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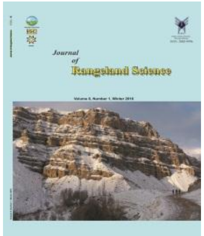

Review and Full Length Article:

Dust Particles and Aerosols: Impact on Biota "A Review" (Part I)

Victor Roy Squires[A]

[A]Prof., Ecology and Resources Group, Gansu Agricultural University, Lanzhou, China (Corresponding Author), Email: dryland1812@internode.on.net

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Abstract. The impacts of Dust and Sand Storms (DSS) on people, crops, livestock, infrastructure and health are well documented. Data have accumulated on the deleterious effects of dust aerosols when they settle on plants. Sand blasting of low growing plants is a common cause of failure in reforestation efforts. Burial of plants by moving sands are also a cause of much damage. The physics of moving sand and dust particles is outlined and the mechanics of each type of damage is elaborated. The physical effects of dust accumulating on leaf surfaces, leaf physiology such as photosynthesis, transpiration, stomatal conductance and leaf temperature of many different species of plants were investigated. It was found that dust decreases stomatal conductance in the light, and increased it in the dark by plugging the stomata, when the stomata were open during dusting. When dust of smaller particles was applied, the effect was greater. However, the effect was negligible when the stomata were closed during dusting. The dust decreased the photosynthetic rate by shading the leaf surface. The paper also reviews experimental work on the physiological effects of dust on photosynthesis, stomatal function, respiration and transpiration. Examples are drawn from western Iran where oak woodlands (*Quercus brantii*) are under threat from dust that blows in from Iraq and Syria.

Key words: Dust, Aerosols, Dust and Sand Storms, *Quercus brantii*

Introduction

Research on the effects of dust pollution on plant communities and their associated biota, both vertebrate and invertebrate, suggest that the effects of dust may be important and are worthy of greater research attention. Dust is considered as one of the most widespread air pollutants. Observations of dust deposits on vegetation in regions prone to frequent and severe dust storms in western China, western Iran and elsewhere show that the effects of dust on crops, grasslands, woodlands, and cryptogam (lichen etc.) communities are particularly affected. Dust accumulation, especially on xerophytes that frequently are hirsute or have vesicles to assist in salt excretion, are affected by reduced rates of photosynthesis, respiration and transpiration. Farmer (1993) provided a comprehensive review of the global literature on the effects of dust on plants and their communities. Various studies have reported a serious setback in plant physiology due to the effect of dust (Vardaka *et al.*, 1995). Chemical composition of dust, its particulate size (Fluckiger, 1979) and deposition rate determine its influence or toxicity on plants (Van Jaarsveld, 2008). Dust particulates are reported to be absorbed through the outer surface of the plants showing some common effects such as chlorophyll degradation, necrosis, and reduction in photosynthesis and decline in growth (Davison and Blakemore, 1976). Dust deposition reduces diffusive resistance and increases temperature of leaf making the tree more likely to be susceptible to drought (Farmer, 1993).

Visible injury symptoms may occur and generally there is decreased productivity. Most of the plant communities are affected by dust deposition so that community structure is altered. Cryptogam dominated communities (lichen etc) are the most sensitive of those studied. However, there have been very detailed studies on natural systems in dust prone regions. The effects of sand blasting on vegetation has received more attention, especially in China where large-scale afforestation efforts have been a feature of rural development in Dust and SandStorm (DDS) prone areas for many decades (Heshmati, 2014). Tree seedlings, planted in their tens of thousands, are particularly susceptible to abrasion by dust and sand particles.

Dust types and principal characteristics

Some dust types are more destructive than others. Dust types are also understudied. Dusts consist of solid matter in a minute and fine state of subdivisions so that the particles are small enough to be raised and carried by wind. They may originate from many sources. A large range of industrial processes can produce particulate emissions many of them as aerosols that can bond with dust aerosols arising from the soil surface. Fe and Al and $S0_2$ are common in emissions from industrial processes and mining. The main processes that regularly cause problems, however, are those concerned with mineral extraction. This ranges from the quarrying itself to the various processing operations (e.g. cement manufacture or coal processing). Dust suppression in these operations is more difficult and dust levels can be very high. Mineral extraction is increasing in many countries in order to meet increased construction demand. Roads are a further common source of dust. Aerosols may be produced from car exhausts and from the road surfaces. A number of characteristics of dust are important in considering its impacts. Dust, depending on its source, can have both a physical and a chemical impact. For example, much of the salt laden dust from the bed of the dried up Aral Sea is highly toxic as a result of the accumulation of pesticides and salinity (Olorvsky and Olorvsky, 2000). In the Aral Sea basin salt is an indispensible component and companion of dust. Chemical analysis revealed at 47.4% of the deposit was soluble salts and 52.6% was insoluble residue. From the total amount of salts, sulphates accounted for 90.6%, chlorides for 7.4% and bicarbonates for 2%. Dust-salt storms are commonly observed over the giant solonchaks of Central Asia, in Iran, India and the western deserts of USA and in the Lake Eyre basin in Australia. These dusts are detrimental to plants and other biota. The chemistry of dusts is varied. Some dusts are relatively inert in their chemical effect *others can be highly toxic*. For example, dust that passes over western China collects aerosols from fly ash from coal-fired power stations, from steel mills, and from petro-chemical plants. When dust particles mix with emissions from industrial and urban sites, it triggers chemical changes inducing morphological deformation of primary particles along with formation of new secondary ones.

a. Entrainment and Deposition of dust

Dust is entrained if the soil surface is dry (the critical surface wetness is 0.3 on a scale of 0 (dry) to 1 (saturated) and wind velocity exceeds a threshold (about 7 m/sec). It is also likely to be more severe if there is a vertical updraft as well as a horizontal air flow. The threshold friction velocity for lifting dust is 60 (cm/s) (Fig. 1).

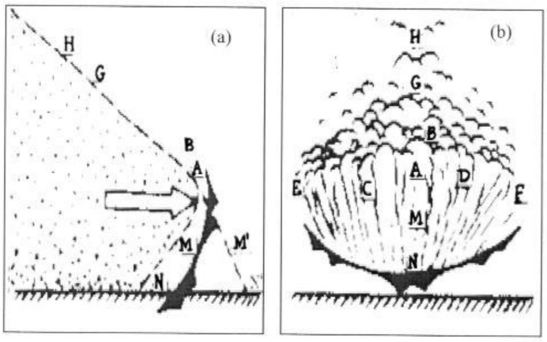

Fig. 1. Sketch from a video capture of (a) the side view (b) and front-view of dust storm peak as a cold front passed through the Hexi Corridor, Gansu March, 2002

Field observations and wind tunnel laboratory research allow us to understand the physical process (Squires, 2001). Consider a surface made up of separate particles that are held in place by their own weight and some inter-particle bonding. At a low speed wind, there will be no indication of motion, but when the wind force reaches the threshold value a number of particles will begin to vibrate. Increasing the wind speed still further, a number of particles will be ejected from the surface into the airflow. When these injected particles impact back on the surface, more particles are ejected, thus starting a chain reaction. Once ejected, these particles move in one of three modes of transport depending on particle size, shape and density of the particle. These three modes are designated suspension, saltation and creep. Its size and density determine movement pattern of sand-dust particles (Table 1).

Table 1. Movement of soil particles under a wind force of 15 metres/second

Particle Size (mm)	Period of Suspension (time)	Comment/Description
0.1	0.3-3.0 seconds	Fine sand
0.01	0.83-8.3 seconds	Dust. Can go up to 700 m high
0.001	0.95-9.5 seconds	Fine clay can go up to 77 km high

The suspension mode involving dust particles of less than 0.1 mm in diameter and clay particles of 0.002 mm in diameter are small in size and light in density and can be lifted by vertical air currents carried over long distances (Squires, 2000).

A number of factors determine rates of dust deposition (Yang *et al.*, 2000). Many of these are similar to those governing deposition of other pollutants. An increase in surface roughness causes a significant increase in deposition rates. This is particularly important for xerophytic plants, many of which have rough, sclerophyllous leaves, often with hairs or bristles. Deposition is likely to occur at a rate dependent on particle size. The heavier particles are deposited sooner but a greater deposition rate may occur at high wind speeds and for particles greater than 10 /µm diameter, much of it caused by collisions at the higher wind speeds and changes in trajectory.

Arslan and Boybay (1990) studied dust fall mechanisms and concluded that dust from nearby sources such as cement works had particulates of >30 µm that travelled relatively short distances. Work of a joint Japan-China team showed that dust aerosols, by contrast can travel thousands of km from the point of entrainment.

Dust deposition onto vegetation

Dust falling onto plants may physically smother the leaves. Thus the absolute level of deposition is important. This is affected by dust emission rates after entrainment, by meteorology and conditions on the leaf surface. Wet surfaces contribute to increased deposition. Thus while rain may partially wash leaves clean of deposited dust, the resulting wet surfaces may then experience higher deposition rates. Chaturvedi *et al.,* (2013) analysed the effect of Dust Load (DL) on the leaf attributes of the four tree species (*Tectona grandis*, *Syzygium cumini*, *Anthocephalus cadamba)* planted along the roadside at a low pollution site and a highly polluted industrial area in India. The studied leaf attributes were: leaf area, Specific Leaf Area (SLA), Relative Water Content (RWC), Leaf Nitrogen Content (LNC), Leaf Phosphorus Content (LPC), Chlorophyll Content (Chl), maximum stomatal conductance (Gs_{max}), maximum photosynthetic rate (A_{max}) and intrinsic Water-Use Efficiency (WUEi). Results showed significant effect of sites and species for DL and the leaf attributes. Average dust load across the four tree species was 28 times greater near the industrial site than at the low pollution site. Maximum DL was observed for *Tectona grandis* near the industrial site and the minimum for *Syzygium cumini* at the low pollution site. Crop architecture seemed to account for the differences between species in their propensity to accumulate dust. Maximum photosynthetic rate was suppressed by DL in all four tree species but some (*Anthocephalus cadamba* and *Syzygium cumini* L.) were less affected than others.

Dust can physically block stomata. Krajickova & Mejstrik (1984) noted that the stomatal diameter was 8-12/µm for a range of plant species and that dust particles, especially dust aerosols are much smaller. The diffusive resistance in leaves is increased in some cases where dust has accumulated and it was suggested that the dust may act directly on the guard cells, though the mechanisms for this are uncertain (cited in Farmer, 1993). Other effects are increased rate of transpiration, increase in leaf temperature, reduced rate of photosynthesis, cell plasmolysis, leaf necrosis, leaf rolling, inhibition of leaf expansion and interference with pollination and fruit set. This last mentioned is of great concern to orchardists.

All of these lead to lower levels of productivity and in serious instances, loss of whole communities of plants. In addition to physiological effects, there is physical injury and growth reduction. Which of these effects is dominant will depend on the type of dust. Dust effects on plants may occur as result of changes to the soil. This may be one of the most important long term effects that contribute to loss of whole plant communities (see below for case study on oak woodlands in western Iran).

Depending on the source of the dust there may be pollutants that damage the soil surface or dust deposits that change the pH or other factor. e.g. high Fe or Al can affect uptake of other soil nutrients.

a. Effect of dust deposition on grasslands and other rangelands

The earliest reference to dust effects on a natural community are those of Parish (1910) concerning cement dust deposition onto shrub and grassland vegetation in California. On slopes facing the cement factories there were almost pure stands of *Artemisia californica*, with species such as *Encelia farinosa, Salvia apiana and Salvia mellifera* having declined or become extinct. The leaves of *Aspidotis californica* are narrow and although dusty, did not allow the production of hard surface scales which occurred on the other species. These leaves still become yellow, but generally the species remained resistant.

The most extreme effects of dust on grassland were those found by Krajickova & Mejstrik (1984) around a magnesite factory in Czechoslovakia. There deposition was so great that surface crusts were often formed on the leaves and stems. Species that usually occur in this region, such as *Lolium perenne, Polygonum aviculare* and *Poa annua*, were replaced by *Puccinellia distans, Chenopodium glaucum* and *Agropyron repens*. The community here seemed to be responding to the very high ionic levels in the soil as the tolerant species were basically halophiles rather than strictly calcicoles.

Lower rates of deposition also cause changes to grasslands, although the effects are more subtle. Greig *et al.*, (1974) noted changes in acidic grassland at Grange Hill, Derbyshire due to lime quarry dust. The upper soil horizon was found to be less acidic than lower horizons and calcicolous species were more abundant. The invertebrate fauna had also altered, with the occurrence in the dusted grassland of the snail *Cepaea nemoralis*, a species usually restricted to calcareous grassland.

Topley Pike is a Derbyshire shrub land that has been affected by limestone dust deposition. The unpolluted shrub lands have a soil pH of 3-4 and a number of acidophilous species as dominants, including *Calluna vulgaris, Vaccinium myrtillus* and *Galium saxatile*. The dust-affected areas have a soil pH of 1-5 units higher and are characterised by calcareous species such as *Primula veris*. Tree species, such as *Corylus avellana*, may also have died as the result of the dust.

The consequences of this change in the vegetation has been an alteration in the invertebrate communities. The leaf beetles that feed on *Galium saxatile, Timarcha goettingensis* and *Sermylassa halensis* have declined in abundance. Even species common on calcareous grassland, such as *Cepaea* spp. and *Arianta arbustorum*, have declined due to their food plants being very heavily dusted. As a result of the decline in these herbivores, four insect predators, including *Lampyris noctiluca*, were also of low abundance in the region receiving dust.

b. Impact of dust deposition on shrubs, trees and woodlands

Trees and shrubs are very efficient at filtering dust. There are differences between evergreens and deciduous species. A comparison of broadleaved *Carpinus betulus* and conifer species *Picea abies* showed that dust was deposited mostly to the upper branches of *C. betulus*, but to the lower and middle branches of *P. abies*. In contrast, Pyatt (1973) found that there was greater deposition onto the lower branches of three broadleaved species in a field examination. The ability of trees to trap dust efficiently has led to their use as windbreaks, especially around artificial oases in Northwest of China, Iran and elsewhere and for protection of vulnerable infrastructure.

The level of dust on the leaf surface that is necessary to cause damage has been studied. Fluckiger (1979) found that, while 1 mg cm^{-2} of dust was necessary to cause a decrease in stomatal diffusive resistance in *Populus tremula*, only 0.5 mg cm^{-2} was necessary to cause an increase in leaf temperature. Thompson *et al.* (1984) were only able to find effects on *Viburnum tinus* with deposition rates of 5 g m^2 d ~.

It is not certain how important some of the physiological responses described above are for the long-term health of the trees but what is known is that through a combination of mechanisms (see above) the structure and function of a plant community and the accompanying biota can change.

c. Affect of dust on Terricolous cryptogams

Cryptogams are terricolous species, mainly lichen-based but mosses and liverworts and cyanobacteria (blue-green algae), green algae and fungi are involved (Eldridge, 1993) and may either be affected directly by the deposited dust, or there may be an indirect effect via changes in soil chemistry.

Road dust was found to kill lichens along a dirt road in Alaska (Walker & Everett, 1987). Sensitive terricolous species included *Cladonia* spp., *Peltigera* spp., *Cetraria* spp. and *Stereocaulon* spp.

The diffuse growth form of many crypotams is thought to be efficient at trapping dust particles and some species have been found to incorporate dust into the thalli as they grow (Garty & Delarea, 1987). Direct effects are likely to be most important for these terricolous species, which normally receive most of their nutrient input directly from the atmosphere. Dust could either shade them or adversely alter the chemistry of the cell wall exchange sites and so affect nutrient uptake.

Case study of a dust-affected oak woodland in western Iran

Western Iran borders Iraq is a region that is subject to severe dust storms from source materials originating in those neighbouring countries (Fig. 2).

External dust is 95% of external origin. Iraq, Syria and Turkey have generated the largest amount of dust, respectively. The Tigris-Euphrates alluvial plain has been recognized as the main dust source in the Middle East. One of the main reasons for the occurrence of dust can be attributed to the dam constructed by Turkey on the rivers Tigris and Euphrates that impedes the flow of water downstream towards Iraq. The resulting drought and drying of wetlands and groves of Iraq due to loss of moisture has led to the formation of regional dust. Furthermore, marshes in Iraq acting as air filters have drained and their water has been transferred to other parts by means of some canals and this has destroyed marshes such as Hoorolazim.

Other main causes of dust phenomenon in the region are drought, the invasion of western countries and its impact on the agriculture of Iraq and redirection of the rivers to Al-Anbar. The dust originating from this area can be transported over large distances because the dust particles from this area mainly consist of fine sediments from the Tigris and Euphrates rivers. Therefore, the dust storms from the Middle East also have important impacts on the neighbouring countries like Iran. The dust activities have intensified in the area in recent years, partly due to the development of the dam construction projects on Tigris and Euphrates rivers.

Construction of new dams decrease the humidity and water content of soil in the downstream areas, which consequently lessen the threshold friction velocity of the soil and its resistance against wind erosion.

Fig. 2. Source of dust in the neighboring countries of Iran

Dust storms result from a convergence of atmospheric and surface conditions and these are often favourable to dust events in western Iran[1]. The root cause is the damming of rivers in Turkey (Bastan *et al.*, 2013) that provide water to the Tigris-Euphrates system. As flows to Iraq and Syria were reduced, ground water recharge has diminished and riparian vegetation has died, exposing floodplains (comprising fine sediments) to the action of wind. Diversion of water westward to Al-Anbar for never completed projects within Iraq itself has led to land abandonment and created conditions favourable to dust entrainment. Al-Anbar is mainly a plain area covered with sand and clay with soil particles smaller than 0.05 mm that are susceptible to entrainment by winds that blows from west to east.

[1]- More information including case studies, is available at the NRL Aerosol Website: http://www.nrlmry.navy.mil/aerosol/]

Over the past decades the situation has become more serious in some countries such as Iraq and Kuwait (Fig. 3). The disaster damages nearly 6 million hectares especially notable farmlands, residential and industrial areas. There is serious damage to field crops and horticultural production - especially in stone fruits like apricots and peach and in palm groves during budding and fruiting seasons. Natural woodlands dominated by deciduous Persian oak (*Quercus brantii*) and covering almost 1 million ha (Sagheb-Talebi *et al.*, 2004) are declining (as dust accumulation on leaves affecting their physiology (see above) Dust deposition on the soil surface affects the pH and the nutrient balance and also affects cryptogams and soil biota. Dust deposition can have adverse effects on ecosystems (McTainsh and Strong, 2007 and Okin, 2008). Dust loads on leaves are high because frequently there is dust deposition that exceeds 24 g/m. maximum Total Dust Fall (TDF) was

24.42 g/m^2.month and the minimum 6.56 g/m^2.month (These values are higher than the standard for good air quality). The implications for the human population are also grave[2]. Dust-sand storms are believed to contribute to lung diseases like silicosis, caused by breathing in small, airborne particles (<2.5 µm). Particles larger than 10 µm are inhalable but do not penetrate the respiratory system depth. These particles create problems for the upper respiratory tract. Generally, these particles have led to a great concern on the terrestrial environment at local, regional and global scale Settle able particles usually have aerodynamic diameters of more than 10 µm. Dust fall, affects not only the air quality of cities, but also public health. Dusts and dust fall can lead to diseases such as tonsillitis, allergy, daily pneumonia, asthma and eye irritation. Dust events have been seen as a risk factor for daily hospitalization for respiratory and cardiovascular diseases.

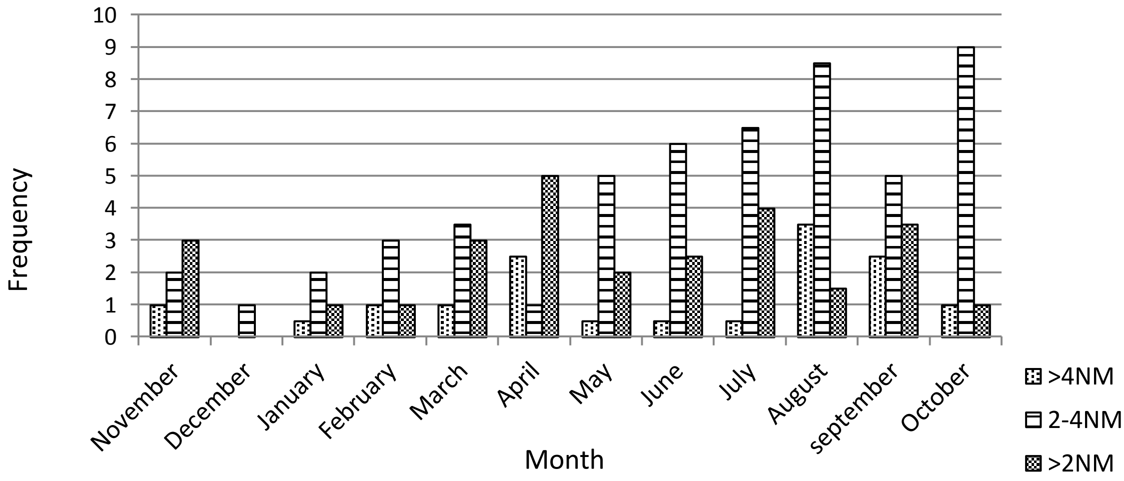

Fig. 3. Monthly Frequency of Dust Storms in Iraq and Kuwait, by Visibility

Conclusions

Dust and sand storms are an increasingly common phenomena, even in places like Australia and western USA where the scourge of the 1930s was thought to be under control, but the everyday effects of dust deposition on the biota are persistent and insidious. It can lead to long term effects on the local ecology from shifts in species composition and diversity. The impact of dust particles and dust aerosols on biota deserve more attention from researchers. Observations of dust deposits on vegetation in regions prone to frequent and severe dust storms in western China, western Iran and elsewhere show that the effects of dust on crops. Grassland, woodland, and cryptogam communities are particularly affected. Dust accumulation, especially on xerophytes that frequently are hirsute or have vesicles to assist in salt excretion, are affected by reduced rates of photosynthesis, respiration and transpiration.

[2]- http://www.epa.gov/region07/air/quality/pmhealth.htm

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تاثیر ریز گردها و آئروسول‌ها بر زندگی جوامع گیاهی و جانوری (قسمت اول)

ویکتور روی اسکورز[الف]

[الف]استاد دانشکده منابع طبیعی و اکولوژی دانشگاه گانژو، گانژو، چین (نگارنده مسئول)، پست الکترونیک: dryland1812@internode.on.net

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چکیده. اثرات سوء ریزگردها و طوفان‌های شنی بر انسان، محصولات، احشام، زیر ساخت‌ها و سلامت جامعه به خوبی اثبات شده است. منابع متعددی در مورد تاثیرات مخرب ریز گردها به هنگام نشست آنها بر روی گیاهان منتشر شده است. نشست ریزگردهای ماسه ای بر روی گیاهان دیر زیست که دارای رشد کند و بطئی هستند از جمله علت شکست تلاش‌های احیای جنگل‌ها محسوب می‌شود. همچنین مدفون شدن گیاهان بوسیله‌ی شن‌های روان سبب آسیب و تخریب‌های بسیار زیاد می‌شود. در این مطالعه جابجایی فیزیکی ماسه‌های روان و ریزگردها بطور خلاصه بیان شده است و مکانیسم تخریب و آسیب هر یک از آنها تبیین گردیده است. همچنین تاثیرات مخرب تجمع ریزگردها بر روی سطوح برگ، فیزیولوژی برگ، مثل فتوسنتز، تنفس، هدایت روزنه‌ای و دمای برگ در بسیاری از گونه‌های گیاهی بیان شده است. تحقیقات ثابت نموده که ریزگردها هدایت روزنه‌ای برگ‌ها را در نور کاهش و در تاریکی افزایش می‌دهند زیرا روزنه‌ها در تاریکی در طول نشستن گرد و غبار باز می‌باشند. تاثیر ریزگردها با ابعاد کوچکتر بسیار شدیدتر است به هر حال این تاثیر زمانی قابل اغماض می‌باشد که روزنه‌ها درطول جریان گرد و غبار بسته باشند. علاوه بر این ریزگردها میزان فتوسنتز را از طریق سایه‌اندازی بر روی سطح برگ کاهش می‌دهد. در این مقاله آثار تجربی و آزمایشی در مورد تاثیرات فیزیکی ریزگردها بر فتوسنتز، عملکرد روزنه‌ها، تعریق و تنفس مرور می‌شود. در این مطالعه بیشتر به مناطق غربی کشور ایران اشاره شد چرا که در این منطقه جنگل‌های بلوط (***Quercus brantii***) به واسطه ریزگردهایی با منشاء عراق و سوریه تهدید می‌شوند.

کلمات کلیدی: ریزگردها، آئروسل، طوفان شن، ***Quercus brantii***