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On-Farm Evaluation of Field-Scale Soil Losses by Wind Erosion Under Traditional Management in the Sahel

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Abstract

In the West African Sahel, few direct estimates are currently available on the extent of soil losses by wind erosion in traditionally managed farmers fields. Field scale sediment balances in western Niger were derived from airborne sediment fluxes measured using BSNE sand traps. Results from a first study in 1997 indicated that sediment fluxes in a cultivated field increased linearly over distances ≤ 80 m, irrespective of wind power. Sediment deposition in an adjacent fallow was well described by an exponential decay function with a near constant trapping efficiency coefficient of 0.1 m^{-1} for incoming sediment fluxes ≥ 10 kg m^{-1}. Mass balances up to -17.5 and + 10.5 Mg ha^{-1} were measured in a single storm in the field and fallow, respectively. Starting in 1998, a second study was setup in a newly cleared, 8 ha farmer's field equipped at 87 locations with BSNE sand traps. Whereas a net sediment balance of +5.4 Mg ha^{-1} was measured in 1998, the experimental field was subject to a net soil loss of -5.0 Mg ha^{-1} in 1999. This was attributed to changes in ground cover and differences in sediment influx from adjacent fields.

Keywords. Sahel, Wind erosion, On-farm, Land degradation, Sand trap.

Introduction

In the Sahelian zone of West Africa ongoing land degradation and resultant loss of the soil's productive capacity constitutes a major concern to the local populations and the international community alike. In particular, wind erosion, which is favored by the long dry season and low vegetation cover that characterizes large tracts of the Sahel, is often pinpointed as a major land degradation process (Mainguet and Chemin, 1991).

Although the occurrence of wind erosion is indisputable, the exact extent and impact of this low grade, long-term cumulative process on soil productivity is difficult to quantify at all but the most local scale. Currently, very few estimates are available of the extent of soil losses by wind erosion under traditional management. Regional soil losses as high as 48.5 Mg ha^{-1} yr^{-1} have been reported over a 30 yr period, based on the ^{137}Cs methodology (Chappell *et al.*, 1998). Such estimates are extremely high and would be expected to have major repercussions on soil productivity. Two studies were therefore initiated in the Sahelian zone of Western Niger in order to assess field-scale eolian sediment balances under traditional management on the basis of direct measurements of near-surface airborne sediment fluxes.

Materials and Methods

Both experimental fields were located in western Niger near the village of Banizoumbou (13°31'8''N, 2°39'5''E), approximately 60 km E of the capital city Niamey. Average annual rainfall is *ca.* 500 mm. Erosive easterly convective storms and southerly monsoon winds are typically observed prior to and during the growing season from May to September. The soils at the experimental sites are classified as psammentic Paleustalfs with 95% sand and 3% clay in the top 0.05 m (Bielders et al., 2000).

Sediment mass fluxes were measured using Big Spring Number Eight (BSNE; Fryrear, 1986) sand traps placed at 0.10 and 0.35 m above ground. Sediment mass fluxes (q) were calculated for each storm by assuming unit trapping efficiency, fitting a power function of the type $q = a\,(z+1)^b$ to the 0.10 and 0.35 m height (z) data, and then integrating the sediment flux density profile between 0 and 0.35 m height.

Wind speed and direction were recorded at an automatic weather station located in or very near the experimental fields as described previously (Bielders *et al.*, 2000). Sand trap location as well as boundaries of the experimental field and adjacent land units were determined using differential GPS technology. Soil loss or deposition was estimated by difference between the measured sediment mass fluxes of successive sand traps.

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Experiment 1: In 1997, a ~25 ha farmers field was selected. The field was cropped with millet [*Pennisetum Glaucum*] and was bordered on the northeastern, northern and western side by non-erodible, fallow land. On the northeastern boundary, pairs of sand traps were installed into the field at 10, 20, 40 and 80 m from the boundary along 2 (< 26 July) or 3 (≥ 26 July) east-west oriented transects. On the western side, pairs of sand traps were equally installed into the fallow at 5, 10, 20 and 40 m from the field boundary along three transects.

Experiment 2: Starting in 1998, a 180 m by 400 m experimental field was delimited in a newly cleared ~11 ha farmer field and was equipped at 87 locations with pairs of BSNE sand traps (see Fig 2c). The field was bordered on the north, eastern and southeastern side by non-erodible fallow land. Mass balance calculations were carried out on the basis of incoming and outgoing sediment fluxes using the sediment traps located at the edge of the experimental field. Spatial variability of sediment fluxes was estimated by krigging. Parameters for sediment flux semi-variograms were derived after removal of a fitted second order polynomial trend surface.

Results and Discussion

Experiment 1: Sixteen sand storms were recorded between 20 June and 15 August 1997. However, depending on average wind direction during the sand storm with respect to field or fallow boundaries, only a subset of events could be used for sediment mass balance calculations (Table 1).

Table 1. Characteristics of selected sand storms in 1997 and sediment balance in a field and fallow (- = loss, + = gain). 'Distance' refers to the distance into the field or fallow over which the balance applies

			Field		Fallow	
Date	Wind speed†	Duration†	Mass balance	Distance	Mass balance	Distance
	$m\ s^{-1}$	h:min	$Mg\ ha^{-1}$	m	$Mg\ ha^{-1}$	m
21 June	13.0	0:30	-17.5	51	+10.5	42
27 June	11.7	0:25	-1.6	56	+2.4	40
30 June	14.0	0:10	-2.8	76	+7.4	41
26 July	12.0	0:05	-4.8	55	+3.3	41
5 August	9.1	0:05	-0.8	54	+0.5	41

† average wind speed during saltation period preceding rainfall, and duration of saltation period.

In the field, a linear increase in sediment flux was observed consistently for all suitable events irrespective of wind power (6 events; Fig. 1a). In the fallow (Fig. 1b), sediment fluxes showed an exponential decay with distance of the type $q = q_{in} \cdot \exp(-\alpha x)$, where q ($kg\ m^{-1}$) is the sediment flux and q_{in} ($kg\ m^{-1}$) is the incoming sediment flux at the field-fallow boundary, x (m) is the distance into the fallow and α (m^{-1}) is a sediment trapping efficiency coefficient. For $10 < q_{in} < 45\ kg\ m^{-1}$, α tended to be constant at $0.101 \pm 0.013\ m^{-1}$ (n = 7). For $q_{in} < 5\ kg\ m^{-1}$, the value of α tended to be lower. There was no consistent change in the value of α over the period of observation.

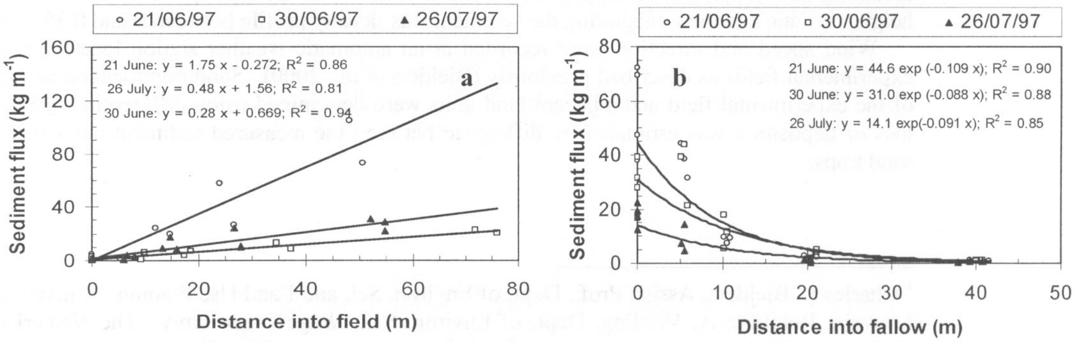

Figure 1. Changes in eolian sediment flux with distance into a field (a) and a fallow (b) for the three most erosive dust storms in 1997.

Based on the fitted linear (field) or exponential (fallow) regressions of sediment fluxes vs. distance, sediment mass balance calculations were carried out for sand storms with suitable wind directions (Table 1). Erosion rates as high as 17.5 Mg ha^{-1} were measured within the first 51 m of the field on 21 June 1997. An average deposition rate of 10.5 Mg ha^{-1} was measured on the same date within the first 42 m of the fallow land. This latter value is only indicative, however, since 90% of the sediment deposition actually occurred with the first 23 m of the fallow as a result of the exponential decay of sediment flux vs. distance.

Experiment 2: Eight and 10 events were recorded between 15 May and 30 June in 1998 and 1999, respectively (Table 2). Considerable spatial heterogeneity in surface sediment fluxes was observed in both years (Fig. 2a and 2c).

Table 2. Characteristics of sand storms during the 1 May– 30 June period of 1998 and 1999 and eolian sediment mass balance (- = loss, + = gain) on an 8 ha experimental field

1998	Wind speed†	Duration†	Mass balance	1999	Wind speed†	Duration†	Mass balance
	m s^{-1}	h:min	Mg ha^{-1}		m s^{-1}	h:min	Mg ha^{-1}
16 May	13.8	1:26	0.2	17 May	7.9	1:17	-0.04
28 May	10.2	2:33	0.2	23 May	10.2	0:51	1.6
31 May	10.3	2:54	2.8	27 May	8.5	2:27	-0.3
8 June	14.5	0:26	1.1	30 May	8.5	1:23:	-0.2
16 June	12.5	0:56	0.9	2 June	9.7	3:29	-3.2
25 June	10.8	0:20	-0.06	11 June	8.7	1:29	-0.8
26 June	10.6	1:00	0.2	19 June	8.3	1:05	-0.2
30 June	12.4	0:18	0.03	21 June	8.1	2:36	-0.1
				24 June	11.8	0:30	-0.9
				28 June	10.4	0:27	-0.9
Total			5.4				5.0

† average wind speed during saltation period preceding rainfall, and duration of saltation period.

The spatial pattern of sediment fluxes was very different between the two years (Fig. 2 a and 2c). All events recorded in 1998 showed the same pattern as in Fig. 2a irrespective of wind direction, with sediment fluxes approximately 5 to 10 times higher in the southwestern corner than in the remainder of the experimental field. This effect resulted from the passage of an uncontrolled bushfire initiated in an adjacent field which affected only the southeastern part of the experimental field. The remainder of the field was unaffected by the bushfire and sediment fluxes remained very low as a result of a higher ground cover during the 1st year of cultivation. On the basis of visual observations, soil cover, which includes both litter and standing dead grassy vegetation, was estimated at 3% in the burned and 7% in the unburned parts of the field in 1998 ($n_{obs} \geq 270$). In 1999 a general trend of increasing fluxes with distance was observed for most sandstorms. Although the scatter in the experimental data is large as a result of the considerable spatial variability in sediment fluxes, in none of the sandstorms did the wind transport capacity appear to be reached after distances of 300 to 400 m (not shown).

As opposed to the first year of cultivation (1998) where a net sediment deposition of 5.4 Mg ha^{-1} was observed during the May-June period, a net soil loss of 5.0 Mg ha^{-1} was observed during the same period in the second year of cultivation (Table 2). The available data on storm characteristics provides no evidence that this reversal in land erodibility may have been caused by large differences in sand storm characteristics. Besides the gradual disappearance of ground cover over the two-year period (approx. -1% change in ground cover on the burned and –2.5% in the unburned sections of the field), the apparent reversal in land erodibility is influenced to some extent by the influx of sediment from adjacent fields. This is particularly apparent in 1998, where the sediment deposition largely results from large influxes of sediment from a cultivated field located south of the experimental field and which was also affected by the uncontrolled bushfire.

The above mentioned field scale sediment mass balances mask large spatial variability in sediment balances within the experimental field (Figs. 2b and 2d). For instance, on 2 June 1999, mass balances varied locally from erosion rates > 20 t ha^{-1} to deposition rates > 15 t ha^{-1} (Fig 2d).

31 May 1998 2 June 1999

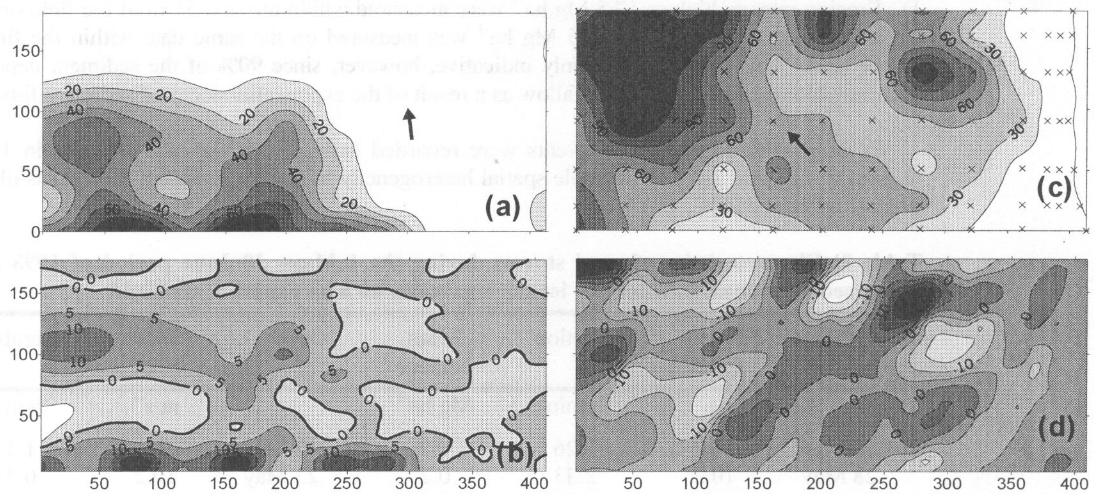

Figure 2. Contour plots of sediment flux (kg m^{-1}) (a, c) and mass balance (Mg ha^{-1}) (b, d) for 2 sand storms on 31 May 1998 (a, b) and 2 June 1999 (c, d). Arrow indicates average wind direction during sand storm. Crosses on sediment flux map (c) indicate location of sediment flux measurements. Distances in meters.

Conclusions

Based on the measurements of airborne sediment fluxes in traditionally managed cultivated fields in western Niger, it appears that wind erosion may result in considerable soil losses at scales < 100m. Because the eroded material is dominated by sand size particles travelling by saltation, the eolian sediment is quickly deposited in adjacent fallow land as a result of the increased surface roughness due to the open savanna vegetation. Sediment balances are shown to be sensitive to land clearing practices as well as to the duration of cultivation. The present results do not support previous estimates of regional scale soil erosion rates in excess of 48 Mg ha^{-1} yr^{-1} because, under present land use conditions, most of the eroded sediment is subject only to local redistribution within fields or between adjacent land units. The results indicate that, although wind erosion may not be of concern on the sandy aeolian soils of western Niger in the first year of cultivation if land clearing is done without burning surface litter, the threat of wind erosion may increase substantially in the following years.

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