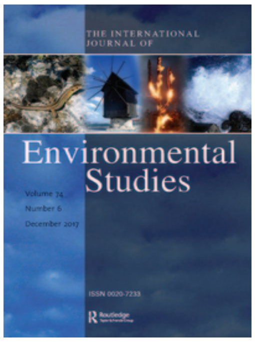

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Effects of dust deposition from two major dust source regions of Iran on wheat (*Triticum aestivum* L.) production

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ABSTRACT
In order to study the effects of dust on yield and yield components of wheat, an experiment was conducted in a factorial layout based on a randomized complete block design with three replicates in Mashhad, Iran in 2015. The experimental factors included the concentration of dust at three levels (0, 500 and 1500 $\mu g.m^{-3}$), the number of dust applications (one, two and three) and the type of dust. The results showed that biological yield, grain yield and harvest index significantly decreased and total soluble sugar content increased when plants were exposed to a 1500 $\mu g.m^{-3}$ dust concentration.

KEYWORDS
Biological; desert; dust; harvest; sugar; wheat

Introduction

Dust storms are one of the main types of air pollution that cover Iran's western, eastern and even central areas [1]. Dust can be harmful for human health, natural resources and the environment; also it has adverse effects on agriculture and causes damage to agricultural and horticultural crops, and leads to unsustainable agriculture [3]. Dust particles may occlude stomata [4] or reduce photosynthetically active radiation [5]. Dust deposition on plant leaves causes a reduction in plant growth [5]. Ghorbanli et al. [6] in results of their study on the effect of gaseous air pollution in a polluted and an unpolluted area of Tehran, Iran, on *Nerium oleander* and *Robinia pseudoacacia*, reported that air pollution caused a reduction in soluble carbohydrate concentration in epidermal cells in *R. pseudoacacia*. Nadioo and Chirkoot [7] reported that coal dust causes gas exchange to decrease, as well as the rate of photosynthesis and yield in *Avicennia marina* by occlusion of stomata. Vardaka et al. [8] stated that dust deposition on *Quercus coccifera* leaves caused disturbance in photosynthesis processes by occlusion of stomata. Darley [9] showed that cement-kiln dust deposition reduced the rate of CO_2 exchange in bean leaves. Hirano et al. [4] studied physical effects of dust on the leaf physiology of cucumber (*Cucumis sativus* L.) and kidney bean (*Phaseolus vulgaris* L.) plants. They found that the dust decreased stomatal conductance in the light, and increased it in the dark by plugging the stomata, when the stomata were open during

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dusting; they stated that when smaller dust particles were applied, the effect was greater. Studies have shown that stone crusher dust reduced grain yield of rice (*Oryza sativa.* L.) [10] and gram (*Cicer arietinum* L.) [11] and cement dust also reduced yield and 1000-seed weight [12].

Most countries regard wheat as a strategic product, the main supplier of the food quota, protein and calories needed by people. This product is very important in terms of economics and food supply; even in areas where there is no possibility of producing other crops, owing to unstable climate conditions or drought, wheat can be produced [13]. The Sistan region in southeast Iran which borders with Afghanistan and Pakistan and Khuzestan Region in west Iran have long been recognized as the most intense and year-round active dust source regions in the Middle East and southwest Asia. Wheat is the main food for the people living in these areas. Therefore the purpose of this study is to evaluate the effect of dust on yield and yield components of wheat.

Materials and methods

The experiments were conducted at the research farm of the Ferdowsi University of Mashhad in 2015, located 10 km SE of the city of Mashhad, Iran, with coordinates 36°15′ N and 56°28′ E and at 985 m above sea level (MSL) (Figure 1). The experiment was conducted in factorial layout based on randomized complete block design with three replicates. The experimental factors were desert dust concentration in three levels (0, 500 and 1500 μg m^{-3}), number of

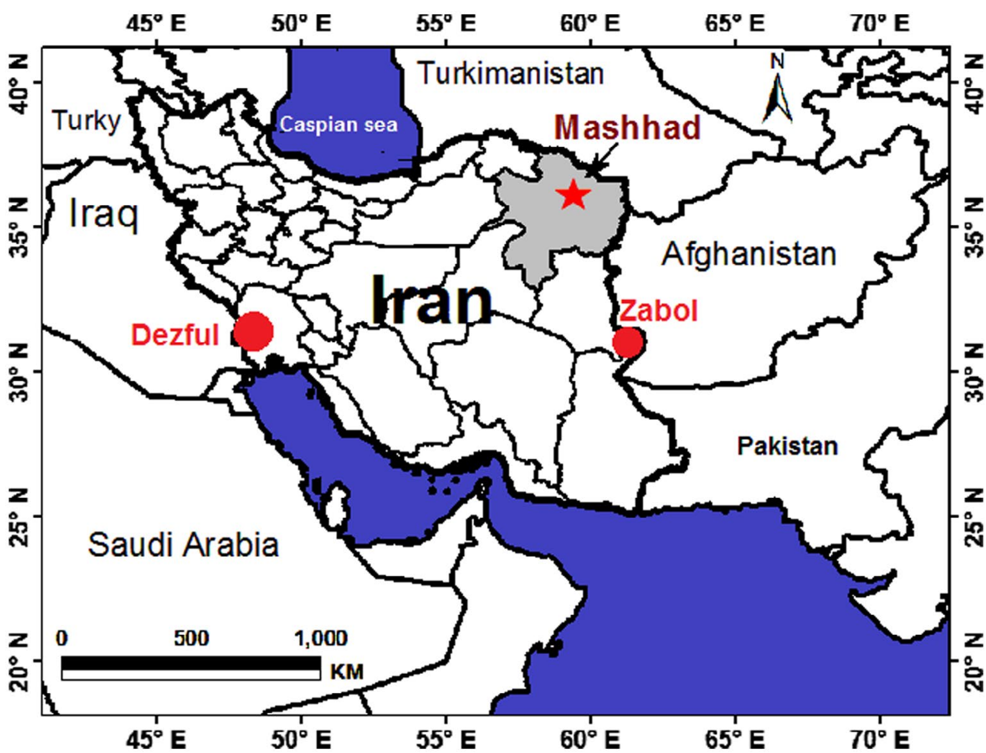

Figure 1. Geographic map of the study area which is defined by red star in Khorasan Razavi province, Iran. Zabo and Dezful (red circles) are sampling sites of dust for this research.

desert dust applications (one, two or three) and two types of desert dust (Dust samples from Dezful to Zabol) (the number of investigated plots are $(3 \times 3 \times 2 \times 3) = 54$). The amount of dust samples were collected during dust storms using passive dust samplers over the period April 2014 to October 2014 from Dezful in west Iran and Zabol in the south–east of Iran. The collection method used was described by Rashki et al. [2].

Every plot area was 2×2 m and the distance between plots and replicates was 0.5 and 1.5 m, respectively. Tillage was done in autumn, 2014. Land was prepared and levelled by two perpendicular discs and a leveller, respectively, on 10 March 2015. The land was then furrowed by a furrower and the plot borders were determined. On 11 March 2015 wheat seeds were sown with 150 $kg.ha^{-1}$ seeding density, by hand, in 3–4 cm depth of soil on ridges with 25 cm between rows. The first irrigation was done immediately after sowing and the field was irrigated once every week up to the end of the growing season. The initial emergence occurred 5–10 days after sowing and weed control was done manually once at the mid-tillering stage.

In order to identify physical and chemical characteristics of soil, soil samples were taken from 0 to 30 cm depth. Table 1 shows results of physical and chemical soil analysis. Collected dust was sent to the Geology laboratory at the University of Pretoria, South Africa to identify chemical content. Table 2 shows results of chemical analysis of dust samples. Several mobile chambers, with a cross section 1×1.5 m and a height of 2 m, were used to collect dust; dust was imported by a blower through the upper valve to the chamber while the dust concentration was monitored by TSI Trak (dust monitor). Performance of the different levels of a number of dust application treatments was done based on growing stages (tillering, booting and milk stage). The single dust application treatment was done once in the tillering stage. In the two-time dust application treatment, dusting was done at tillering and booting stages. In three-times dust application treatment, dusting was done at tillering, booting and milk stages. Tillering, booting and milk stages in wheat plants occurred on 20 April 2015, 11 May 2015 and 22 May 2015, respectively.

Identifying the growing stages of wheat in this study was based on observation of each growing stage in 50% of plants on the farm. Before harvest, 10 plants were selected randomly in every plot and the number of fertile tillers, plant height, number of spikelets per spike, and the number of seeds per spikelet were measured. One m^2 from the middle of each plot was harvested at ground level to measure the yield; total weight and seeds were weighed to determine biomass and grain yield. Seeds were counted by seed counter and weighed.

Total soluble sugar in above-ground dry matter was measured by the Kochert [14] method; the light absorption of prepared solutions was measured using a spectrophotometer at 485 nm, and using a standard curve, soluble sugar content was calculated. Data were analysed by SAS ver. 9.1 software and means were compared with Duncan's multiple range test ($p \leq 0.05$). Excel software was used to create graphs.

Results

Results showed that there were significant effects of dust concentration on plant height, number of spikelet per spike, number of grain per spikelet, 1000-seed weight, biological yield, grain yield, harvest index and soluble sugar content (Table 3). The effects of the number of dust applications on 1000-seed weight, grain yield and harvest index were also significant (Table 3). The interaction effect between dust concentration and number of

Table 1. Physical and chemical characteristics of soil (0–30 cm depth) in experimental site in 2015.

Season	Electrical conductivity ($\mu s.m^{-1}$)[1]	Acidity	Total nitrogen (%)	Organic matter (%)	Available phosphorous ($mg.kg^{-1}$)	Available potassium ($mg.kg^{-1}$)	Soil texture
2015	640	7.65	0.067	0.67	14	325	Silty loam

[1]Micro Siemens per metre.

Table 2. Chemical components of used dust samples (%).

Dust source	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Cr_2O_3	NiO	V_2O_5	ZrO_2	CuO	LOI	Total
Dezful	31.60	0.44	5.89	4.16	0.06	4.73	23.30	1.11	0.32	0.14	0.03	0.01	0.01	0.02	0.00	27.78	99.60
Zabol	46.7	0.62	10.45	4.15	0.09	3.72	12.77	3.19	0.02	0.19	<0.01	<0.01	<0.01	<0.01	<0.01	19.1	99.8

dust applications was significant just on 1000-seed weight. There was no significant effect on biological yield and seed yield from the type of dust or the interaction effects (Table 3).

Increasing dust concentration caused a decrease in biological yield and grain yield. The decrease in biological yield and grain yield was, however, significantly affected equally by 1500 μg.m^{-3} dust treatment, and compared with the control (22.6 and 35.5%, respectively). There was no significant difference in biological yield and grain yield in 500 μg.m^{-3} dust concentration compared with control treatment. Grain yield obtained from three dust applications was significantly lower than for one and two dust applications. There was no significant difference between grain yield obtained from two to three dust applications (Table 4).

According to the results (Table 3) it seems, 1000-seed weight was the most sensitive yield component as affected by experimental factors, such that the main effects of dust concentration and number of dust applications and also their interaction effect were significant on 1000-seed weight; the 1000-seed weight obtained from 1500 μg.m^{-3} dust concentration treatment indicated a significant reduction (10.0%) compared with the control. There was a non-significant reduction in 1000-seed weight obtained from 500 μg.m^{-3} dust concentration treatment compared with the control (Table 4). The 1000-seed weight obtained from the three dust applications indicated a significant reduction compared with one and two dust applications (4.5 and 2.8%, respectively); the difference between 1000-seed weight obtained as affected by one and two dust applications was non-significant (Table 4). The most significant decrease in 1000-seed weight was observed in two and three dust applications with 1500 μg.m^{-3} dust concentration treatments, equal to 21.96 and 20.93 g (11.1 and 15.3% reduction compared with control), respectively (Figure 2). The type of dust and other interaction effects did not have any significant effect on 1000-seed weight.

The number of spikelets per spike, the number of seeds per spikelet and plant height indicated significant reductions as affected by 1500 μg.m^{-3} dust concentration, equal to 6.7, 8.1 and 7.99%, respectively, compared with the control; none of these yield components nor plant height indicated significant reduction as affected by 500 μg.m^{-3} dust concentration (Table 4).

Table 3. Analysis of variance for plant height, number of spikelet per spike, number of grain per spikelet, 1000-seed weight, number of fertile tillers, biological yield, grain yield, harvest index and soluble sugar content of wheat as affected by dust concentration, number of dust application and type of dust.

	Plant height	No. of spikelet per spike	No. of grain per spikelet	1000-seed weight	No. of fertile tillers	Biological yield	Grain yield	HI	Soluble sugar
Dust concentration (A)	**0.0140**	**0.0455**	**0.0134**	**<0.0001**	0.8998	**0.0026**	**<0.0001**	**0.0001**	**0.0137**
No. of dust applications (B)	0.0521	0.3712	0.8966	**0.0035**	0.1191	0.0632	**0.0309**	**0.0402**	0.4887
Type of dust (C)	0.4750	0.1044	0.6137	0.1034	0.0697	0.9885	0.5144	0.2817	0.5319
A × B	0.4554	0.1610	0.4711	**0.0022**	0.5707	0.3705	0.3552	0.4653	0.7645
A × C	0.3061	0.3863	0.9260	0.3436	0.8786	0.9985	0.6729	0.2936	0.6907
B × C	0.4358	0.4928	0.0982	0.5960	0.5968	0.5173	0.5872	0.5083	0.8197
A × B × C	0.6535	0.2534	0.0766	0.8110	0.1778	0.4451	0.6540	0.9142	0.5933

Note: Significant ($p < 0.05$) factors are marked in bold.

Table 4. Mean comparison of the effect of dust concentration, number of dust application and type of dust on for plant height, number of spikelet per spike, number of grain per spikelet, 1000-seed weight, number of fertile tillers biological yield, grain yield, harvest index and soluble sugar content of wheat.

	Plant height	No. of spikelet per spike	No. of seed per spikelet	1000-seeds weight (g)	No. of fertile tillers	Biological yield ($kg.ha^{-1}$)	Grain yield ($kg.ha^{-1}$)	HI (%)	Soluble sugar (%)
Dust concentration									
Control	56.80a	13.07a	2.03a	24.71a	1.81a	10,480.0a	3886.7a	37.11a	1.26b
500 $\mu g.m^{-3}$	55.78a	12.98ab	2.00a	24.21a	1.79a	9453.3a	3404.3a	35.42a	1.45ab
1500 $\mu g.m^{-3}$	52.83b	12.19b	1.86b	22.23b	1.80a	8112.2b	2505.4b	30.41b	1.58a
No. of dust applications									
Once	56.92a	12.76a	1.98a	24.23a	1.85a	10,168.0a	3626.4a	35.58a	1.36a
Twice	54.92a	13.01a	1.95a	23.79a	1.79a	9237.2a	3291.3a	35.22a	1.47a
Thrice	53.58a	12.48a	1.96a	23.13b	1.76a	8640.6a	2878.7b	32.14b	1.46a
Type of dust									
Dezful	54.75a	12.50a	1.95a	23.92a	1.82a	9344.8a	3338.0a	34.95a	1.46a
Zabol	55.53a	13.00a	1.98a	23.51a	1.78a	9352.2a	3192.9a	33.68a	1.40a

Notes: Means with similar letters in each column and separately for every factor, show non-significant differences according to Duncan's Multiple Range Test (The degrees of freedom was 34) at 5% level of probability.

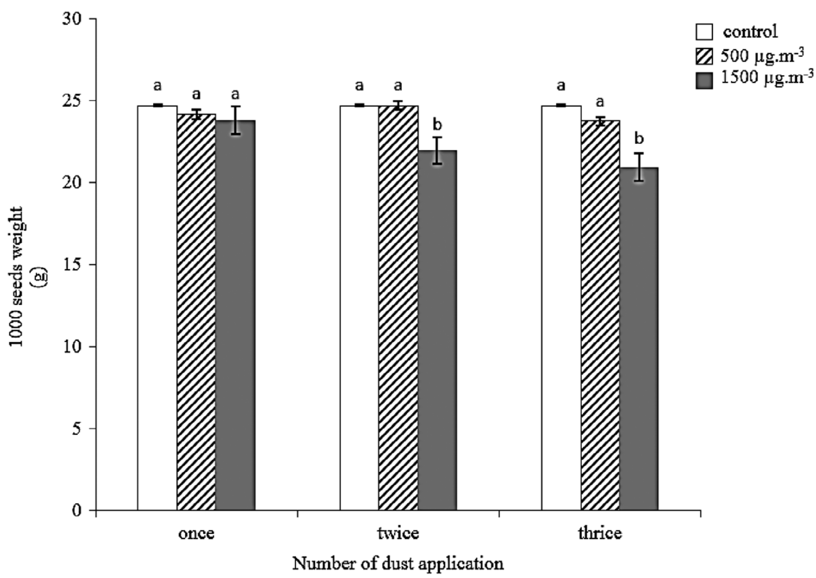

Figure 2. Interaction effect of used dust concentration and number of dust application, once, twice and thrice, on 1000-seeds weight of wheat ± SE. Letters above bars indicate difference between dust concentrations within number of applications, means with different letters are significantly different based on Duncan's tests at $p \leq 0.05$.

The results in Table 4 show that soluble sugar content changes are in line with dust concentration changes, such that increase in dust concentration caused an increase in soluble sugar content; despite this, soluble sugar content indicated a significant increase, as affected by 1500 $\mu g.m^{-3}$ dust concentration treatment, compared with the control.

Discussion

In the present study biological yield and grain yield were significantly decreased because of increasing the dust concentration (Table 4). These results are in line with previous studies on plants affected by dust [10, 12, 15, 16]. Reduction of incident light on leaf surfaces [17], especially reduction in the photosynthetically active radiation [5], and clogging of stomata by dust particles [4, 12, 16] reduce the resource use. Thus, there is less photosynthesis and consequently less dry matter accumulates, and finally there are lower yields, as affected by dust treatments compared with control. Results of a study by Hirano et al. [4] show that deposition of dust on plants causes shading and reduces the incident light on plants; they state that a reduced photosynthesis rate in the dusted leaves is apparently induced by shading.

Results of several studies to determine the effects of shading on plants indicate that shading causes reduction in the grain yield [18–21], the biological yield [19, 20] and in the harvest index [18–20]. Reduction of grain yield is caused by reduction in the yield components. In the present study the lowest grain yield was obtained from plots affected by 1500 $\mu g.m^{-3}$ dust concentration with 31.55% reduction compared with control and mainly was related to 1000-seed weight, the number of seeds per spikelet and the number of spikelets per spike, such that the lowest amounts of these yield components also were obtained from 1500 $\mu g.m^{-3}$ dust concentration treatment. Reduction of incident light can cause reduction in the 1000-seed weight [18–20, 22–25] and also reduce the number of seeds [18, 19, 22, 26] and through this, produces effects on grain yield [22]. Lack of light at the early filling stage causes a decline in the number of endosperm cells and results in reduced seed weight at maturity and in the middle and late seed filling stages; apart from the number of endosperm cells being decreased a more important reason for grain weight reduction was that the endosperm cells had smaller sizes [24].

In the present study dust concentration treatments caused a decrease in seed weight and conversely, increased soluble sugar content significantly; it seems because of the deposition of dust on photosynthetic organs, the photosynthesis is disturbed and results in a reduction in photosynthetic assimilation. It seems that this shading on photosynthetic organs causes a reduction in transport of assimilation products to seeds, leading to increased concentration of stagnant assimilation products in plant tissue and reduced seed weight [24]. It appears that sugar accumulation occurs as a consequence of a co-ordinated regulation established between sucrose synthesis and translocation to allow the maintenance or the increase of the pool of soluble sugars in leaves with restricted photosynthetic activity [27, 28]. Abdel-Rahman and Ibrahim [29] reported an increase of the soluble sugars in *Zygophyllum coccineum*, *Salsola tetrandra*, *Cyperus conglomeratus*, *Limonium axillare* as a result of the application of cement particle dust. Mu et al. [30] studied the effect of shading on wheat and observed that shading decreased the redistribution of pre-anthesis stored total soluble sugars in vegetative organs to reproductive organs, resulting in a decrease of the grain yield. Shi-fang et al. [24] reported that soluble sugar content in maize cob increased as affected by shading. This indicated that a large number of stagnant products assimilated in the cob were not successfully transported into the grain.

Biological yield was not affected by the number of dust applications factor; since in this study dust application times for the different numbers of dust application factor were adjusted based on plant growing stages (tillering, booting and milk stages). Non-significant changes in biological yield as affected by different levels of the number of dust applications factor can be inferred to stop the vegetative growth after the first stage of dust application.

Grain yield obtained from three dust applications was significantly different from that of one and two dust applications; but grain yields obtained from one and two dust applications were not significantly different. The difference between grain yield obtained from three dust applications and that of one and two dust applications can be related more to the amount of dust deposited on the plant. It seems wheat plants are more sensitive to the effects of dust deposition during seed filling than previous stages. A crop has a reduced ability to compensate for the adverse effects of shading with ageing, and the lack of light during seed filling leads to considerable decrease in seed weight, such that there is no possibility to compensate [19]. Since rapid ear elongation starts at the stage in which the flag leaf ligule is just visible [31] and according to that the flag leaf and ear are the main photosynthetic organs contributing to seed filling [32–36], it seems that the reason for significant reduction of grain yield as affected by three dust applications, done during seed filling, is that the main photosynthetic source for seed filling was disturbed at this stage compared with previous dusting stages.

The number of spikelets per spike and number of seeds per spikelet were not affected by the number of dust applications. But these traits were significantly affected by 1500 $\mu g\ m^{-3}$ dust concentration and indicated a significant reduction as affected by this treatment compared with the control. In the present study, 1000-seed weight was significantly affected by both dust concentration and number of dust applications and their interaction effect. There was no significant difference between 1000-seed weight obtained after one and two dust applications, while 1000-seed weight obtained from three dust applications indicated a significant difference with lower levels of this factor. It seems, in the present study, that 1000-seed weight is the most effective yield component. Significant reduction of 1000-seed weight as affected by three dust applications despite the non-significant effect of the number of dust applications on biological yield, number of spikelets per spike and the number of seeds per spikelet, finally caused the decrease in grain yield as affected by the three dust applications.

Conclusion

Generally results indicated that dust application had a significant adverse effect on yield and yield components of wheat. The type of dust did not have any significant effect on studied traits. Biological and grain yield of wheat were decreased through deposition of dust. The interaction effect between dust concentration and number of dust applications was significant only for the 1000-seed weight. Results showed that for yield components such as 1000-seed weight, number of spikelets per spike and number of seeds per spikelet affected by dust concentration, only the 1000-seed weight was affected by the number of dust applications. It seems reduction of photosynthetic active radiation caused by dust cover on plant leaves and reduction of gas exchange through the stomata by dust particles, cause reduction in resource use and thus less photosynthesis and consequently less dry matter accumulation, as affected by dusted treatments compared with control.

Disclosure statement

No potential conflict of interest was reported by the authors.

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