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WIND EROSION IN A MARGINAL MEDITERRANEAN DRYLAND AREA: A CASE STUDY FROM THE KHANASSER VALLEY, SYRIA

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ABSTRACT

Evidence of wind erosion is widespread in the drylands of the Mediterranean region. The purpose of this study was to quantify the extent of windblown dust and to assess the factors that affect the susceptibility to wind erosion in areas that are marginal due to their aridity. The study was carried out in Khanasser Valley, a typical degraded, marginal area in northwestern Syria. The average annual rainfall is about 200 mm and falls mainly in the winter months. In the valley floor, cultivation of rainfed barley using conventional tillage has spread over the past decades due to mechanization, reducing the area of natural grazing land. After harvest, the stubble is grazed by sheep leaving the land bare and vulnerable to wind erosion during the following hot and dry summer months. BSNE (Big Spring Number Eight) samplers were installed to sample the horizontal flux of airborne dust during the summer months of 1998–2001 at two land uses in the study area, i.e. on natural grazing land and on harvested and grazed barley fields. Sediment samples were collected at weekly intervals. The average daily mass flux of airborne material for the 5 to 100 cm height was $0{\cdot}285$ g cm^{-1} width for the cropland, as compared to $0{\cdot}089$ g cm^{-1} width for the degraded grazing land. During two of the four seasons, more than 45 per cent of the total airborne sediment trapped for the season was captured during a single week, at both landuse locations. The quantity of airborne materials transported by wind was related to the wind factor, soil management and surface conditions. Nutrient and organic matter content of the airborne sediments exceeded the amounts in the parent soils, indicating that wind erosion could contribute to nutrient depletion of the source areas. Copyright © 2003 John Wiley & Sons, Ltd.

KEY WORDS: wind erosion; dust; aggregate distribution; Syria; drylands

INTRODUCTION

Wind erosion occurs in all parts of the world and is a cause of serious soil degradation, especially in drylands (Middleton and Thomas, 1997). Vast areas of the Mediterranean region have an average annual precipitation below 250 mm, with large variations in time. Lack of adequate and reliable rainfall to support a sustainable, protective land cover against the erosive forces of the wind is a major limitation in this region. Although these fragile natural ecosystems exhibit an amazing ability to recover from very variable climatic conditions, their resilience is strongly affected by human influence. Large populations exert pressure on these natural resources and these lands are often used beyond their carrying capacity, paving the way for serious land degradation, such as wind erosion. Wind erosion affects both rangeland and arable land. The deposition of wind-blown sediment on irrigated land and irrigation infrastructure has also serious implications for agricultural productivity (Zöbisch, 1998).

Rangelands in West Asia and North Africa cover about 30 per cent of the land and provide a third of the diet of some 420 million small ruminants (El-Beltagy, 1997). These lands are typically open to unrestricted grazing and are in poor condition. Cultivation of annual crops in degraded rangelands, a regularly occurring practice in this region, is leaving the lands bare during a large part of the year. In arable areas, due to growing populations and the need to produce more biomass, traditional practices of fallowing have often been replaced with continuous cultivation. When little or no nutrient amendments are used to replace the rapidly declining soil-nutrient pool, soil cover is decreasing rapidly, leaving the soil without protection.

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Drylands are more susceptible to wind erosion than any other biome because soils are dry, often loose, and sparsely covered with vegetation. Together with the soil particles, organic matter and nutrients are removed leading to significant soil-fertility decline in the source areas (Zobeck and Fryrear, 1986). Removal of silts and organic matter has an adverse effect on structure and soil moisture retention. On the other hand, the suspended dust supplies the depositional areas with valuable nutrients.

The low rate of soil formation in dry areas is an additional concern. Middleton and Thomas (1997) quoted rates between 0·01 and 1 mm a^{-1}. Thus, loss at even a slow rate of 1 mm annually may not be fully replaced by soil development.

In Syria, widespread devastation of land and resulting crop failures due to drought and wind erosion have drawn broad attention to soil degradation, over the last 25 years. Several surveys of the frequency, intensity, and duration of dust storms conducted over the past twenty years showed that the steppe areas in Syria are frequently affected by wind erosion. In 1984, for example, 11 major dust storms with durations of more than 1 hour and visibility of less than 100 m were observed (Askar, 1991). AOAD (1994) reported annual soil losses between 40 and 96 t ha^{-1} for the Syrian steppe areas. Askar (1999) observed 100 dusty days in 1990 and 120 dusty days in 1991 in a rangeland area in eastern Syria, which had been used for rainfed cereal cultivation. Soil flux measurements in a bare field with poor soil structure in northern Syria indicated that soil losses of up to 30 t ha^{-1}, which is equivalent to a loss of approximately 3 mm soil depth, could occur during the windy and hot summer months of July to September (Timmerman, 1991).

The purpose of this study was to quantify fluxes of wind-blown soil particles during the hot summer months in a marginal dryland area in northern Syria, both in natural grazing land and in fields used for rainfed cereal cropping. The study area, located in the transition zone between natural grazing lands and rainfed cereal cropping systems, suffers regularly from fugitive storms of aeolian dust. The cultivated fields are usually bare after harvest because the residue and stubble are grazed by sheep. The dry soil surface becomes disturbed due to the trampling of the sheep, rendering it extremely vulnerable to wind erosion. Dust devils, small convective vortices that transport the sediment up to great heights, are common in the area, especially during the hot summer months on the dry and bare crop fields.

MATERIALS AND METHODS

Study site

The study was conducted in the Khanasser Valley, located at the northern fringe of the Syrian steppe, about 70 km southeast of the city of Aleppo, northwest Syria (Figure 1). The valley is predominantly flat. Its altitude is approximately 350 m above mean sea level and it receives an annual rainfall of 150–250 mm, which occurs erratically between October and May. The average (1998–2001) mean monthly temperature for the dry months of June to September varied between 25 °C (September) and 31 °C (July). The valley is situated between two hill ranges, Jebel Al Hass in the west and Jebel Shbeith in the east. The soils in the valley floor are fine to moderately textured dark-brown to brown Calcisols, Gypsisols, Leptosols and Cambisols (Louis Berger International, 1982). The soils of the Jebel Al Hass and Jebel Shbeith hill ranges are Inceptisols. Most households practice a combination of crop production and livestock rearing. Rainfed farming, with barley as the dominant crop, occupies the major part of the arable land. Sheep graze the fields after harvesting, leaving a bare and loose soil surface, due to the trampling of the animals.

Measurements

The aeolian mass fluxes during the dry summer months of 1998–2001 (four years) were measured in natural grazing land on the plateau and in the cultivated land on the valley floor. The grazing-land test site was permanently located close to Um Mial village on the plateau of Jebel Shbeith. This site was sparsely covered with natural vegetation. The cultivated test site was composed of four test areas, with a different site identified on the valley floor each year (Figure 1).

Big Spring Number Eight (BSNE) sampling clusters, following the design of Fryrear (1986), were used for the wind erosion observations. A sampling cluster consisted of five samplers, each attached to a pivoting wind

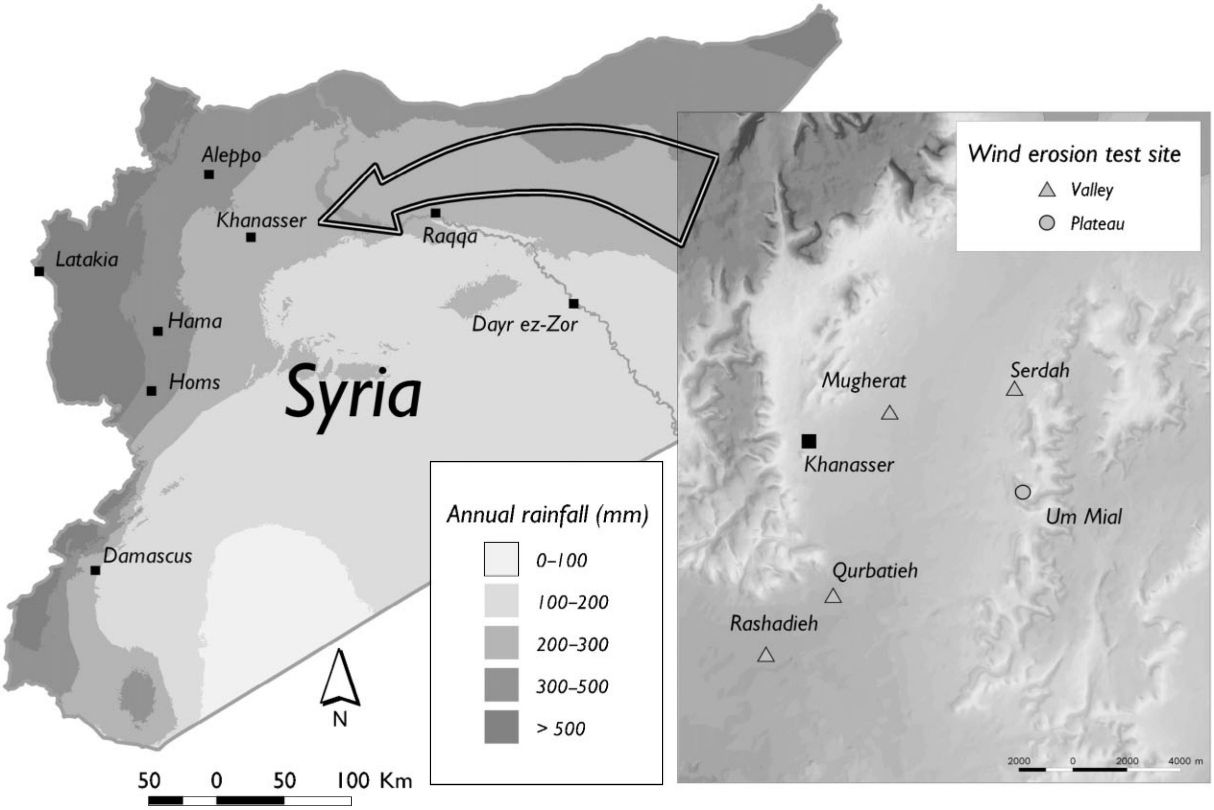

Figure 1. Location of the study area

vane. The samplers were mounted at 5, 10, 20, 50 and 100 cm above the ground (mid-level of sampler inlet). The sampler inlet areas were 2, 4, 6, 10, and 10 cm^2 at heights of 5, 10, 20, 50 and 100 cm above the soil surface, respectively (Figure 2). At each site, 17 clusters were arranged in a radial pattern covering the eight main compass directions. The radial distances from the centre sampler location were 50 and 100 m.

The cropland sites in the valley were located in a large flat and bare area. No non-erodible field boundaries were present within at least 100 m of the samplers. In the grazing land, the samplers were located in the centre of an isolated section of the plateau. It is connected by a narrow passage to the main plateau in the south. The maximum length and width of the plateau were 600 m (north–south) and 500 m (east–west), respectively. The flat area of the plateau ends in stone-covered, steep scarps. The plateau rises approximately 60 m above the cultivated fields at its foot.

Sampling started in late June or early July after the barley was harvested and the stubble grazed by sheep. The sampling continued for 12 to 14 weeks. The trapped airborne particles were collected on a weekly basis and stored until the end of the season. On a few occasions the sample weeks were not exactly a week. There was generally a two-day difference between the sample collection at the plateau and valley sites. All airborne sediment samples were weighed. For the analysis of mass discharge and wind, a 12 week period, which closely overlapped at the plateau and valley sites was used. The complete set of samples for the season for all 17 clusters was composited at each sampling height for subsequent physical and chemical analysis.

The top 5 cm surface soil from all study sites was sampled using a flat shovel. The soil was analysed for texture using the pipette method (Gee and Bauder, 1986). Dry aggregate size distribution was determined according to Kemper and Rosenau (1986), but using sieve sizes of 10, 5, 4, 2, 1, 0·5, 0·2, 0·1, and 0·05 mm.

Composite samples of the parent soil at each site and of the trapped airborne materials at the five sampler heights were dry-sieved on 1·0, 0·5, 0·2, 0·1, and 0·05 mm sieves. Organic matter, available phosphorus (Olsen method), total Kjeldahl nitrogen, inorganic calcium carbonate ($CaCO_3$), and extractable potassium (K) were

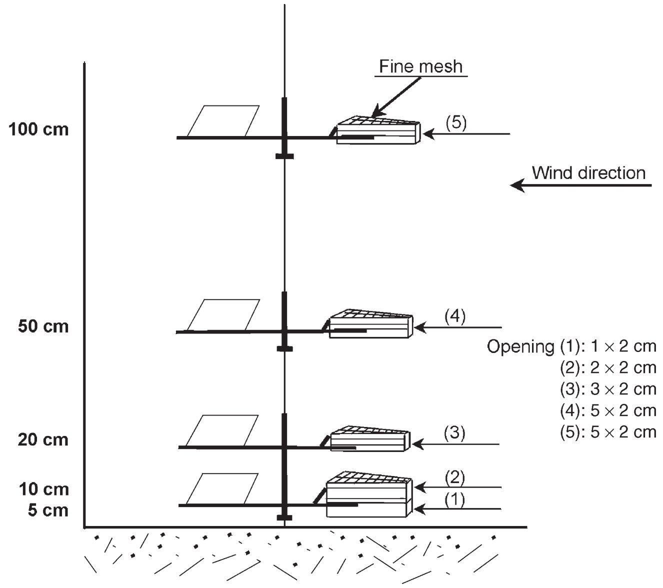

Figure 2. Setup of a BSNE sampler cluster

Table I. Physical and chemical properties of the surface soil (0–5 cm), at the study sites on the plateau (Um Mial) and in the valley (Qurbatieh, Serdah, Mugherat, Rashadieh)

Location	Texture (%)			OM (%)	Olsen-P (ppm)	Kjeld-N (ppm)	$CaCO_3$ (%)	Extr.K (ppm)	pH_w	EC_w ($dS\ m^{-1}$)	Soil taxonomy	FAO classific
	Clay	Silt	Sand									
Um Mial	24·4	53·7	21·9	3·5	13·7	2037	34·1	371	8·07	0·65	Lithic Xerochrept	Eutric Leptosol
Qurbatieh	37·8	49	13·2	1·58	17·7	993	33·1	591	7·78	2·95	Calcic Gypsiorthid	Calcic Gypsisol
Mugherat	22·3	48·7	29	1·85	21·3	869	49·6	676	7·98	0·77	Typic Calciorthid	Luvic Calcisol
Serdah	21·1	40·1	38·8	1·17	6·9	770	27·1	453	8·08	0·67	Typic Calciorthid	Luvic Calcisol
Rashadieh	10·3	44·1	45·6	1·37	3·8	762	13·1	241	7·69	1·85	Calcic Gypsiorthid	Calcic Gypsisol

Abbreviations: OM: soil organic matter; Olsen-P, available phosphorus; Kjeld-N, Kjeldahl nitrogen; $CaCO_3$, inorganic calcium carbonate; Extr.K, extractable potassium; pH_w, pH of 1 : 1 soil water extract; EC_w, electrical conductivity of 1 : 1 soil-water extract.

determined according to standard procedures (Ryan *et al*., 2001). The pH and electrical conductivity (pH_w, and EC_w, respectively) were determined from a 1 : 1 (soil:water) suspension (Ryan *et al*., 2001). Table I summarizes the physical and chemical properties of the top 5 cm of the parent soils and their soil taxonomy. The soils are classified according to Soil Survey Staff (1994) and FAO (1990).

Automatic climate stations, which recorded both wind velocity, with a cup anemometer, and wind direction at 2 m height, were installed on the eastern plateau at Um Mial and in the southern part of the valley in Qurbatieh. Wind parameters were sampled at a 5 s interval; minimum, maximum, and average wind speed, and average wind direction were computed and stored on an hourly basis. To assess the transport capacity of the wind for smooth surfaces, a wind factor was computed, analogous to Fryrear *et al*. (1998). The wind factor was defined as follows:

$$WF = \sum_{I}^{N} U(U - U_t)^2 \tag{1}$$

where WF is the average daily wind factor, U is the observed average hourly wind speed, U_t is the threshold wind velocity, and N is the number of hours per day (24). The hourly component is set to zero if the wind speed is smaller than the threshold wind speed. No measurements have been conducted at the sites to determine wind erosion threshold velocities. A threshold velocity of 5 m s^{-1} was assumed (Fryrear, 1995).

RESULTS AND DISCUSSION

Mass transport

For each site, the sediments collected at the five different heights were calculated as an average of the 17 samplers. Masses for each height were converted to horizontal sediment flux per square centimetre in a vertical plane. The total mass fluxes for the 12 sampling weeks at each site are presented in Table II.

To estimate the mass flux for a vertical plane, a model is fitted through the fluxes measured by the samplers at the discrete heights. Many authors have reviewed the distribution of airborne material with height above the soil surface (e.g. Fryrear and Saleh, 1993; Sterk and Raats, 1996). Fryrear and Saleh (1993) used a combined model with an exponential equation to describe the vertical distribution caused by saltation and creep processes and a power function to describe the vertical distribution of suspended materials. Our sampling clusters did not have sufficient sampling heights to justify the fitting of this four-parameter equation. Therefore, we used the modified power model suggested by Van Donk and Skidmore (2001):

$$q(z) = a(z+1)^b \tag{2}$$

where $q(z)$ is sediment flux (g cm^{-2}), z is the height of the sampler opening above the soil surface (cm), and a and b are fitting parameters. Sediment discharge, passing the BSNE clusters, was determined by integrating Equation 2 from 5 to 100 cm:

$$Q = \int_0^{100} q(z)dz = \frac{a}{b+1}[(100)^{b+1} - (5)^{b+1}] \tag{3}$$

where Q is the sediment flux or mass discharge (g cm^{-1} width).

Equations were fitted for each sampling week as well as for the total mass fluxes of the 12-week sampling period. Although the equations took a different shape during highly erosive weeks, the difference between the summarized weekly mass discharge and the computation from the 12-week totals was generally less than 1 per cent, indicating the robustness of the equation within the sampled height. The computed total mass discharge (g cm^{-1} width day^{-1}), for the 5 to 100 cm height is summarized in Table II for all four seasons. The results show

Table II. Soil mass flux at sampler heights and mass discharge for the 5 to 100-cm height on the plateau (Um Mial) and in the valley (Qurbatieh, Serdah, Mugherat, Rashadieh)

Location	Year	Sampling period (days)	Soil mass flux (g cm^{-2}) at 5 heights					Total mass discharge* (g cm^{-1} width d^{-1})
			5 cm	10 cm	20 cm	50 cm	100 cm	
Um Mial	1998	84	0·42	0·21	0·11	0·05	0·03	0·078
Qurbatieh	1998	84	0·58	0·36	0·26	0·19	0·16	0·246
Um Mial	1999	82	0·18	0·07	0·04	0·03	0·04	0·050
Mugherat	1999	83	1·15	0·43	0·32	0·21	0·14	0·284
Um Mial	2000	82	0·49	0·27	0·22	0·15	0·13	0·199
Serdah	2000	83	0·92	0·44	0·37	0·22	0·21	0·334
Um Mial	2001	86	0·12	0·06	0·03	0·02	0·02	0·029
Rashadieh	2001	83	0·91	0·57	0·33	0·17	0·14	0·277

* Mass flux integrated over the 5 to 100 cm height using a modified power function (Equation 3).

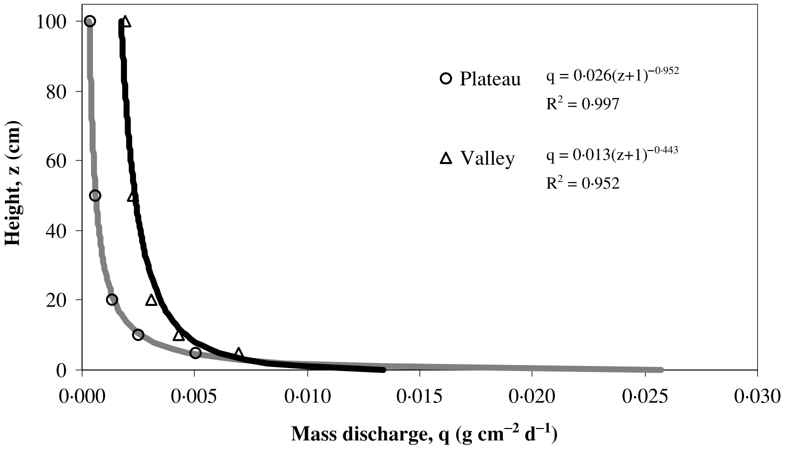

Figure 3. The mass discharge between 5 and 100 cm height during the summer of 1998 for the plateau and valley sites

clearly that the Um Mial site, located in the degraded natural vegetation of the plateau, had substantially lower mass discharge compared with the harvested and grazed barley fields in the valley floor.

The mass flux profiles for the 1998 season are presented in Figure 3. The higher mass discharge at the 100 cm height for the Qurbatieh site in the valley floor indicates that soil moved above the 100 cm height, while the mass discharge at the Um Mial site on the plateau was likely to be limited to 100 cm height. Similar results were found for the plateau and the valley in 1999 and 2001. In 2000, more airborne material was trapped at the 100 cm height on the plateau than during the other seasons (Table II). However, 74 per cent of that season's airborne sediment at 100 cm height was trapped during a single highly erosive week in July, in which 70 per cent of the total airborne sediment of the season was captured.

Figure 3 also illustrates that the extrapolation of the sampled fluxes to the ground level is strongly influenced by the fitted equation. For the 1998 season on the plateau, the flux between 0 and 5 cm, computed as a difference between integration over the 0 to 100 and 5 to 100 cm heights, constituted 58 per cent of the total mass discharge between the ground surface and 100 cm. The average for all seasons and sites was 24 per cent, with two of the four seasons having a higher 0 to 5 cm flux for the plateau than for the valley.

Wind speed and wind direction

In the valley, wind speeds are substantially higher in summer than during the other months of the year. Average monthly wind speeds during the months of June to September for the years 1998–2001, range between 2·8 (September) and 4·6 m s^{-1} (July), whereas the average for the remainder of the year is 2·3 m s^{-1}.

The wind parameters observed at the Um Mial and Qurbatieh stations during the 12 erosion sampling weeks are summarized in Table III. To establish wind protection measures, it is important to know the direction of the winds that are causing erosion. During the first two seasons the prevailing summer winds came from the west. The average daily wind direction for the four seasons varied between 186 and 273° (from north). In 2000, the prevailing wind direction was south. During the 2001 season, the number of days with northerly winds almost equalled those with westerly winds. There was no correlation between the daily maximum average hourly windspeed and wind direction. Wind speeds for all four seasons and wind factors for all except the 2000 season, were lower in the valley than on the plateau.

The weekly sampling did not allow the establishment of direct relationships between mass fluxes and wind parameters, but evidence of the effect of the wind was clear for extreme events. For three of the eight trials, Qurbatieh in 1998 and Um Mial and Serdah in 2000, more than 50 per cent of the soil that was captured during the season was trapped during a single weekly sampling event. In Qurbatieh, the average wind speed during this extreme week (11–18 July 1998) was 54 per cent higher and the maximum wind speed was 35 per cent higher than the average values for the season. The average daily wind factor for this week was five times the value

Table III. Average values of wind parameters for the Um Mial station on the plateau and the Qurbatieh station in the valley during the 12-week sampling period in 1998–2001

Location	Year	Wind speed (m/s)	Maximum speed* (m s^{-1})	Wind factor† (m^3 s^{-3})	Wind direction (° from N)	Wind direction distribution (% days)‡			
						North	East	South	West
Um Mial§	1998	3·7	10·1	114	237	12·7	4·8	6·3	76·2
Qurbatieh	1998	3·2	9·5	105	261	14·3	2·4	1·2	82·1
Um Mial	1999	4·8	11·0	214	255	2·4	1·2	0·0	96·3
Qurbatieh	1999	3·9	10·3	133	273	0·0	1·0	0·0	99·8
Um Mial	2000	4·3	10·6	148	219	4·8	8·4	43·4	43·4
Qurbatieh	2000	3·8	10·3	152	189	0·0	19·5	53·7	26·8
Um Mial	2001	4·5	10·6	175	194	38·4	18·6	9·3	33·7
Qurbatieh	2001	3·9	10·3	129	194	30·1	10·8	33·7	25·3

* Average maximum daily wind speed.

† Average daily wind factor.

‡ Distribution of average daily wind direction (e.g. 315–45° = north, 45–135° = east).

§ Data for 1998 available for the last 9 weeks of the sampling period only.

for the season. The daily wind direction during this week ranged between 257 and 287°, similar to the direction of the prevailing winds for the season.

A review of the wind parameters in Um Mial for the week of 7–14 September 1998, in which 46 per cent of the total soil mass for the season was trapped, showed no extreme values, except for an observed maximum wind speed of 20·3 m s^{-1} on 12 September. However, this wind gust was of short duration. For the hour during which this gust occurred, the average wind direction was 306° and the wind speed was 6·0 m s^{-1}. Obviously, the wind factor, computed using average hourly wind speeds is not always suitable for identifying highly erosive events.

During the 2000 season, more than 70 per cent of the total trapped mass for the season was captured during a single week in July. At the Um Mial station, five days within this week had maximum daily wind speeds between 12·6 and 16·6 m s^{-1} and wind factors between 318 and 2967 m^3 s^{-3}. Daily wind directions varied between 213 and 357°. At the station in Qurbatieh, the wind parameters were also substantially higher than the season averages. A maximum daily wind speed of 15·8 m s^{-1} and a wind factor of 2560 m^3 s^{-3} were observed on 17 July. The daily wind directions for this week varied between 177 and 256°.

The average daily values of the mass discharge for each sampling week in the valley sites showed a linear relation with the wind factor. Coefficients of determination (r^2) for the relations for the first three seasons in the valley were higher than 0·92. Regression analysis for the average seasonal totals in the valley (Table II and III) gave an r^2 of 0·87. On the plateau, the relations were not so clear. The relations were affected by a few sampling weeks with high mass discharge and a low wind factor.

Spatial distribution

The spatial variability of the mass discharge during the above-mentioned highly erosive week in July 2000 for the natural grazing site in Um Mial is illustrated in Figure 4. Mass discharge functions were fitted for each sampler and integrated for the 5 to 100 cm height. The data were spatially interpolated using ordinary kriging (Golden Software Inc., 2002). The wind during the most erosive period is coming from the north. The fact that the escarpment is within 100 to 200 m from the samplers, explains the general increase in mass discharge in the southerly direction. The variability of the mass discharge is probably caused by the inhomogeneity of the site. The coefficients of variation of the seasonal mass discharge observed by the 17 clusters varied between 15 per cent (plateau, 2000) and 54 per cent (valley, 1998). The average coefficient of variation for the four seasons was 21 per cent for the natural grazing site on the plateau and 35 per cent for the cropland sites in the valley. Even small variations in surface roughness, residue cover, and texture can have a substantial impact on the erodibility of a field (Stout and Zobeck, 1996). High spatial variability is typical for many agricultural fields. Even experimental fields that were made uniform for purposes of experimentation frequently showed large spatial variations in erosion (Hagen, 2001).

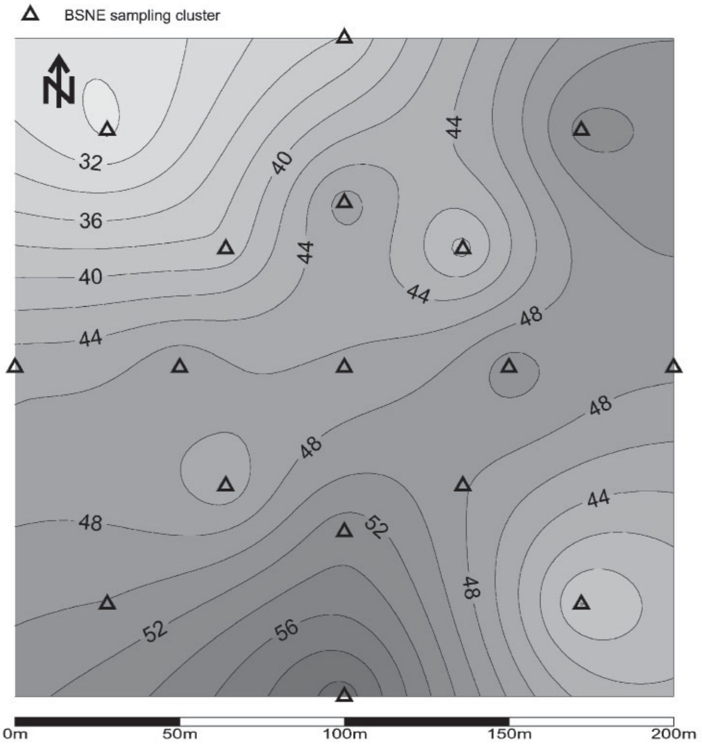

Figure 4. Spatial distribution of mass discharge for the 5–100 cm height (g width cm^{-1}) during a single week of erosive wind (15–21 July 2000) on the plateau

Aeolian dust

Aeolian dust is composed of fine-grained particles winnowed from the soil surface to often travel great distances. Over time, aeolian dust changes surface-soil texture, both in the source and fallout areas. It depletes the soil in the source area and enriches it with nutrients and organic matter in the fallout area. Results of the four years of monitoring give an idea about the sizes of the particles above the wind-eroded surface in the study area (Table IV). The suspension-sized particles (less than 0·1 mm diameter) remain in the air for an extended period, whereas saltation and creep particles quickly return to the surface. The trapped airborne mass was composed of 50 to 83 per cent suspension particles; the coarser mode or saltation particles (0·1–0·5 mm diameter) varied between 15 and 33 per cent, and the larger saltating material ranged between 1 and 17 per cent.

Considering that the efficiency of the BSNE samplers is low for fine particles, the contribution of aeolian dust to the airborne material is expected to be higher than reported. Several researchers tested the efficiency of the BSNE samplers. Goossens and Offer (2002) reported an efficiency around 40 per cent for silt soils (95 per cent

Table IV. Percentage of the airborne sediment at the sampled sites in suspension and saltation

Location	Year	Suspension <0·1 mm (%)	Saltation 0·1–0·5 mm (%)	Saltation >0·5 mm (%)	Total mass (g)
Um Mial	1998	50·6	32·7	16·7	3·14
Qurbatieh	1998	73·7	21·3	5·0	7·67
Um Mial	1999	66·4	27·1	6·5	0·36
Mugherat	1999	73·0	24·3	2·6	3·60
Um Mial	2000	82·7	15·5	1·9	1·26
Serdah	2000	82·9	16·2	0·9	2·14
Um Mial	2001	62·3	30·5	7·2	0·30
Rashadieh	2001	69·8	27·4	2·8	2·26

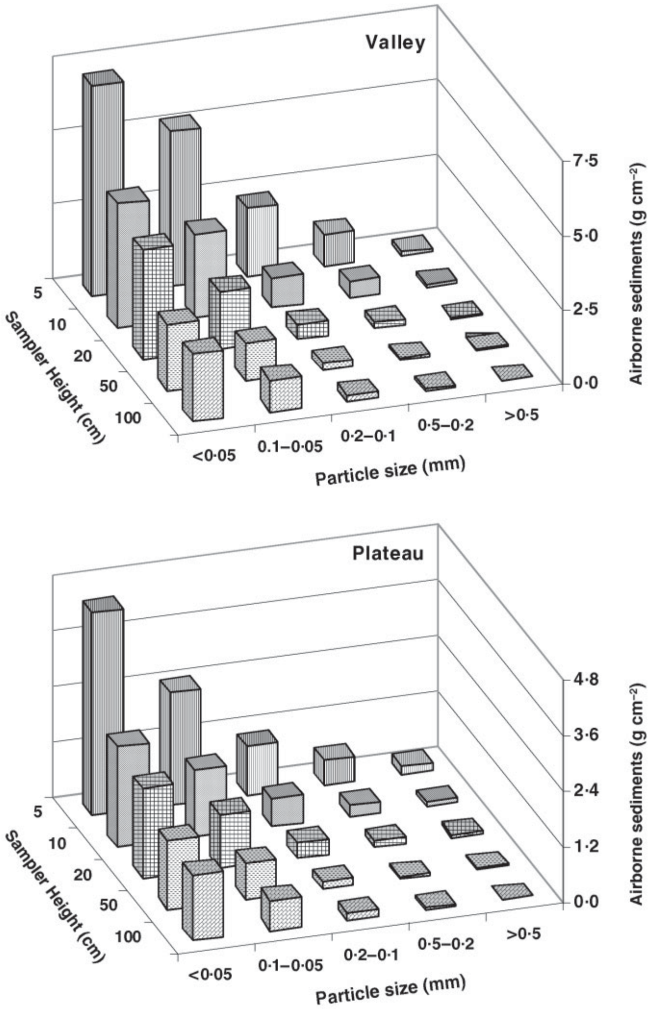

Figure 5. Particle-size distribution of the airborne sediments at different heights above the soil surface during the summer of 2000, in the valley and on the plateau

particles between 2 and 63 μm) at wind speeds between 1 and 5 m s^{-1}. Efficiencies between 70 and 130 per cent were obtained for sand with median diameters ranging between 0·13 and 0·29 mm at wind speeds above 6·6 m s^{-1} (Goossens *et al*., 2000). Assuming an efficiency of 50 per cent for the suspension-size particles and 100 per cent efficiency for the saltation particles, the contribution of suspension to the airborne mass would range between 67 and 91 per cent and the total airborne mass at the study sites would be 50 to 83 per cent higher.

The percentage suspension was always higher at the cropland sites in the valley floor than on the plateau. The plateau has a protective vegetative surface cover (approximately 40 per cent), whereas the soil surface in the valley is heavily disturbed by sheep and therefore more susceptible to wind erosion of the finer fractions. Rashadieh, which has the lowest percentage suspension of the four cropland sites, has the highest percentage of sand in the parent soil. The finer particles could have been removed by earlier events.

The suspended fraction can travel several kilometres (Tsoar and Pye, 1987). Thus, the results indicate a potential for far-distance translocation of airborne material in the study area.

Figure 5 demonstrates the measured aggregate size distribution of airborne fraction quantities with height. The trapped sediment decreased with height above the soil surface, while the particle-size distribution became more skewed towards the finer fractions. The differences between the two shown sites, Um Mial on the plateau and Mugherat in the valley, demonstrate that the near-surface portion of the mass flux clearly responded to soil

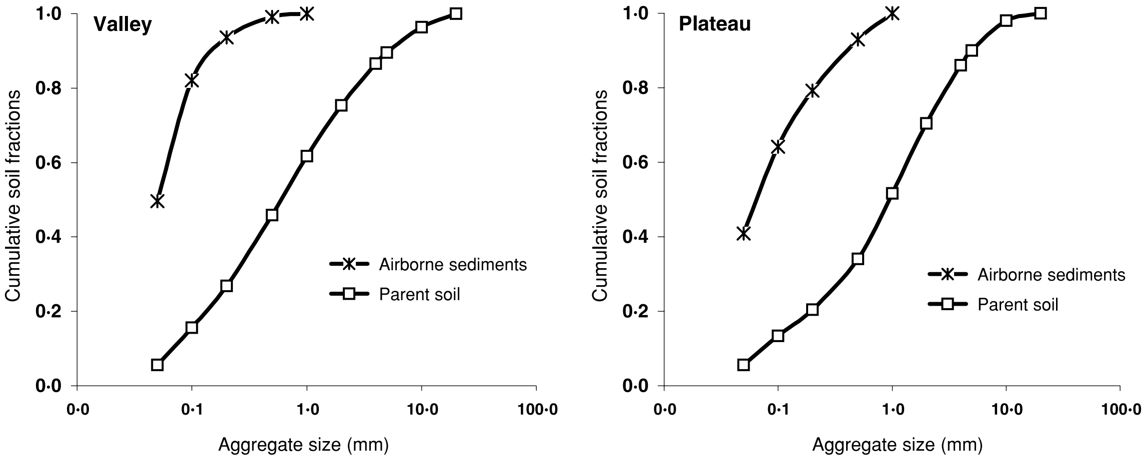

Figure 6. Cumulative curves of aggregate size distribution of the parent soil and airborne sediments at the valley and plateau sites for the year 2000

surface conditions. Similar results were found by Stout and Zobeck (1996). The degraded vegetative cover on the plateau in Um Mial provided more protection than the clean-grazed barley fields of Mugherat.

It is probable that dust deposition has influenced a variety of soil properties. McTainsh (1999) has shown that dust deposition measured in the north and southeast of the Mediterranean region was low (0·38 t km^{-2} a^{-1}); but even at this rate the dust deposition could exceed soil formation rates from weathering. Airborne dust quantities generally show a good inverse relationship with total annual precipitation. Middleton *et al.* (1986) suggest that this may be because infrequent stream runoff limits the dust supply, or because strong wind is less associated with fronts and cyclonic disturbances proportionate to more annual precipitation. However, it is more likely that it reflects the effects of sparse vegetation cover due to limited rainfall and high grazing intensities and the recent cultivation of marginal land. In the study area, the observed present-day dust storm activity is heavily influenced by agricultural activity.

Aggregate size distribution

Figure 6 shows the dry aggregate size distribution of the parent soil and the airborne sediment on the plateau in Um Mial and in the valley in Serdah for the 2000 summer season. The parent soil in Serdah had a higher percentage fine aggregates than that in Um Mial. The higher airborne mass in the valley, as compared with the plateau, was likely to be affected by the higher percentage of fine aggregates in the valley. The aggregates in the valley were pulverized by the trampling of the grazing sheep. On the plateau, on the other hand, the high organic matter content is expected to have a positive effect on the stability of the aggregates. The grain size distribution of sediments transported above a wind-eroded surface is strongly influenced by the grain size and structure of the surface material. Nevertheless, the fractions of airborne materials were always less than 1·0 mm regardless of the aggregate size distribution of the parent soil.

Nutrient and organic matter losses

Nutrient loss is a major concern of wind-erosion hazard assessments. The selective removal of fine fractions by the wind causes loss of essential plant nutrients, and a reduction in moisture-holding capacity, and leads to the formation of coarse-grained, infertile soils. These factors combine to reduce crop yields.

Organic matter, available phosphorus, total nitrogen, and exchangeable potassium quantities in the wind-blown soil varied considerably between the two land uses and between different heights. However, they were always higher than their content in the parent soil. The nutrient enrichment ratios for the grazing land of Um Mial and the cropland of Mgherat for 1999 are presented in Table V. The results show clearly that considerable quantities of nutrients are transported along with the airborne material. Enrichment ratios of organic matter, phosphorus and nitrogen increased with the height above the surface. Thus, while the trapped fractions and mass

Table V. Enrichment ratios of the airborne material on the plateau (Um Mial) and in the valley (Mugherat), for the 1999 season

Height above surface (cm)	Enrichment ratio*				
	OM (%)	Olsen-P (ppm)	Kjeld-N (ppm)	$CaCO_3$ (%)	Extr.K (ppm)
Um Mial					
5	0·8	3·4	1·6	0·8	3·7
10	1·1	3·3	2·3	0·8	3·7
20	1·5	3·7	2·5	0·7	4·1
50	1·6	4·2	2·7	0·9	3·7
100	1·8	5·3	4·0	0·8	3·1
Mugherat					
5	1·0	1·0	2·6	0·9	1·4
10	1·0	1·4	2·8	1·0	1·4
20	1·2	1·5	3·0	0·9	1·6
50	1·6	1·7	3·1	0·9	1·5
100	1·7	1·6	3·2	0·8	1·5

* Abbreviations as in Table 1 footnote. Ratio of nutrients in airborne material to that in the parent soil.

of airborne material decreased with height, the concentrations of nutrients and organic matter increased. This pattern is similar to the increase of the small-grained soil fraction above the surface, suggesting the nutrients and organic matter are closely bound to the smaller sized soil particles. Moreover, sheep dung, which is not mixed with the dry surface soils, could have contributed to the high concentrations of nutrients in the wind-blown mass. The high phosphorus and potassium enrichment ratios in Um Mial, compared to Mgherat, reflect the low concentrations of these nutrients in the parent soil in Um Mial (Table I). On these marginal sites, wind erosion is an important cause of nutrient depletion.

CONCLUSIONS

Results of four seasons of wind erosion research in the Khanasser Valley, northern Syria, showed that there is substantial movement of wind-blown material. The airborne mass consisted of the lighter soil constituents such as organic matter, clay, and silt.

Erosion mass fluxes were substantially higher on the residue-grazed barley fields in the valley than on the overgrazed and degraded natural grazing land on the plateau. The combination of winter cultivation with conventional tillage and stubble grazing leaves the cropland susceptible to wind erosion during the dry and windy summer months. On the barley fields – in addition to the removal of the protective residue cover (i.e. mainly stubble) – the trampling of the sheep pulverizes the dry soil and reduces the surface roughness. On the plateau, on the other hand, the high organic matter content could have contributed to the stability of the soil aggregates, thereby reducing the susceptibility of the soil to wind erosion. The sediment fluxes above the grazed barley fields in the valley were related to the erosive forces of the wind.

The amount of nutrients measured in the wind-blown sediment indicated that wind erosion makes a significant contribution to the nutrient depletion of the source areas. Losses of the most fertile part of the soil will reduce the productivity of already poor soils. The study indicated the importance of even a partial vegetative cover in reducing wind erosion during the dry and windy summer months. Further research is needed to determine the sources and sinks of the wind-blown particles. Future research work will also include the introduction and evaluation of natural resource management practices that reduce the effect of wind erosion in this fragile dryland ecosystem.

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