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Wind erosion measurement on fallow lands of Yazd-Ardakan plain, Iran

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Abstract

Wind erosion is a significant problem on 20 million ha of Iran, especially in central plains and coastal areas. Wind erosion samplers, meteorological equipments and measurement procedure have been developed over the last two centuries to measure the particles moving across the field in modes of creep, saltation and suspension. In recent research as the first technical measurement in Iran, wind erosion was measured with these advanced procedures. Field data was collected from a small (1.9 ha), square, fallow field with nonerodible boundaries. Wind erosion measurement equipment containing 14 clusters with samplers at 0.05, 0.10, 0.25, and 0.50 and 1.0m above the soil surface and a 4× surface creep sampler (0 to 0.02m height by 0.005m wide) was arranged in a circular pattern. The sampling cluster consisted of an array of five samplers each attached to a pivoting wind vane and each mounted at a different height on a central pole. This permitted field erosion data collection regardless of the wind direction and provided a range of field lengths with a minimum number of sampler locations. A combination equation of power and exponential functions expressed the variation of transition material to a height of 2m. An exponential model described the horizontal distribution of transported soil in the field. Twelve single events were recorded and analyzed between May 2006 and May 2007. Several inherent soil properties such as soil texture, organic matter and calcium carbonate content affect the erodibility of soil and change very slowly in research time. Other properties, such as surface roughness and aggregate crust strength are temporal and change rapidly in response to climatic conditions. Total soil mass transported across the fallow field was measured at 220.93 kg/m per year and soil loss at 1.356 kg/m^2 (13.56 ton/ha) per year.

Keywords: BSNE; Iran; Measurement; Near Surface Sampler; Wind Erosion

1. Introduction

Wind erosion is a significant problem on agricultural land throughout Iran as well as in many other parts of the world. Wind erosion is particularly severe in arid and semiarid areas, which constitute one-third of the worlds total land area and includes about one-sixth of the world's population (Dregne, 1979). In Iran, wind erosion is the dominant problem on 20 million ha of land area. Wind erosion is of particular concern in the central plain of Iran, comparising Yazd, Kerman, Semnan, Isfahan, Sistan-Balochistan and Khorasan provinces which is the driest zone of the country. However, it also occurs in coastal areas within the boundaries of Hormozgan, Boshehr and some part of Khozestan provinces in the south (Figure 1). Average wind soil loss due to wind erosion is about 19 ton/ha annually (Iran Forest and Rangeland Organization, 2000). Wind erosion was measured at about 2 mm/yr in bare lands of

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Yazd-Ardakan plain (Ekhtesasi, 2005). The rate of erosion increases to bout 40 mm/yr in coastal areas of the Persian Gulf, Jask in the south of Iran (Ekhtesasi, 2005).

Erosion research can be conducted in the laboratory or in the field. Advantages of calculating erosion measurements in the laboratory include better control of the range of dependent variables the use of advanced (automated) equipment, and the possibility to conduct replicated measurements. Advantages of undertaking research in the field include the possibility to conduct measurements at the proper scale, with realistic soil and plant characteristics and temporal changes in environmental variables. There are three variable scales for wind erosion measurement: (1) the point ($1m^2$) scale for creep, (2) the field (<1 ha) scale for saltation and (3) the regional scale for suspension (Stroosnijder, 2005). Techniques for measuring wind erosion are less well established than those for monitoring water erosion (Morgan, 1995).

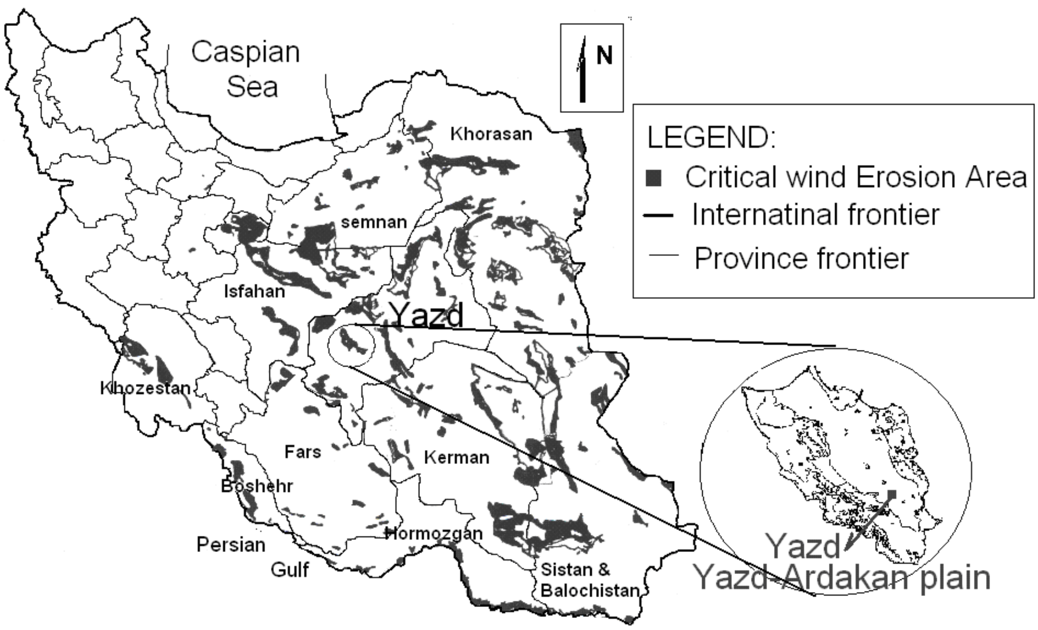

Fig. 1. Wind erosion critical area and location of Yazd-Ardakan plain (Tahmasei et al., 2006)

Research on wind erosion processes was initiated by Chepil and Miline (1939) and Bagnold (1973). Almost all the basic studies on wind erosion have been carried out in the laboratory using a wind tunnel. The results provide a basic understanding of wind erosion processes. Long term erosion trends can be studied by using a grid of reference points or observing depth of root exposure. However, these observations provide little detailed information about wind erosion processes. Thus, to investigate processes, measurements encompassing a single storm are needed (Fryrear et al, 1991). Three groups of instrumentation are required for measuring meteorological variables, the soil passing flux and surface soil properties (Funk et al. 2004, Hagen 2004, Fryrear et al. 1991).

Soil surface properties (temporal and intrinsic properties) combined with climate and management gives rise to the temporal soil state. Temporal soil properties include size distribution, mechanical stability of soil aggregates, depth, coverage, stability and loose saltation size particles on the crust, surface roughness and surface wetness (Fryrear et al. 1991, Hagen 2004). Measurement methodology of the size distribution and erodibility has been reported by Fryrear et al. (1994). Temporal soil properties including mechanical stability of soil aggregates, coverage, stability and loose saltation size particles on the crust, surface roughness and wetness has been discussed by Zobeck and Popham (1990, 1992).

For the study of field wind erosion and the design and evaluation of wind erosion control techniques, detailed observation of wind erosion processes are needed. Wind blown particle transport in the field is usually sampled with sediment catchers (Bagnold 1973, Fryrear et al. 1991). Various types of traps are used to catch sand moving in a band of unit width. Horizontal traps consist of troughs set in the ground level with the surface and parallel to the direction of the wind. The trap is sometimes divided so that rolling and saltation particles fall into different compartments according to their length of hop. The vertical slot sampler designed by Bagnold (1973) was the first instrument used to collect eroded sand in the field, but did not adjust to changes in wind direction. Horizontal traps have the advantage of minimum interference with the wind, but considerable length is required to collect a representative sample (Morgan, 1995).

2. Materials and methods

Wind erosion instrumentation was installed in a 1.9ha (140m*140m) square field fallow land located about 15 km north-west of Yazd in Yazd-Ardakan plain, Yazd province, Iran (Figure 1). Twelve single events were recorded for 12 months from May 2006 to May 2007. The annual mean precipitation in Yazd is about 67 mm showing a serious water deficit during the year. The highest average monthly wind speed is 11.1 knots at a height of 10 m.

Fortheen clusters of erosion samplers (BSNE) with samplers at 0.05, 0.10, 0.25, 0.50 and 1.0m above the soil surface (Figure. 2) and a four surface creep sampler (0 to .02m height by 0.005m wide) were installed in the field. The sampling cluster consists of an array of five samplers each attached to a pivoting wind vane and each mounted at a different height on a central pole. The heights of the individual samplers can be adjusted up or down the supporting pole. Sediment-laden air enters the sampler inlet and is slowed within the sampler by a diffuser section. The near-surface sampler, shown in Figure 3, was based upon a design by Stout & Fryrear (1989). The near surface sampler collects material from a height of 20 mm above the soil surface and a` width of 5.5 mm. The near-surface unit is mounted on a turntable and is directed into the wind by a vane. Sampling inlets funnel sediment to a collection pan located beneath the surface. The combination of the near-surface sampler and the BSNE sampling cluster provides sampling points above the eroding soil surface.

According to the recommendation of Fryrear et al. (1988) a circular pattern was utilized. This permitted field erosion data collection regardless of the wind direction and provided a range of field lengths with a minimum number of sampler locations. Wind speed was measured in the Yazd synoptic station located near the field station. Wind speed was recorded at a height of 10m with a 10min interval.

Soil transport was measured with BSNE clusters and near surface (creep) sampler's site as shown in Figure 4. Six clusters were located at 60˚ intervals on each of two concentric circles with radii of 25 and 30m. After every dust storm, all samplers should be emptied. The contents were transferred to a plastic bag and the field conditions including soil roughness, aggregate size distribution of the soil surface, the presence of non erodible clods or rock and the crust characteristics were recorded.

Initial soil properties were determined of soil samples from depths of 0-10, 10-50 and 50-300mm. The later samples were taken from 10mm below the soil surface. Dry sieving of soil was applied for determining erodible fraction, geometric mean diameter (GMD) and standard deviation (STD) of the soil. The plot was maintained under fallow condition tillage operations in April 2006 to establish a fresh erodible surface. Random roughness was measured with a pin-meter.

3. Results

3.1. Field Surface conditions

The soil is on Typic torriorthents *(soil taxonomy, 1998)*. Main initial soil chemical and physical properties are shown in Table 1. Soil formation was influenced by hyper arid climatic conditions, wind erosion and deposition. Soil texture is coarse and erodible and contains a high percentage of particles smaller than 840μ. Soil grain size distribution is almost uniform ($STD \leq 3$) and geometric mean diameter is about 0.3mm.

Several inherent soil properties such as soil texture, organic matter and calcium carbonate content affect the erodibility of soil and change very slowly in research time. Other properties, such as surface roughness, aggregate crust strength are temporal and change rapidly in response to climatic conditions (table 2).

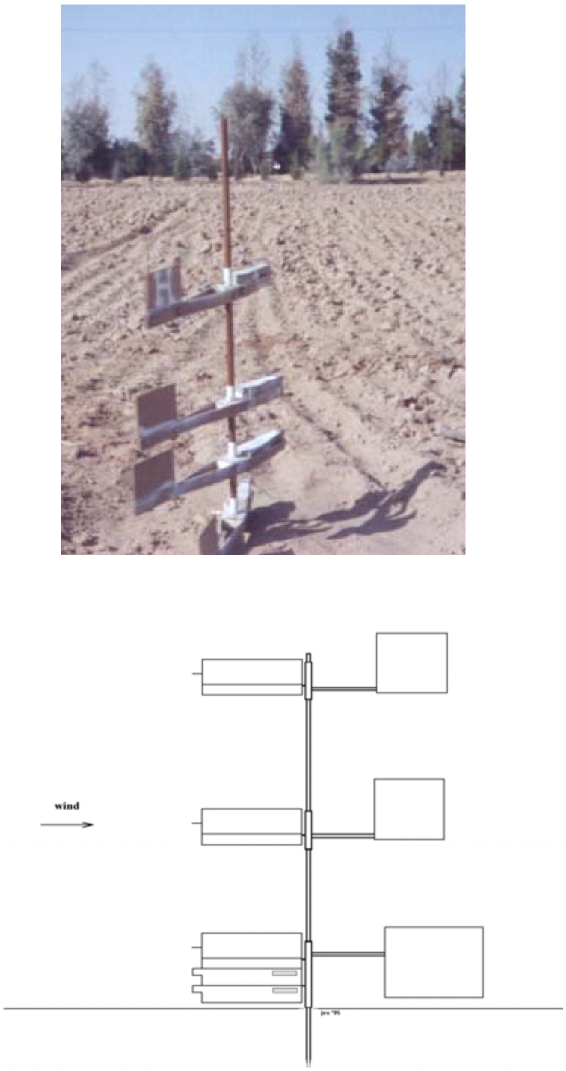

Fig. 2. BSNE (Big Spring Number Eight) sampling cluster used to measure sediment mass flux at various heights above a wind-eroding surface (schematic and in field)

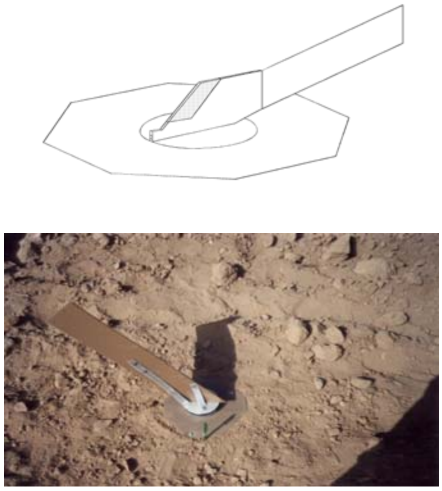

Fig. 3. Near-surface sampler used to measure the sediment mass flux close to the eroding surface

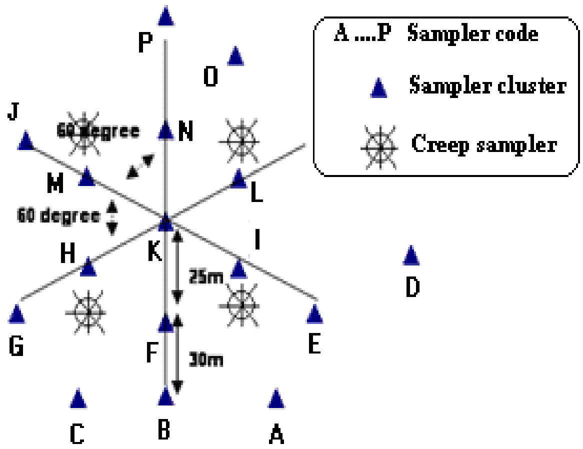

Fig. 4. Schematic layout of field site instrumentation

Table 1: Soil properties in the upper 30 cm of the measuring field

Soil depth (mm)	Soil texture	Sand (%)	Silt (%)	Clay (%)	STD	GMD	<840μ (%)	<10 μ (%)	O.M (%)	Lime (%)	pH	EC (dS/m)
0-10	SL	70	18	12	3.00	0.31	86	18	0.5	20	7.8	2.9
10-50	SL	73	19	8	2.66	0.35	87	17	0.3	18	7.7	2.43
50-300	SL	74	17	9	2.73	0.40	89	18	0.2	17	7.7	3.6

Table 2: Soil properties during wind erosion measurement

Date	Clay (%)	Silt (%)	Sand (%)	GMD (mm)	STD	<840μ (%)	<10 μ (%)	O.M (%)	Lime (%)	RR† (mm)	Crust Strength (kg/cm2)
May 2006	12	18	70	0.31	3.00	86	17	0.5	20	51	0.50
Jun. 2006	14	23	63	0.33	3.16	86	16	0.3	19	40	0.50
Aug. 2006	13	18	69	0.27	3.08	85	19	0.3	17	35	0.75
Oct. 2006	8	17	75	0.30	2.64	87	12	0.4	18	35	0.75
Dec. 2006	4	10	86	0.36	2.09	87	6	0.3	21	15	0.60
Feb. 2007	4	9	87	0.46	2.09	79	5	0.3	21	10	1.25

† Allmaras Random Roughness

3.2 Collection efficiency

To test collection efficiency, the sampler, along with the pan, was placed in a wind tunnel (Figure 5). Field evaluation would have been preferable; however, it is difficult to control soil fluxes under field conditions. A 150mm wide x 5mm deep x 171mm long, open ended, thin metal tray with known quantities of field soil (110 g) was positioned upwind from the sampler intake. The tunnel was operated until all material was removed from the tray and an aliquot of the eroded material passed the sampler opening. The sampler has an average collection efficiency of 72%. Wind tunnel speed was set to 8m/s equal to wind threshold velocity in field conditions. The ability of the BSNE sampler to retain aeolian material once it enters the sampler opening was tested in the wind tunnel. Twenty five gr of the field soil was directly filled into the sampler through a funnel connected to a copper tube 3-mm in diameter. The sampler has a retention efficiency of 80 to 94% for field soil.

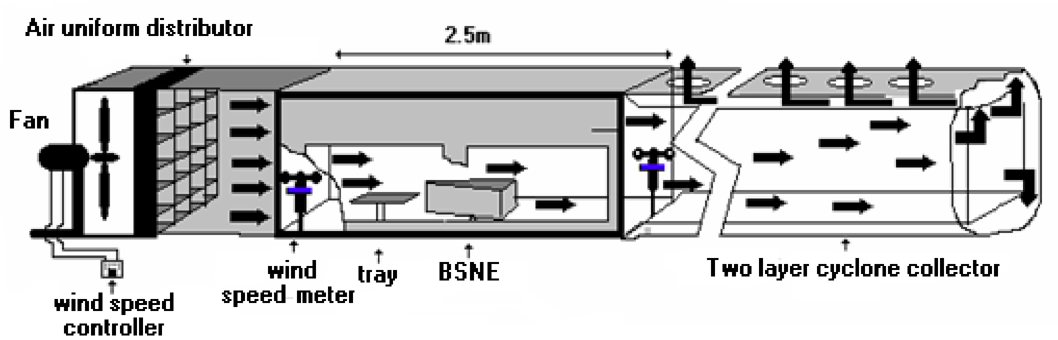

Fig. 5. Test procedure for determining sampling efficiency of assembled sampler

3.3. Vertical distribution

After the erosion samples have been dried and weighted, vertical profiles can be determined using the sample weights and the heights of the samplers at each cluster. This leads to the equation below that describes the profile form soil surface to a height of suspension:

$$Q_{passing} = f(z) = aZ^b + c\exp(dZ) \qquad (1)$$

$$Q_{passing} = \int_{TSS}^{2} aZ^b \cdot dz + \int_{0.003}^{TSS} c\exp(dZ)\cdot dz + \int_{0}^{0.003} c\exp(dZ)\cdot dz \qquad (2)$$

$$Q_{passing} = Suspension + Saltation + Creep \qquad (3)$$

Where *f (z)* or $Q_{passing}$ is the quantity of material being transported (kgm^{-1}), Z is the height above the surface(m), a and b are regression coefficient for suspension, c and d are fitting coefficients for saltation. This equation describes the distribution of both suspension and saltation but the transition point from saltation for integration purposes is undefined at the point where Z=0. The point of interest is the height of intersection of saltation and suspension, because to determine the total mass being transported at the transition height between saltation and suspension (TSS), the computed quantities for saltation and suspension are identical (Figure 6). This height represents the maximum height of saltation for that particular storm and field condition. The vertical profile of horizontal flux (transport capacity) was then integrated to a height of Z (m) to determine the soil discharge (kgm^{-1}) passing each cluster location.

Vertical distribution was computed by fitting power and exponential function on the actual data of each cluster and integrated between heights from 0 to 0.003 for creeping, 0.003 to TSS for saltation, and TSS to 2m for suspension.

3.3. Horizontal distribution

Stout (1990) used the self balancing concept to drive a relationship that "describes the variation of the horizontal component of mass flux down wind of a distinct field boundary". This relationship is a negative exponential equation for transport capacity and field length (equation 4).

$$f_x = f_{\max}(1 + e^{-x/b}) \qquad (4)$$

Where f_x the horizontal component of mass flux, $f_{\max}$ maximum transport capacity of mass flux, *x* distance from upwind field boundary and *b* distance at which f_x attains a value 63.2% of $f_{\max}$.

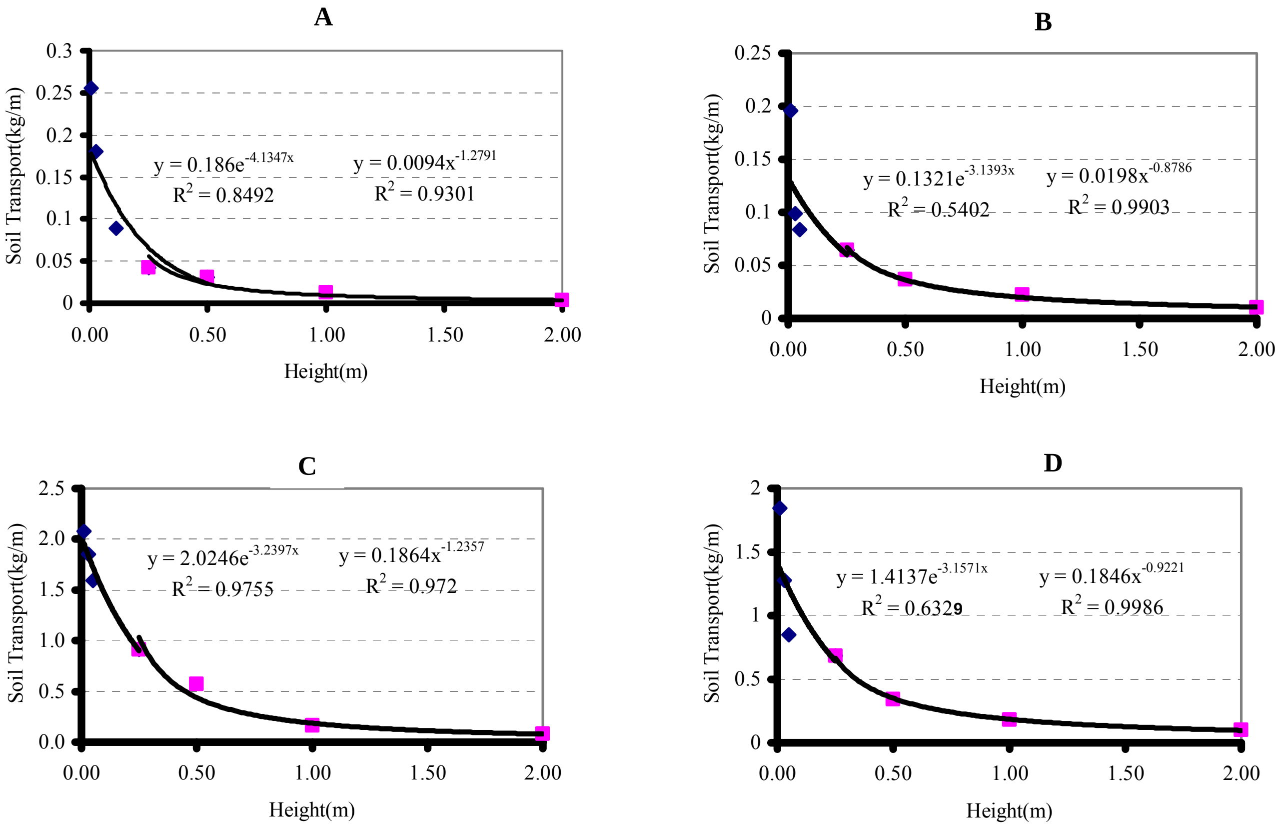

Fig. 6. Examples of vertical distribution of wind eroded material over a bare, sandy loam soil at Yazd-Ardakan plain, A and B 22 August 2006, C and D 13 June 2007

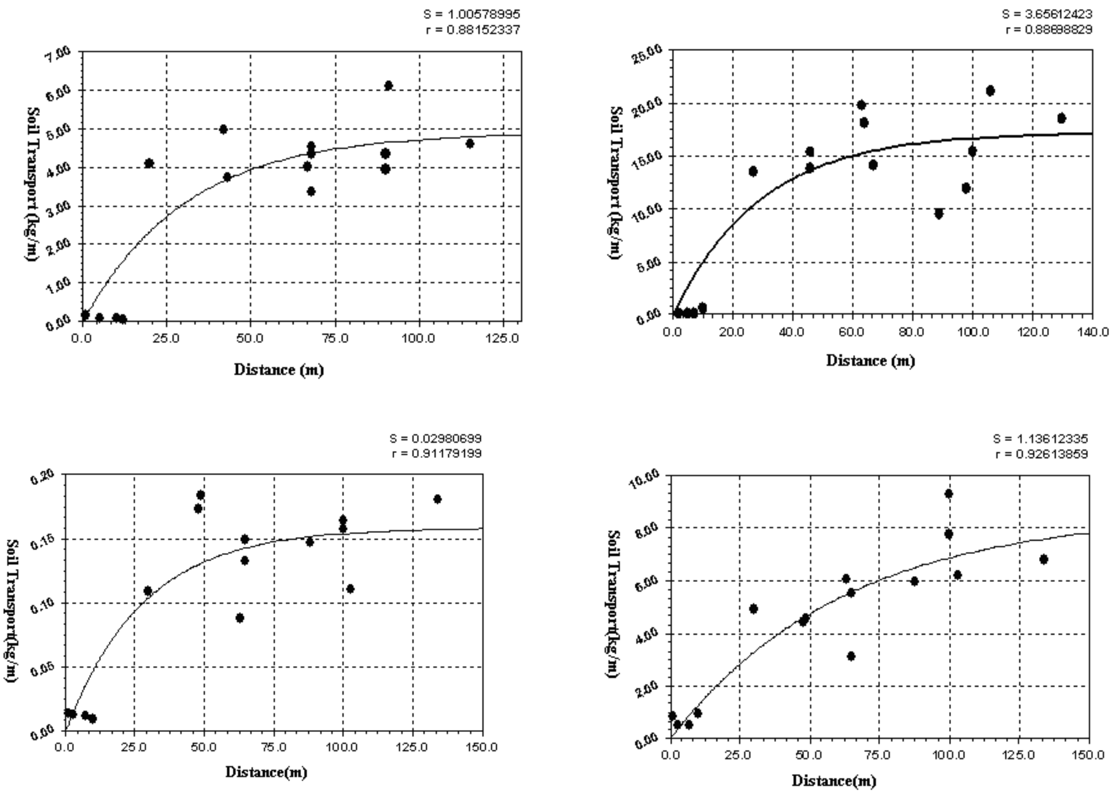

Fig. 7. Examples of measured soil loss variation with downwind distance for single storms

Table 3: Fitting curve, Maximum transport capacity and mean of soil loss of events

Date	Wind			Fitting curves	Max soil transport *(kg/m)*	Mean soil loss *(kg/m²)*
	Max velocity (m/s)	Direction (Degree)	Duration (hr)			
22 May 2006	17.2	NW	8.0	$f_x=70.02(1-e^{(-x/96.44)})$	70.02	0.398
24 May 2006	17.4	NW	2.5	$f_x=33.31(1-e^{(-x/29.12)})$	33.31	0.263
26 May 2006	17.8	NW	3.5	$f_x=74.50(1-e^{(-x/111.38)})$	74.50	0.388
5 June 2006	15.1	NW	1.0	$f_x=17.28(1-e^{(-x/29.19)})$	17.28	0.131
12 June 2006	12.2	NW	0.5	$f_x=0.111(1-e^{(-x/5.08)})$	0.111	0.0008
13 June 2006	14.2	NE	2.5	$f_x=4.901(1-e^{(-x/30.67)})$	4.901	0.043
20 June 2006	14.2	NW	0.5	$f_x=8.587(1-e^{(-x/61.93)})$	8.587	0.0509
13 July 2006	14.4	NW	0.5	$f_x=7.302(1-e^{(-x/38.55)})$	7.302	0.0528
22 Aug. 2006	10.3	W	1.0	$f_x=0.158(1-e^{(-x/27.73)})$	0.158	0.0012
15 Oct. 2006	15.1	N	3.5	$f_x=0.334(1-e^{(-x/21.75)})$	0.334	0.0033
9 March 2007	15.9	NW	5.0	$f_x=2.823(1-e^{(-x/102.07)})$	2.823	0.015
30 March 2007	16.3	N	3.0	$f_x=1.61(1-e^{(-x/111.1)})$	1.61	0.009
Total				-	220.93	1.356

Stout's equation assumes that the field upwind is non-eroding but has a roughness similar to the field. Wind direction and up wind distance to the edge of the field also was calculated for each cluster. Average soil loss was extrapolated from equation 4 (fitting curve) at the end of the field in a downwind direction (e.g. 130m) and average soil loss was calculated from division max transport capacity to distance from non-erodible edge of field. Table 3 indicates the fitting curves of events, the maximum transport capacity and mean soil loss in each event. Total soil transported in the field was calculated at 220.93 kg/m and mean soil loss was about 1.356 kg/m^2 annually.

4. Discussion and conclusions

The goal of this paper was to present a technical method for measuring wind erosion in fallow lands of Yazd-Ardakan, Iran. This research is the first accurate, reliable field wind erosion measuring in fallow lands. Within the last two centuries, wind erosion techniques and equipments have been developed perfectly. Aerodynamic passive sampler (BSNE) of different height together the creeping sampler can be used to measure the soil loss of the single event and total annually. The BSNE sampler is simple to construct. Moreover, several samplers can be located at the same site to determine changes in quantity of collected material with height. Advantages of the BSNE sampler include its ability to orientate in to erosive wind; the opportunity to collect samples from various heights at the same location, and the capacity of the sampler, which allows extended collection periods without frequent servicing.

Two most important factors in wind erosion measurement are the collection and retention efficiency of the sampler. The collection and retention efficiency were determined in the wind tunnel. Determinations of the efficiencies are difficult because the control of soil fluxes under field conditions is not easy.

An expression, $Q_{passing}=f(z)=aZ^b+c\ \exp(dZ)$ describes the vertical distribution of material moving in saltation and surface creep. With this expression, soil flux decreases as the height increases and produces a maximum flux at the soil surface. The model can be integrated between specific heights to compute total soil transport, and the total mass can then be determined by adding the saltation /creep and suspension flows. By solving both equations to determine the height where the equations are equal, the average height of saltation for the erosion event can be computed. This height, called the TSS, is where the curve for saltation and the curve for suspension cross.

Starting from a non-eroding upwind boundary, as the length of a field along the path of the eroding wind increases there is an increase in the quantity of material being transported between the soil surface to a height of 2 m. The self balancing concept has been used in the numerical model of the saltation process, $f_x=f_{max}(1+e^{-x/b})$. This rate of increase is limited by emissions from the soil, but it continues until the wind has attained 63.2% of its transport capacity at the critical field length "b". Beyond "b" the mass being transported will increase but at a decreasing rate (because of the limited transport capacity of wind) until the wind attains its maximum transport capacity. For the data currently available, the critical field length is usually less than 111 m. The "b" values varied from 29 to 111 in largest events.

The largest erosion events sampled on the three consecutive erosion dates (22, 24 and 26

May 2006). Total soil mass transported across the fallow field in Yazd Ardakan plain was measured at 220.93 kg/m and annual soil loss at 1.356 kg/m^2 (13.56 ton per ha.yr).

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