Evaluation of Soil Losses by Wind Erosion under Different Soil and Residue Management Practices in Niger, West Africa.

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Introduction

In the Sahelian zone of Western Niger the prolonged dry season, dominantly sandy soils, low soil organic matter contents and low soil cover at the time of occurrence of the most erosive winds create an environment with a high potential wind erosion hazard. This hazard has been aggravated in recent years by the rapid spatial extension of agricultural land as well as overgrazing and deforestation. This has lead to low residual levels of vegetation and crop residue at the end of the dry season, and to an increase in the area of soil directly exposed to the erosive force of the wind.

In the traditional millet cropping systems, the most predominant forms of wind erosion-induced damage are seedling burial under sand deposits (Photos 1 and 2) and the loss of topsoil (Michels et al., 1993; Michels et al., 1995a; Sterk and Stein, 1997). Following intensive monitoring of sand fluxes in a 40 x 60 m experimental field, Sterk and Stein (1997) estimated soil losses from only four sand storms in 1993 at 45.9 t ha^{-1}. These measurements were made on a millet field with a 0.8 t ha^{-1} mulch of millet stover, which reflects on-farm conditions under favorable circumstances.

Photo 1. Millet seedlings partly covered by blown sand.

Photo 2. Recovering millet after burial by blown sand.

Soil mass flux measurements have been reported in other on-station studies both for low-input management conditions and after implementation of wind erosion control measures (Banzhaf et al., 1992; Michels et al., 1995b; Buerkert et al., 1996). However, in all these studies, the mass flux measurements were limited to a single measurement point in the center of the experimental plots. Hence, the data collected in these studies do not allow for mass balance calculation and, consequently, of soil losses by wind.

On the basis of repeated measurements of surface elevation, Michels et al. (1995b) reported a decrease in surface elevation of 33 mm after one year on bare millet plots. Buerkert et al. (1996) reported a loss of 12 mm of topsoil in one year, equivalent to a loss of soil of approximately 190 t ha^{-1}. In this latter case, however, water erosion may have contributed significantly to the total soil loss because of specific topographic conditions and the presence of extensive surface crusts.

No data is currently available on soil losses for on-farm conditions in the Sahel for common wind erosion control measures such as millet stover mulches or ridges. In this paper, we present the results of two years of investigation of the effect of two types of residue management and ridging on soil losses by wind and on millet productivity.

Materials and methods

The experimental field was located at Banizoumbou (13°31’8’’N, 2°39’5’’E), Niger, approximately 60 km N-E of the capital city Niamey. Average annual rainfall is 550 mm. The climate, as in most of the Sahel, is characterized by a prolonged dry season from October to May. During this period northeasterly “Harmattan” winds occur, but these are less erosive than the south-westerly monsoon winds and easterly convective storms typically observed from May to

September (Michels et al., 1995b). This latter period corresponds to the cropping season. The soils at the experimental site are classified as psammentic Paleustalfs with 95% sand and 3% clay in the top 0.05 m. Soil organic carbon content in the top 0.15 m is 0.2 g kg^{-1}.

The experiment was initiated in 1995 and consisted of 5 treatments in a randomized complete block design with 4 blocks. The 15 x 20 m plots were aligned in a single, 300 m long, N-S oriented strip on the western end of a farmer's field. The field had been planted annually with millet for at least 5 years prior to the experiment. Management operations were limited to sowing by hand and 2 or 3 manual weeding operations per cropping season. The farmer's field extended for more than 380 m to the east of the experimental field. It was cropped each year with millet and managed by the farmer in the same manner as before. The experimental field was cropped with a millet-cowpea intercrop planted in alternating rows spaced 0.75 m apart. Both millet and cowpea were sown in hills spaced 1 m apart and were thinned to three plants per hill approximately three weeks after sowing.

Of the five treatments, only four have been considered for wind erosion purposes: strip-applied residue, ridging, broadcast residue (1996 only), and a bare control. Both the ridges and the residue strips were limited to the cowpea row, spaced 1.5 m apart and oriented N-S. Residue consisted of millet stover applied at a rate of 2 t ha^{-1}. Millet was sown on June 20 in 1995 and June 3 in 1996 after the first rain exceeding 15 mm. Cowpea was sown approximately 3 weeks later. Residue was applied at the start of the rainy season prior to millet sowing. Ridging was carried out by hand using a traditional hoe immediately prior to sowing cowpea. No fertilizer was applied.

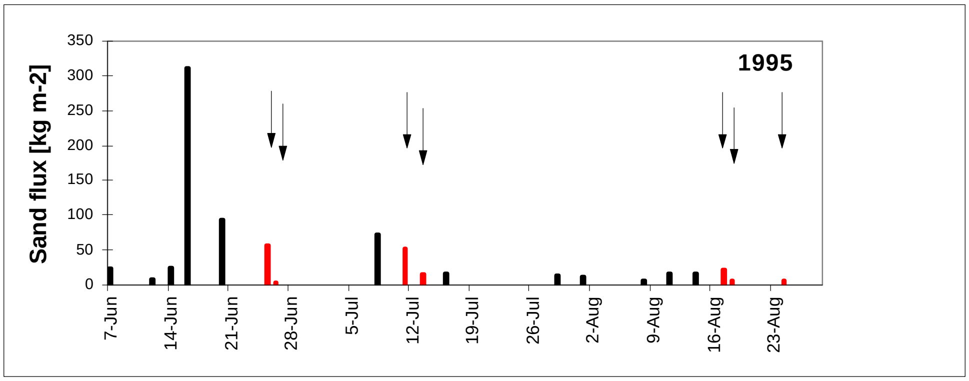
Soil mass fluxes were measured on the eastern and western side of each plot using BSNE (Big Spring Number Eight) sand traps (Fryrear, 1986) with 10 cm^2 openings placed at 0.1 and 0.35 m above ground and approximately 0.5 m outside the plot boundaries. Because of limitations in the number of traps available, only three out of four blocks were equipped in this way. Sediment was collected from the traps after each storm and dried at 105°C. Sand mass fluxes (q) at the eastern and western plot boundaries were calculated for each storm by fitting an exponential equation of the type $q = a * \exp(b*z)$ to the 10 and 35 cm height (z) data (Fryrear and Saleh, 1993), and then integrating the equation between 0 and 35 cm height. Wind velocities and directions were recorded automatically for each storm and averaged over 5 minute intervals. Soil loss or deposition was estimated from the difference between incoming (eastern side) and outgoing (western side) soil mass fluxes for those dust storms with an average wind direction comprised between 249.5 and 290.5 degrees (approximately E-SE and E-NE).

Results and discussion

A total of 19 and 20 dust storms were recorded in 1995 and 1996, respectively (Fig. 1; Photo 3). For comparison, from 1990 to 1996, between 4 and 21 sand storms were recorded annually. In 1995 and 1996, only 7 and 6 events, respectively, had average wind directions suitable for mass balance calculations.

Photo 3. Dust storm in millet plots with (front) and without (back) crop residue mulch.

Soil fluxes at the eastern side of the experimental field were highest in the first month following the start of the season and showed a gradual decline as the season proceeded (Fig. 1). Because the soil mass fluxes presented in Fig. 1 were measured at 0.1 m height, the values result from the dominant contribution of saltation, which is highly affected by local surface coverage conditions. Soil erosion is known to vary exponentially with surface coverage (Siddoway et al., 1965). As a result of the low planting densities in farmers fields (~5000 hills ha^{-1}), soil surface coverage by millet becomes significant only 6 to 8 weeks after sowing. Hence, it is probable that the observed decrease can be attributed to a large extent to the growth of millet in the farmer's field to the East of the experimental field. Weed development may also have contributed, but its effect should be less pronounced as weeding is carried out 2 to 3 times during the season.



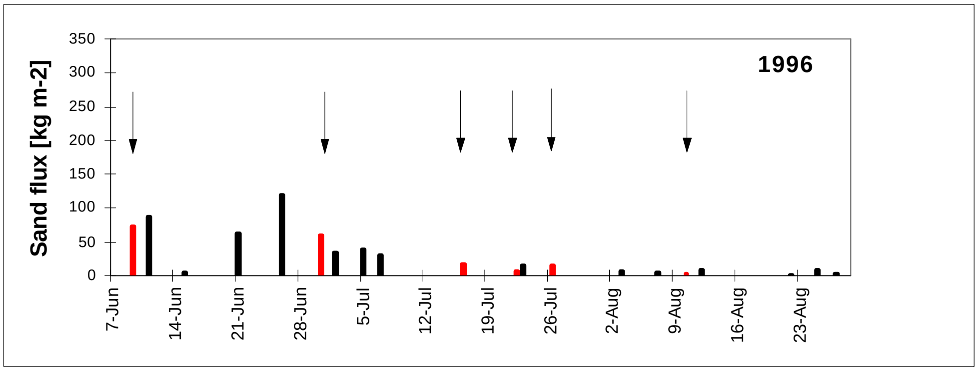


Figure 1. Severity of dust storms in 1995 and 1996. Values are averages of 15 sand traps located 0.1 m above ground on the Eastern side of the experimental field. The red bars, indicated by arrows, correspond to dust storms used for calculating soil erosion or deposition.

The extent of soil losses or deposition for those dust storms with a suitable wind direction in 1996 are presented in Figure 2. Soil loss is observed on bare and ridged plots consistently over time whereas deposition occurred on all dates on mulched plots. These trends are similar to those observed in 1995 (not shown). Despite the large spatial variability in input fluxes (not shown) which could have a significant effect on the accuracy of the mass balance calculations, the consistency in the trends observed in Fig. 2 supports the validity of the results presented here.

For those dust storms which had suitable wind directions, total soil losses on the bare plots amounted to 20.8 and 15.3 t ha^{-1} in 1995 and 1996, respectively (Fig. 3). This is equivalent to an average soil thickness of approximately 2.3 mm over two years. On plots with either banded residue or broadcast residue net deposition rather than erosion was measured. This amounted to a total of 30.1 t ha^{-1} over 2 years for strip applied residue (Fig. 3). The magnitude of soil losses reported here for bare soils compares favorably with those reported by Sterk et al. (1997). They are also in agreement with the trends reported by Buerkert et al. (1996), which are based on surface topography measurements, even though these authors measured much larger values of soil loss or deposition than presented here. The difference in the magnitude of soil losses observed by Buerkert et al. (1996) and in the present study may to a large extent be due to differences in the measurement technique. Indeed, as a result of the field layout, only selected dust storms could be used in the present study to calculate soil erosion. Topographic measurements integrate all events over a given time interval but suffer from the disadvantage that it is impossible to separate soil losses by wind and by water. Whereas the figures presented by Buerkert et al. (1996) are therefore likely to overestimate soil losses by wind erosion, those presented here most certainly underestimate reality since the most erosive events could not be included in the calculations (see Fig. 1).

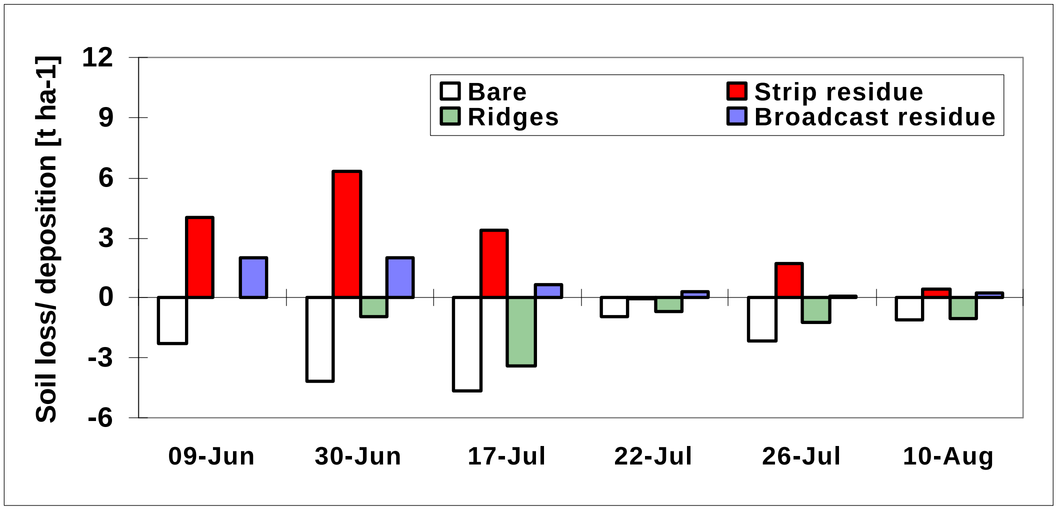


Figure 2. Soil loss (-) and deposition (+) during the 1996 season as affected by surface management for storms with an average wind direction comprised between 249.5 and 290.5 degrees. The ridges were prepared on June 19.

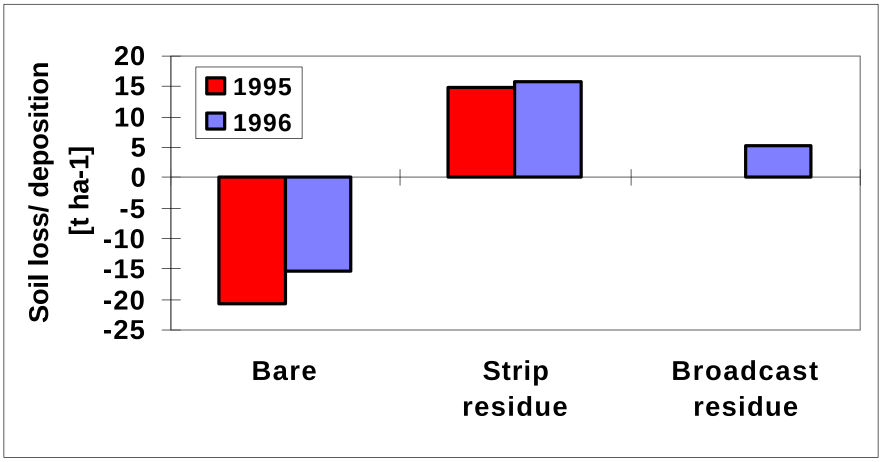


Figure 3. Total soil loss (-) or deposition (+) during the 1995 and 1996 seasons as affected by two types of residue management for storms with an average wind direction comprised between 249.5 and 290.5 degrees. The broadcast residue treatment was implemented in 1996 only.

In 1996, the broadcast residue plots trapped approximately 66% less sand than strip-applied residue (Fig. 3). For the present application rate, surface coverage of broadcast residue has been estimated at 7% (Michels et al., 1995b). For broadcast residue at such low surface coverage, sediment trapping can be expected to occur only in the immediate vicinity of the millet stems. In the case of banded residues, the stems are packed on top of each other. This creates a “dead” volume between the stems were wind velocity is effectively reduced and sediment deposition can occur. This is in agreement with field observations that banded residue in essence favors the formation of natural ridges by trapping wind blown sand.

For the period following ridge making, it appears that ridges reduced erosion rates by 41% on average each year compared to the bare control plots (Fig. 4). On these sandy soils poor in organic matter, ridges are fairly unstable. Hence the ridges quickly collapse after a few rainfall events, which greatly diminishes their effectiveness (Fryrear, 1984). As can be seen from Fig. 2, ridges reduced soil losses significantly only for the first dust storm following ridging, after which differences between bare and ridged plots became minimal. In addition, the ridge spacing of 1.5 m was rather large. This implies that the effect of the ridges on surface roughness is less pronounced and sediment trapping in the inter-ridge space less effective compared to conventionally more closely spaced ridges (Hagen and Armbrust, 1992). Although much less effective than mulching, ridging could provide an alternative to reduce the rate of land degradation by wind erosion in areas where the availability of residue for mulching constitutes a problem and where labor is not a constraint. This would require that ridging be implemented early in the season. Re-ridging during the season may also be needed in order to rebuild collapsed ridges.

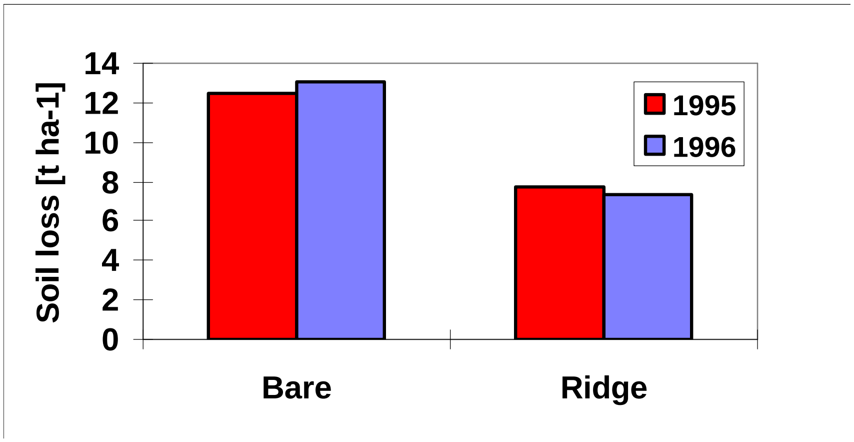


Figure 4. Soil erosion during the 1995 and 1996 seasons as affected by ridging, for storms with an average wind direction comprised between 249.5 and 290.5 degrees. The comparison is made for the period following ridge making, which was on July 8 in 1995 and June 19 in 1996.

On the bare control plots, millet yields declined rapidly from 328 kg grain ha^{-1} in 1995 to 78 kg ha^{-1} in 1996. During the same period, yields on residue plots remained stable at about 500 kg grain ha^{-1} (Fig. 5). Hence it appears that the decline in yield observed on bare plots is mostly the result of the soil degradation that took place during the two years rather than to differences in climatic conditions between years. On the ridged plots, the yield decline approached that of the bare plots, despite the somewhat reduced soil losses. In these inherently nutrient-poor soils, most of the soil nitrogen and phosphorus reserves are concentrated in the first centimeters of the soil. The loss of topsoil by wind erosion can therefore be expected to have contributed significantly to the decline in soil productivity. However, other factors such as nutrient mining, soil acidification or a reduction in phosphorus availability - all of which are strongly influenced by mulching (Bationo et al., 1995) - may also have contributed to the productivity decline. Nevertheless, the observed dramatic drop in soil productivity emphasizes the extreme sensitivity of these soils to degradation after a single year of "mismanagement".

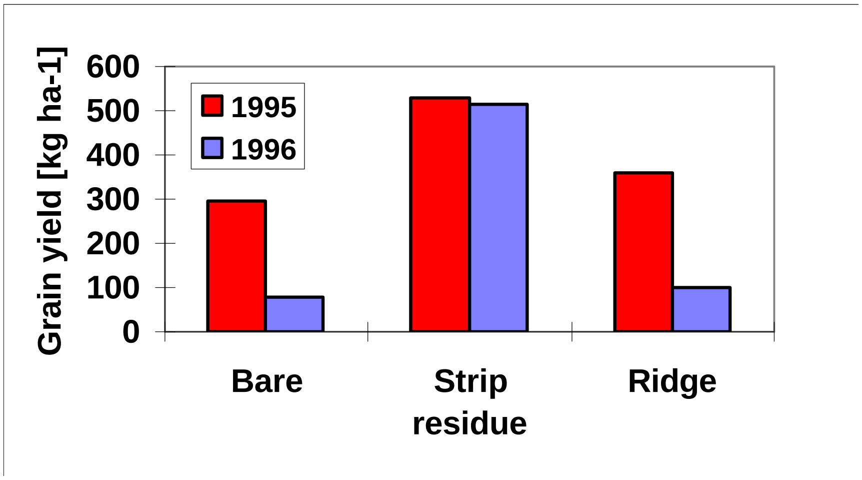


Figure 5. Evolution of millet grain yields under different surface management practices.

By no means should the soil losses reported here for bare surface conditions be equated to soil losses in the traditional millet cropping systems. Except under the most intensively grazed conditions, crop residue is usually present in the fields at levels comprised between a few hundred kg ha^{-1} and 1 t ha^{-1}. Although at the lower end of this range millet stover mulches may not be very efficient at reducing wind erosion (Michels et al., 1995b), it is still likely to be better than nothing.

Because mulching is rarely consciously practiced at the field scale by farmers, the distribution of crop residue can be extremely heterogeneous within a field, reflecting, in particular, the variability in crop yields of the previous year. Within a farmer's field, Brouwer and Bouma (1997) reported millet total dry matter yields ranging from 27 to 13954 kg ha^{-1} for 5 x 5 m subplots. Hence it is not uncommon to find patches within a field with virtually no crop residues. Such patches could easily be subjected to severe wind erosion, and, unless actively reclaimed by the farmer through mulching or manuring (Lamers and Feil, 1995), could contribute significantly to the overall decline in productivity of a field. However, because of the many alternative uses of millet stover, the recommended application rate of 2 t ha^{-1} (Michels et al., 1995b) can usually not be achieved under on-farm conditions at the present levels of productivity. Effective wind erosion control with millet stover mulches will require a boost in millet productivity, which can only be achieved through the use of external inputs such as inorganic fertilizers. Alternate sources of mulching may also have to be sought, for instance through better incorporation of agroforestry practices in the current cropping systems.

Conclusions

Under on-farm conditions, wind erosion can be a major threat to soil productivity if care is not taken to protect the soil surface with an appropriate soil cover such as a millet stover mulch. Dramatic losses in productivity can result from a single year of mismanagement, such as leaving a soil completely bare. It is shown that banded application of residue is more effective than broadcast residue in trapping sediment, probably because of the larger "dead volume" between the millet stems when they are applied in strips. On the sandy, structureless soils considered here, ridging is much less effective in controlling wind erosion than mulching.

Because of its ability to halt wind erosion, greater efforts should be made to boost millet productivity in the Sahel and hence increase the availability of mulching material. This could be achieved through the use of external inputs such as inorganic fertilizers or by integrating agroforestry practices in the current cropping systems. In areas where residue availability is low but labor is not a constraint, ridging may help reduce land degradation through wind erosion.

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