesis rate and



Figure 1. The map of Iran, showing study area and the experimental site in Ahwaz, where trees grown under air dust polluted conditions and intermittently trees affected by dust during growing season. The experimental orchard: (A) Before dust storm; (B) The onset of the storm; (C) The condition of dust storm at the orchard (Spring 2016).



gas exchange. Five treatments with four replications including cleaned leaf (control); rain; dust; dust*rain; and rain*dust were applied in the first experiment using a total of 20 trees.

The second experiment was conducted to study the effects of different combined treatments of dust, rain, and pollination on the final crop yield of mature date palm trees (*Phoenix dactylifera* L.) cultivar 'Sayer'. In the second experiment 12 treatments (T) including pollinated trees (control), pollinated + rain, rain + pollinated, pollinated + dust + rain, dust + pollinated + rain, rain + pollinated + dust, dust + rain + pollinated, pollinated + dust, dust + pollinated, pollinated + rain + dust, rain + dust + pollinated, and unpollinated were applied with 3 replications (R) using 36 mature eight-years-old date palm trees. A total of 56 trees were selected for the experiments. The trees were similar in size, with a planting density of 8×8 m.

The first and second experiments were arranged as a randomized complete block design (RCBD). Some physiological characters were determined on the new fully expanded leaves at four different geographical directions of the tree canopy according to the method described by Al-Khateeb *et al.*, (2002). According to this description, the upper canopy leaves were in the expansion stage (1 to 3 months old); the lower and middle canopy were recent fully

expanded leaves (3 to 6 months old), and the lower canopy leaves were fully expanded (6 to 9 months old leaves). Also, the oldest to youngest leaflets in the fully expanded leaves were considered from lower to the upper parts of the leaflets, respectively. Within each of the selected leaves, three leaflet edges were chosen for measurements as follows: a) the young leaflets (the most upper leaflets at the top of the leaf), b) The middle leaflets, and c) The oldest leaflets, the first leaflets from the base of the leaf. All experimental trees were labeled and the pointed leaves were tagged for all subsequent measurements.

Dust Collection and Treatments Application

Dust was collected after dust storms from the pavement floor on February, 8, winter, 2016 (Table 1), and was later sieved through a series of soil sieves to get a uniform particle size. The sample was analyzed by the Central Laboratory of Geology Department of Shahid Chamran University of Ahwaz. Under windless and sunny conditions, we ran a simulation process of dust deposition using a blower and rain by handy sprayer on leaflets (Moisture was added in an attempt to reproduce the "crusts" described by Czaja, 1962).

Table 1. The chemical composition of the dust sample collected from the date palm research orchard of the Date Palm and Tropical Fruits Research Center in Ahwaz, Khuzestan Province, (31° 12' N, 48° 33' E), Iran.

Element	Concentration (ppm)	Element	Concentration (ppm)
Hg	< 0.04	S	17869
Mo	1.82	Sn	1.7
Ag	< 0.1	Zn	150
As	5.78	Bi	< 0.5
B	30.12	Cd	0.95
Ba	209	Ce	23.55
Be	0.58	Co	27.05
Ni	160	Cr	90.90
P	877	Cs	5.72
Pb	18.64	Cu	1595
Sample: EC= 152 dS m ⁻¹ , pH= 8.8			

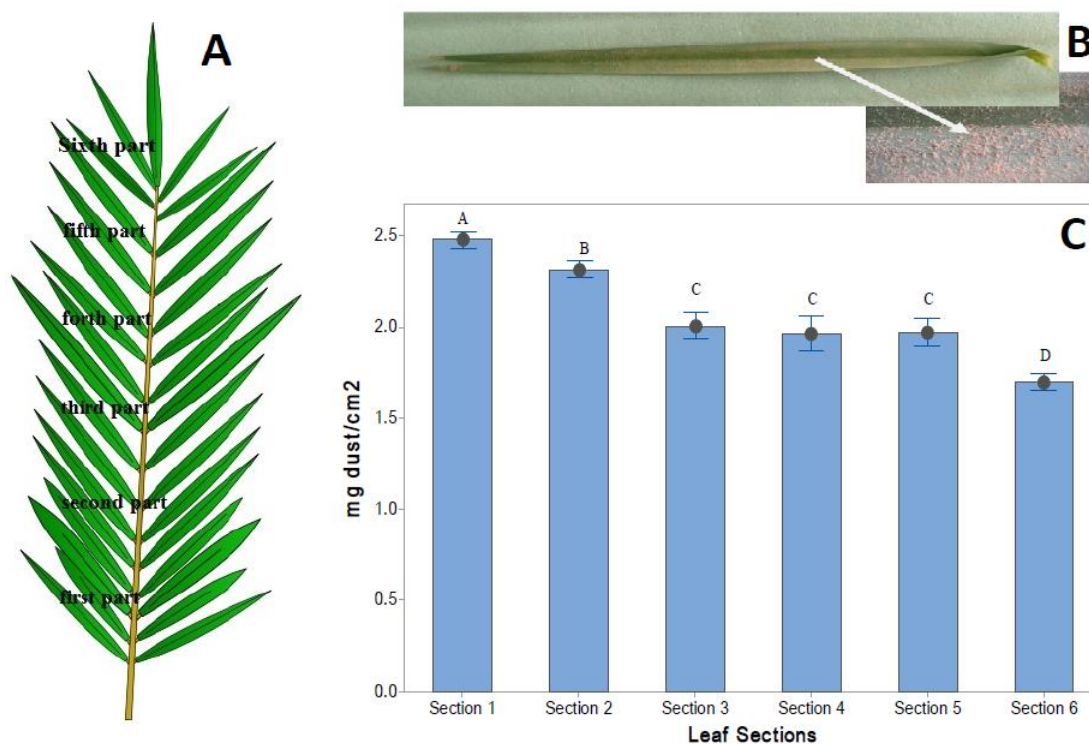


Figure 2. (A) Leaves six longitudinal sections; (B) Dust deposition on the date palm cv. 'Sayer' after dust storm in the orchard at the Date Palm and Tropical Fruits Research Center of Iran, in Ahvaz, Khuzestan Province, Iran (Spring 2016), and (C) Minimum Dust Carrying Capacity (MDCC) in different leaflets of date palm cv. 'Sayer'. Arrows on B, show the magnified surface of a small part of the affected leaflet by dust. Different letters on the bars in graph C indicate significant differences at $P < 0.05$. Also, \pm standard error of the MDCC means.

Minimum Dust-Carrying Capacity (MDCC)

We deposited enough dust on the leaflets to achieve the minimum dust-carrying capacity. Then, the leaflets were hanged down to remove extra dust particles (Figure 2).

Chen (2001) defined the minimum dust-carrying capacity (MDCC) of the leaf as the weight of dust which unit leaf area can stand when the leaf hangs down. It can be calculated by the following equation:

$$\text{Minimum dust-carrying capacity} = (\text{leaf weight with dust} - \text{leaf weight without dust}) / \text{leaf area}$$

For determining the MDCC twelve 8-year-old date palm trees cv. 'Sayer' was selected and 4 leaves of each tree at the four

different geographical directions were labeled for further measurement. For leaf area measurement the leaflets samples were scanned by a leaf area meter Delta-T Scan (Delta-T Devices, England). Then, each leaf was categorized non-destructively into 6 longitudinal sections, and from each section, 2 leaflets were selected for dust application and measurement (Figure 2 A, B, and C). The amount of dust used in this research was determined based on the method described previously by Zarasvandi (2009) and Thompson *et al.*, (1984), as 8 g m^{-2} of tree canopy areas. For this, the canopy surface area for all experimental trees was determined and the average was calculated. Considering the age of the trees and the approximate size of their canopy area, the average calculated canopy for each tree was about 2.25 m^2 . The amount of dust used was about 18 g tree^{-1} . Dusting was done on



tagged leaflets by an electrical blower until the determined dust for every tree finished and then the leaflets hanged down (Xiong-Wen, 2001). These leaflets were cut down and their weights were precisely measured (using Digital Balance, GF-400, AND Co., Japan.). Next, these leaflets were carefully cleaned using a clean sponge, and then their weight was measured.

Physiological Measurements

The leaf gas exchange was evaluated according to Karim et al. (2003) and Knoepf and Vose (2002) by using an infra-red gas analyzer (LCA-4, ADC Herts, UK) equipped with a broad leaf chamber (aperture area of 6.25 cm²) on intact leaves. All combined treatments were carried out on sunny days in late April 2017 from 9 to 11 am. The temperature during measurements at one meter above the soil under the canopy areas of the experimental trees was between 25 to 30 °C and the intensity of photosynthetic photon flux density (PPFD) was between 1050 to 1150 $\mu\text{mol m}^{-2}\text{s}^{-1}$ (measured by MSC15 Handheld Spectral Lightmeter, Gigahertz-Optik Inc., Germany). Control leaves were cleaned slowly using a soft sponge and distilled water.

Experiment Process

For rain treatment, leaflets were washed by a sprayer using distilled water. In dust treatment, leaflets were dusted using electrical blowers. In the dust*rain treatment, the leaflets were sprayed with water after dusting. In the rain*dust treatment, leaflets were dusted after watering. In dust included treatments, dust was sprayed on the surface of the leaflets of each palm, and then the leaves were released to remove excess dust from their surface to reach the leaflet minimum dust carrying capacity.

Two hours after the treatments, photosynthesis rate, transpiration, and

stomatal conductance were measured by LCA-4 ADC portable infrared gas analyzer. The units expressed for photosynthesis rate (A) in $\mu\text{mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$, stomatal conductance (g_s) in $\text{mmol m}^{-2}\text{s}^{-1}$, and transpiration rate (E) in $\text{mmol H}_2\text{O m}^{-2}\text{s}^{-1}$.

Crop Yield Record

In the second experiment, the total yield on each experimental tree was recorded at the time of commercial fruit maturity harvest in late September. For this, in each treatment, all fruit bunches of each palm tree were harvested and separately weighed and recorded. Finally, water use efficiency (WUE) was calculated based on the following equation:

$$WUE = \frac{\text{Yield}}{\text{Water}(\text{Rain} + \text{Irrigation})} \text{ kg m}^{-3}$$

Stomata Study

Four date palms trees cv. 'Sayer' were selected and four fully developed leaves of each tree were tagged and leaflets samples were taken from the bottom part, middle, and top end of each leaf. The number of stomata was evaluated according to the method described by Arzani *et al.*, (2013) and Arzani (2014) by preparing slides from the clear polish impression on both lower and upper epidermis of the leaflets.

To study the stomata structure with an electron microscope, a layer of the transparent polished sample was picked out from the leaflet surface and placed on the microscope stub and then was gold-coated by sputter (SPI Module Sputter Coater and Vacuum Base, Structure Probe Inc., USA). The samples were examined using an LEO 1455 VPSEM 940 scanning electron microscope (SEM). The sample images were analyzed on-screen pixel ruler software. The length and width of the stomata for measurements were considered as Figure 3 diagram.

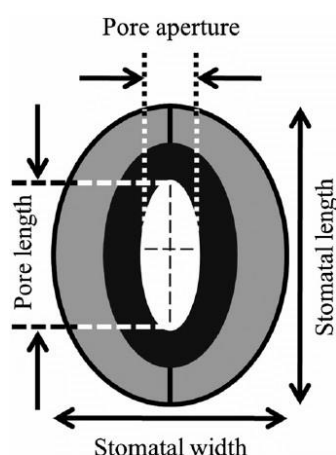


Figure 3. Schematic diagram representing the stomata and its pore dimensions.

For the stomata study, 12 leaflets of different tree directions were chosen and three-section areas of each selected leaflet were considered for counting and comparing the stomata on the abaxial and adaxial surfaces of the leaflet.

Statistics

The obtained results were statistically evaluated by analysis of variance (ANOVA) using MINITAB 17 software and expressed as mean \pm standard error (SE). Means comparisons were made using Tukey's test that differences were statistically significant at $P \leq 0.05$.

RESULTS

Minimum Dust-Carrying Capacity (MDCC)

ANOVA test showed that different leaflets had a significant influence on MDCC ($P < 0.01$). The obtained results showed that the base and top leaflets had the highest (2.5 mg cm^{-2}) and lowest MDCC (1.7 mg cm^{-2}) respectively (Figure 2 C).

Physiological Responses

The physiological parameters including photosynthesis rate (A), stomatal conductance (g_s), and transpiration rate (E) showed significant differences between the combined treatments ($P \leq 0.05$) (Table 2).

The photosynthesis rate of date palm leaves was decreased in the combined rain and dust treatments compared with the control group. Cleaned leaves showed the highest photosynthesis rate, but the rain treatment showed less photosynthesis than control. Dust \times Rain and Dust treatments caused more reduction in photosynthesis than control and Rain treatment ($P < 0.05$). Rain*Dust treatment showed less photosynthesis with significant differences ($P < 0.05$). This analysis showed that compared to the control, the photosynthesis rate of treatments decreased from 7.72 to $2.99 \mu\text{mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$ (Table 2).

Based on the results the stomatal conductance of the leaves decreased in the combined treatments compared with control. Also, Rain treatment showed lower stomatal conductance than cleaned leaves ($P < 0.05$). Dust*Rain treatment caused more reduction in stomatal conductance than cleaned leaves ($P < 0.05$). Dust treatment caused more reduction in stomatal conductance than control, Rain and Dust*Rain treatments ($P < 0.05$). Less stomatal conductance was observed in Rain*Dust treatment with significant differences ($P < 0.05$). This analysis showed that compared with the control, the stomatal conductance of treatments decreased from 37.78 to $17.35 \text{ mmol m}^{-2}\text{s}^{-1}$ (Table 2).

We found that E of the date palm leaves decreased in the combined rain and dust treatments compared with control (Table 2). Dust* Rain treatment caused more reduction in E than control and Rain treatment ($P < 0.05$). Dust showed more reduction in E than control, Rain and Dust*Rain treatments ($P < 0.05$).

**Table 2.** Changes in the leaf photosynthesis, stomatal conductance and respiration rate of dust treated mature 8 years old date palm cv. 'Sayer' has grown under Ahvaz environmental conditions of Iran.

Treatments ^a	Photosynthesis rate (A) $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$	Stomatal conductance (g_s) $\text{mmol m}^{-2} \text{ s}^{-1}$	Transpiration rate (E) $\text{mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$
Control	7.72 ^A (± 0.11) ^{**}	37.78 ^A (± 1.56)	2.78 ^A (± 0.63)
Rain	5.53 ^B (± 0.10)	26.73 ^B (± 1.87)	2.41 ^{AB} (± 0.33)
Dust*Rain	3.07 ^C (± 0.06)	21.64 ^C (± 1.59)	1.52 ^{BC} (± 0.28)
Dust	2.99 ^C (± 0.42)	17.35 ^D (± 0.13)	1.49 ^{BC} (± 0.20)
Rain*Dust	0.82 ^D (± 0.12)	9.1 ^E (± 0.69)	0.8 ^{6C} (± 0.02)

^a Treatments description: Control: no dusting, no spraying, Rain: water spraying on leaves, Dust*Rain: dusting and then spraying on the leaves by water, Dust: dusting the leaves, Rain*Dust: spraying on the leaves by water and then dust. (A-F) Different letters in the same column indicate significant differences at $P < 0.05$. Also, \pm Standard error of the means.

This showed that compared with the control, the transpiration rate of treatments decreased from 2.78 to 1.49 $\text{mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$ (Table 2).

Stomata Study

Results showed that the average stomata length was 20.9 μm . Stomata aperture was oval-shaped and its diameter was from 1 to 2 μm (Figure 4A). The leaflet surface was almost wavy and the stomata were situated in the surface concave part in a linear arrangement on both abaxial and adaxial surfaces (Figure 4B). Stomata density at the abaxial surface was 299 mm^{-2} and at the adaxial surface was 300 mm^{-2} , without any significant differences. Some dust particles were seen close to the stomata openings (Figure 4C and D).

In this study, the smallest dust particles with a diameter of about 156 nm were observed that were smaller than stomata aperture. The cleaned leaflet surface showed no dust particles (Figure 4E). Although, dusted leaves showed a lot of dust particles (Figure 4F) especially on its concave surface that could shade the leaflet surface and reduce the radiation available for photosynthesis rate and also could make stomata blockage.

Crop Yield

The crop yield results of different treatments were shown in Table 3. Pollinated treatment showed the maximum

yield. The minimum yield was obtained from no pollination treatment. Based on the results, dust and rain separately or in combination affected the yield adversely. In the treatment that dust covers the surface of the stigma before pollination, inhibits some of the pollen grains from accessing the stigma, and leads to the reduction of yield. Rain during the date palm pollination period causes washing some of the pollen grains on the stigma surface led to a further reduction in fruit set, yield, and also WUE (Table 3).

DISCUSSION

This simulated dust deposition experiment on date palm created the potential scenarios for monitoring the negative impact on the photosynthesis rate and gas exchange of date palm grown under affected polluted areas of Iran. The obtained results showed the negative impacts of dust on photosynthesis rate, stomatal conductance, transpiration rate, and MDCC of date palm cv. 'Sayer' leaves. Besides, dust and rain in combination caused the reduction in crop yield up to 90%.

Results showed significant differences among leaflets of a date-palm leaf in terms of minimum dust-carrying capacity. This means that a dust storm can differently affect the physiological aspects of different leaflets in different positions on the same leaf. Therefore some differences in leaflets' response to the dust storm enable the

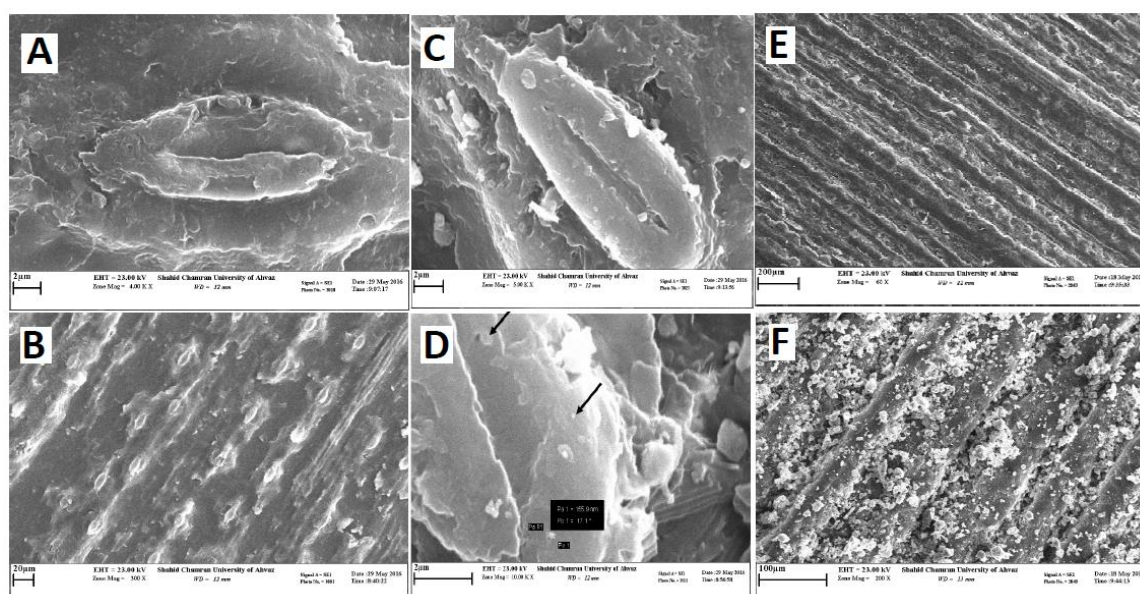


Figure 4. (A) Date palm stomata of cv. 'Sayer' at 4,000X; (B) Stomata arrangement on date palm leaflets surface at 3,000X; C: Dust particles close to the stoma aperture at 5,000X; (D) Dust particles close to the stomata at 10,000X; (E) Cleaned leaflet surface of date palm at 60X, and (F) Dusted leaflet surface of date palm at 200X. All scanned photos were taken from date palm leaf at the middle leaflets position.

Table 3. The effect of different dust combinations on the yield of mature 8-years-old date palm cv. 'Sayer' grown under Ahvaz environmental conditions.

Treatments number	Treatments ^a	Crop yield kg tree ⁻¹	Crop yield Kg ha ⁻¹	Date yield (% Of control)	WUE (kg m ⁻³)
1	Pollinated (Control)	59.17 ^A	8976	100	0.5
2	Pollinated+Rain	46.00 ^{AB}	7222	80.46	0.4
3	Rain+Pollinated	39.83 ^B	6253	69.70	0.3
4	Pollinated+Dust+Rain	39.17 ^B	6150	68.50	0.3
5	Dust+Pollinated+Rain	25.83 ^C	4055	45.18	0.2
6	Rain+Pollinated+Dust	24.50 ^C	3846	42.85	0.2
7	Dust+Rain+Pollinated	22.50 ^{CD}	3532	39.35	0.2
8	Pollinated+Dust	16.67 ^{CDE}	2617	29.16	0.1
9	Dust+Pollinated	16.10 ^{CDE}	2528	28.16	0.1
10	Pollinated+Rain+Dust	10.00 ^{DEF}	1570	17.49	0.1
11	Rain+Dust+Pollinated	6.83 ^{EF}	1072	11.94	0.1
12	unpollinated	1.90 ^F	298	3.32	0.02
ANOVA	Source of variance	Degree of freedom	Means square		
	Year	1	74.22 ^{ns}		
	Replications	2	84.10 ^{ns}		
	Treatments	11	1781.60 [*]		
	Error	57	43.30 ^{ns}		

^a Control: No dusting, no spraying, Rain: Water spraying the on leaves by water, Dust×Rain: Dusting and then spraying on the leaves by water, Dust: Dusting the leaves, Rain×Dust: Spraying on the leaves by water and then dust. (A-F) Different letters in the same column indicate significant differences at P< 0.05.



affected plants to continue their photosynthesis even at a lower rate and under the harsh dust storm conditions.

Also, the cleaned leaves showed the highest level of photosynthesis rate, stomatal conductance, and transpiration rate. Leaves that were just washed by rain, showed less photosynthesis, g_s , and E than cleaned leaves. It seems that rain cannot wash deposited dust on the leaf surface. Ishibashi and Terashima (1995) studied the effects of simulated rain on *Phaseolus vulgaris* L. plants reported that stomata closed completely within 2 min after rain treatment and then gradually opened. Results showed that treatments including dust caused more reduction in physiological parameters, compared to other treatments. In Rain*Dust treatment, rain caused dust stabilization on the leaf surfaces, and the formation of a blockage layer on the leaf that leads to less photosynthesis rate, g_s , and E .

Previous studies indicated that the photosynthesis rate would be reduced after covering the leaf surfaces by dust because of the shading, blockage of the stomata, and increase of leaf temperature (Thompson *et al.*, 1984; Farmer, 1993). The decrease in physiological parameters such as photosynthesis rate, g_s , and E soon after combined dust treatments may have been caused by clogging of the leaf surfaces stomata or absorption or reflection of light by the dust layer and further reduction of radiation available for leaf surfaces. These findings are in agreement with the results reported by Armbrust (1986) on cotton plants, Sharifi *et al.* (1997) on Mojave desert shrubs, Li *et al.* (2012) on wheat, and He *et al.* (2013) on pear. Yamaguchi *et al.*, (2012) after application of fine particles of black carbon (BC) to four plant species during two growing seasons reported that there was no significant evidence of the decline of photosynthesis by the effect of BC particles with sub-micron size because of shading or reducing the light intensity. They concluded that gas exchange rates in leaf or needle of *Fagus crenata*, *Castanopsis sieboldii*, *Larix kaempferi*, and *Camellia japonica* seedlings

were not significantly affected by BC application.

Dust may have different physiological effects on different plants due to the adaptation of the plant leaves to the dust in a short period of exposure time (Xiong-Wen 2001). Armbrust (1986) determined that the photosynthesis rate of dusted plants take returned to normal condition after time elapsed from the dust. In this study, we just studied the different dust treatments on date palm leaves in a short exposure period, so the causing effects after the longer exposure time as well as natural rainy conditions need further investigation.

SEM analyses of the leaf stomata anatomy of date palm demonstrated that they all had the same basic structural characteristics which are common to palm trees in general (Batagin-Piotto, *et al.*, 2012). Zarinkamar (2006) reported that in the majority of monocotyledons leaves, stomata are arranged apparently without regularity. However in some monocots, for example, in the grasses, stomata are situated in regular rows. In this research, we found that stomata of date palm cv. 'Sayer' is equally distributed in a linear arrangement on both abaxial and adaxial. These findings are in agreement with the results reported by Panawala (2017) on monocots stomata.

In conclusion, clogging the stomata lead to negative impacts on the gas exchange and the reduction of photosynthesis rate. Our results are in agreement with Watanabe (2015) that found stomatal clogging of white birch (*Betula papyrifera*) by some particles. In the present research, dust declined photosynthetic activity through the blocking of the stomata (Figure 4F) and other related physiological processes, so led to the reduction of crop yield up to 90% (Table 2). In the present research, we collected the dust in the experimental site, so further research is essential to consider the possible matches or chemical element composition similarity of applied dust in this experiment (Table 1.) with possible dust storm sources. Yamaguchi *et al.*, (2019) studied the effects of deposited dust particles on the leaf of

Japanese cypress grown in Nagasaki areas of Japan reported different particle accumulation on the leaves including Pb, Ni, Cu, Zn, and As. The effects of dust and other related treatments on pollen germination, parthenocarpic fruit formation, fruit set, and fruit abscission were reported by Torahi and Arzani, 2017 and also Torahi et al., 2017. They found that the maximum fruit set was obtained from pollination (66.11%) and the minimum fruit set was recorded in unpollinated treatment (0.5%), maximum abscission was observed in the combined dust, rain, and pollinated treatment (83.82%), and the minimum abscission was observed in pollinated treatment (32.88%).

The serious negative impact of dust on crop yield that showed in the present research gives a clear message to all of the Iranian and Mediterranean regions as well as global related sectors for special considerations on the sources of coming dust. From the global and regional co-operation point of view, there is a strong demand from orchardist for improving the current air pollution in the region. From the horticultural and physiological point of view, we also suggest further research in the natural dust storm environment using the whole canopy photosynthesis measurement and related physiological analysis to warrant a better understanding of the date palm growth and development for optimum photosynthetic activity and sink strength with higher crop yield under harsh dust storm conditions of Mediterranean regions such as Iran.

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اثر فرونشست گرد و خاک برفتوسنتز، تبادل گازی و عملکرد نخل خرما رقم سایر

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چکیده

این تحقیق به منظور تعیین اثرات گرد و خاک و گرده افشانی بر فعالیت فتوسنتزی و عملکرد محصول رقم خرما (*Phoenix dactylifera L.*) تجاری سایر در آزمایش مزرعه‌ای به انجام رسید. درختان بالغ برای غبارپاشی و اندازه‌گیری‌ها در شرایط شهرستان اهواز، ایران، طی فصل رشد سال ۱۳۹۵-۱۳۹۶ مورد استفاده قرار گرفتند. غبار با استفاده از یک دمنده روی درختان دمیده شد و تبادل گازی برگ توسط دستگاه تجزیه گاز فروسرخ بر برگ‌های دست‌نخورده مورد ارزیابی قرار گرفت. بعد از اعمال تیمارها، سرعت فتوسنتز، تعرق و هدایت روزنه‌ای اندازه‌گیری شد. نتایج آنالیز تبادل گازی برگ، اختلافات معنی‌داری را بین اثرات تیمارهای ترکیبی بر سرعت فتوسنتز (از ۹/۱۸ تا ۰/۶۴ میکرومول دی‌اکسید کربن بر متر مربع در ثانیه)، هدایت روزنه‌ای (از ۳۹/۹ تا ۶/۶۷ میلی‌مول بر مترمربع در ثانیه) و سرعت تعرق (از ۲/۷۸ تا ۱/۴۹ میلی‌مول آب بر متر مربع در ثانیه) را نشان داد. نحوه فرونشست ذرات غبار، تعداد روزنه‌ها در سطوح فوقانی و تحتانی برگچه‌ها و ظرفیت حمل غبار حداقل (MDCC) با استفاده از میکروسکوپ الکترونی (SEM) اندازه‌گیری شد. مطالعه روزنه‌ها با استفاده از SEM نشان داد که سطوح برگ نخل خرما تقریباً مواج هستند و روزنه‌ها در سطوح معقر و با ترتیب خطی در هر دو سطح پایین و بالای برگ قرار گرفته‌اند. هر چند اختلافات معنی‌داری بین تراکم روزنه‌ها در هر دو سطح زیرین (۲۹۹ روزنه در میلی‌متر مربع) و روی برگ (۳۰۰ روزنه در میلی‌متر مربع) وجود نداشت، محل برگچه‌ها روی برگ، تاثیر معنی‌داری بر MDCC نشان داد. برگچه‌های قاعده‌ای برگ، بیشترین (۲/۵ میلی‌گرم بر سانتی‌متر مربع) و برگچه‌های بالایی حداقل MDCC (۱/۷ میلی‌گرم بر سانتی‌متر مربع) را به ترتیب نشان دادند. علاوه بر این، مطالعات SEM علائمی از پوشش یا ورود ذرات گرد و خاک در روزنه‌ها را نشان داد که با احتمال گرفتگی و بستن روزنه‌ها منجر به کاهش معنی‌دار سرعت فتوسنتز گردید. درختان گرده‌افشانی شده، بیشترین عملکرد را نشان داد (۵۹/۱۷ کیلوگرم در درخت) و کمترین عملکرد از درختان گرده‌افشانی نشده به دست آمد (۱/۹ کیلوگرم در درخت).