# Extent and Severity of Wind Erosion in West and Central Africa

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## Abstract

The West African Sahel (WAS) is the transition zone between the Sahara desert in the north of Africa and the more humid Sudanian zones in the south. Although diverse in many ways, the WAS countries have in common a fragile agricultural sector, brought about by poor soil, limited rainfall, frequent drought, and wind erosion that accelerates soil degradation and desertification, compounded by rapidly growing populations. Erosive winds occur during two distinct seasons. During the dry season (October–April) the region is invaded by strong northeasterly winds, known as harmattan, resulting in moderate wind erosion. The second and most important wind-erosion period is the early rainy season (May–July), when rainfall comes with heavy thunderstorms that move westward through the Sahel. Wind erosion can be controlled by soil cover, such as a mulch of crop residue, soil roughening, and the reduction of wind speed by annual or perennial grass barriers, artificial barriers, strip cropping, and windbreaks. Based on the strong relationship between the incidence of wind erosion and soil properties, it may be possible to map the incidence of potential wind erosion in the West African Sahel, and hence tell farmers where ameliorative measures can be used to best advantage.

## Introduction

Arid, semi-arid, and dry sub-humid drylands (defined by aridity index criterion) cover 40% of the earth's land surface. Vast areas of drylands, perhaps as much as 70% (3.6 billion ha), suffer from some degree of degradation (Table 1), and roughly 30% (Fig. 1) are located in the West African Sahel (Grainger 1990).

**Table 1. Worldwide status of desertification (UNEP 1992).**

| Classification | Area (million ha) | Total dryland (%) |
|---|---|---|
| Rangelands with soil degradation | 757 | 14.6 |
| Rainfed croplands with soil degradation | 216 | 4.1 |
| Irrigated lands with soil degradation | 43 | 0.8 |
| Total drylands with degradation (GLASOD) | 1,016 | 19.5 |
| Rangelands with vegetation degradation only | 2,576 | 50.0 |
| Total degraded lands (ICASALS) | 3,592 | 69.5 |
| Non-degraded drylands | 1,580 | 30.5 |
| Total dryland (excluding hyper-arid deserts) | 5,172 | 100.0 |

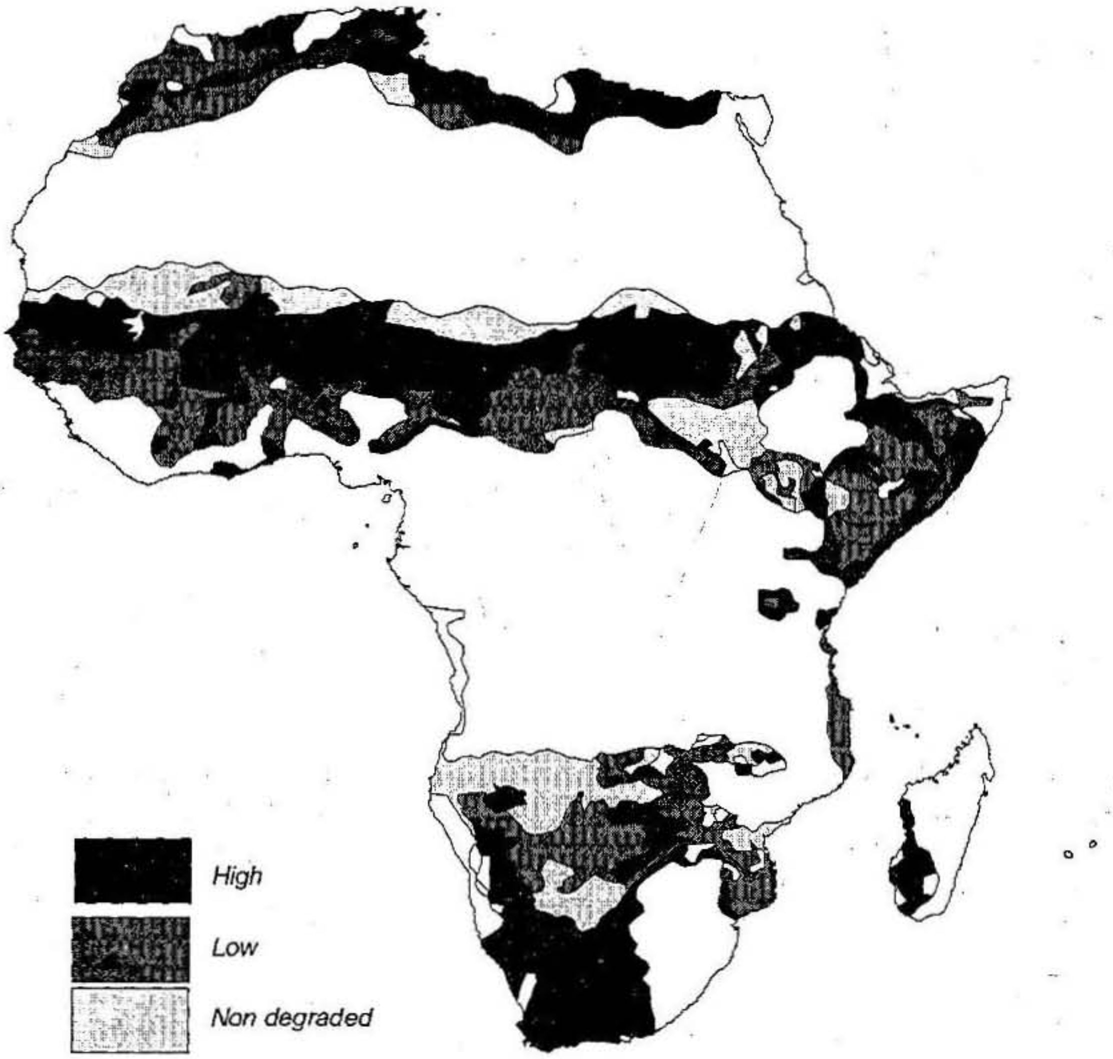


**Figure 1. Soil degradation severity in sub-Saharan Africa.**

The Sahel, located between the 100 mm and 600 mm isohyets (Le Houerou 1989), covers an area 400–600 km wide from north to south, and nearly 6,000 km from east to west across the African continent. It touches eight countries: Senegal, Mauritania, Mali, Burkina Faso, Niger, Chad, Sudan, and Ethiopia. More specifically, the West African Sahel (WAS) is the transition zone between the Sahara desert in the north of Africa and the more humid Sudanian Zones in the south (Lamers 1995). Although diverse in many ways, the WAS countries have in common the problem of a fragile agricultural sector (Table 2). This predicament is caused mainly by poor soils, limited rainfall, frequent drought, and wind erosion that accelerates soil degradation and desertification, compounded by rapidly growing populations (Table 2). The gross domestic product per capita is lower than US$ 500, except for Senegal (Table 2). The contribution of the agricultural sector to the GDP ranges from 31 to 43%, with Senegal (22%) as the only exception (FAO 1995).

**Table 2. Area, population, per capita income, and agricultural statistics in the nine countries participating in the DMI.**

| Country | Total Area (million ha) | Population | | | Fertilizer use (kg/ha) | Millet yield (t/ha) | Sorghum yield (t/ha) | Agricultural contribution to GNP (%) | Per capita income (US$) |
|---|---|---|---|---|---|---|---|---|---|
| | | Number (million) | Density (km$^2$) | Growth (%) | | | | | |
| Burkina Faso | 27,420 | 10.0 | 34 | 3.1 | 2.9 | 0.64 | 0.89 | 41 | 321 |
| Chad | 128,400 | 5.8 | | | | 0.45 | | | 160 |
| Mali | 124,000 | 8.7 | 7 | 2.4 | 5.7 | 0.71 | 0.89 | 43 | 268 |
| Mauritania | 102,600 | 2.1 | | | | 0.19 | | | 480 |
| Niger | 126,700 | 8.7 | 6 | 3.4 | 0.8 | 0.35 | 0.18 | 31 | 262 |
| Senegal | 19,619 | 8.5 | 41 | 3.1 | 4.6 | 0.59 | 0.93 | 22 | 632 |

Sources: Crop Production and Area (FAO 1995); Fertilizers (Mokwunye and Vlek 1986).

The Sahelian soils consist of many different soil types. About 22% of the total area in the Sudano–Sahelian zone is occupied by arenosols (Sivakumar 1989). Most soils are sandy, often with low fertility (particularly phosphorus and nitrogen), humus content, and water retention capacities. Continuous cropping causes soil organic matter and plant-available nutrients to decline. Low fertility is often the major constraint for production of both food grains and natural vegetation, and there is increasing evidence for the use of phosphorus fertilizer to enhance agricultural development. Soils are very susceptible to wind and water erosion, and this forms an additional constraint to food production.

To restore soil fertility, farmers have traditionally kept land under bush fallow for 10–20 years. However, rapid population growth, at an annual rate of 3% in recent decades, has increased food demand. Instead of intensifying farming systems (for example, by using mineral fertilizers), farmers have tried to enhance production by expanding the cropped area. The previously sustainable fallow system has broken down, yields have declined, and marginal land, once used for communal grazing, is now cropped. Over-exploitation has resulted in land degradation, or desertification, on a large scale. Land degradation implies a reduction of resource potential by a single process or a combination of processes acting on the land. These processes include erosion by water and wind, crusting and hardsetting of soils, salinization and alkalinization, and long-term reduction in amount and diversity of natural vegetation (Valentin 1995).

The traditionally livestock-based rural production systems in the Sahelian zone have come under intense pressure through an interaction of factors including drought, population growth, and livestock herd dynamics (Sumberg and Burke 1991). In most of these countries, the forests has declined, and the arable land has also decreased during the past 15 years. Enhanced agricultural productivity requires improvements in input and product markets, rural institutions, and policies creating incentives at the farm level, together with new risk-reducing farming practices that also relieve seasonal labor demands.

Another great constraint for crop production is low and erratic rainfall (Michels 1994). The Sahelian region has a monomodal precipitation pattern, with rainfall between May and September, provoked by monsoon winds coming from the Gulf of Guinea and the northern movement of the intertropical convergence zone (ITCZ; Le Houerou 1989). The ITCZ represents the boundary between the hot, dry air from the Sahara of anticyclonic origin, and the cooler, moister air from the south, of maritime origin (Trewartha 1981). The front of the ITCZ slopes upwards towards the south at a very low inclination angle, since the slope is determined by the density contrast between both air masses.

At the northernmost reaches of the ITCZ, associated thunderstorms occur on an average of 10 days in the year. This number increases southwards, from 20–40 days in the west to 80 days in the Sudan (Martyn 1992 cited in Michels 1994). Wind storms in the Sudano–Sahelian zone are of short duration, less than one hour. During the dry season from November to April, continental northeastern winds, called harmattan, dominate. The average annual wind speed for Dakar is 7 m/s, and for Niamey it is less than 2 m/s (Sivakumar 1986). Air temperatures in the Sahelian zone vary between a mean annual minimum of 18 °C for and a mean annual maximum of 38 °C (Le Houerou 1989).

About 90% of the Sahelian population lives in villages, and is largely dependent on subsistence agriculture (Sivakumar 1989). Insufficient food production threatens the livelihood of the people in this region due to increasing soil degradation, which is often associated with wind erosion (Grainger 1990). Chronic hunger saps people's productivity and increases vulnerability to disease. Food security has deteriorated since independence in sub-Saharan Africa, and severe food shortages are now widespread. Food security at the household level is directly influenced by agricultural performance. In many countries, malnutrition is seasonal and increases before the harvest, when food supplies have dwindled. The gap in food intake widens further in years of drought. Recurrent famines in the 1980s graphically illustrate the high degree of food insecurity in the region (World Bank 1989).

In terms of energy value, food consumption in sub-Saharan Africa between 1965 and 1986 averaged 2,100 calories per person per day, or about 85 percent of recommended requirements. However, averaged over good and bad crop years, one quarter of the population obtains less than 80% of the daily calorie supply recommended by FAO and WHO. In drought and other bad years the undernourished population is even larger.

The Sahelian countries form a core area of food insecurity. To provide universal food security by 2020, action will be needed on both the demand and supply sides. On the demand side, public action will be necessary, especially for households with low or fluctuating incomes or purchasing power. On the supply side, improving agricultural production is imperative, because widespread access to food cannot be adequately ensured without agricultural growth.

Given the magnitude of the food gap, the West African Sahel is far from reaching that goal. Assessing the food needs of African countries up to 2020 for long-term planning is difficult. Such projections are based on assumptions about the prevailing levels of calorie consumption, future population growth rates, and future production performance. Projected food needs were estimated in a World Bank report (1989) under three alternative sets of assumptions:

- Production grows at 4% a year, and population growth gradually declines to 2.75% between 1990 and 2020.
- Domestic production grows at 4% a year and population at 3.3%.
- Domestic food production and population grow at 2 and 3.3%, respectively.

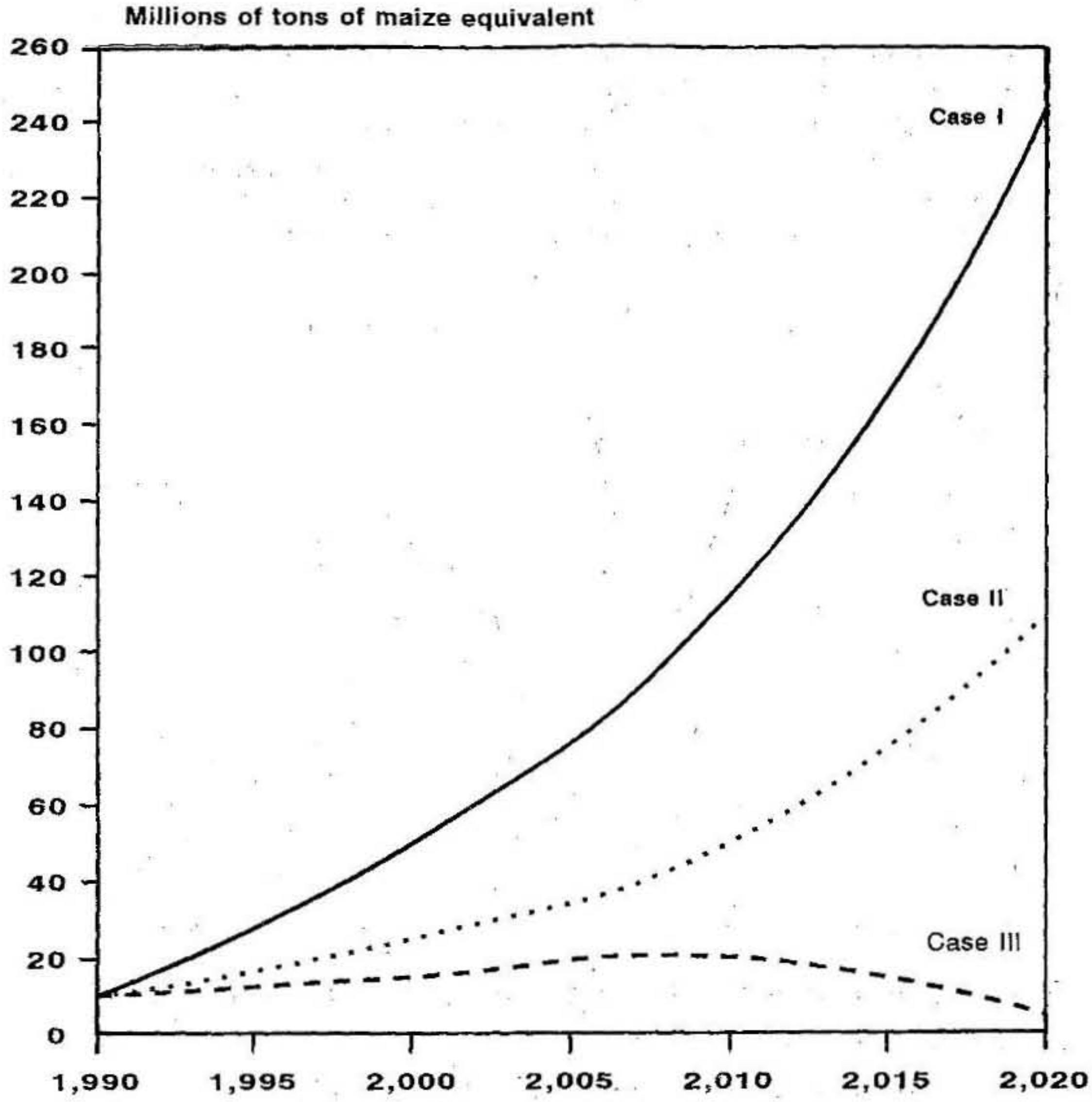
These alternatives are shown in Table 3. The sharp widening of the food imbalance in the latter two cases (Fig. 2) shows how crucial it is to maintain a production growth of 4% a year and reduce population growth in order to ensure long-term food security throughout the region. In order to feed the growing population in these countries (even at a reduced growth rate), an increase in food production is necessary. This, however, can only be achieved through yield increases on land already under cultivation and thus, by protecting and conserving this natural resource, especially from wind erosion.

**Table 3. Population and food security in Sub-Saharan Africa, 1990–2020.**

| | 1990 | 2000 | 2010 | 2020 |
|---|---|---|---|---|
| *Case I* | | | | |
| 1. Population (millions) (constant fertility) | 500 | 700 | 1,010 | 1,500 |
| 2. Food production (mtme) (at current trend growth rate of 2% a year) | 90 | 11 | 135 | 165 |
| 3. Food requirement (mtme for universal food security by 2020) | 100 | 160 | 250 | 410 |
| 4. Food gap (mtme) | 10 | 50 | 115 | 245 |
| *Case II* | | | | |
| 1. Population (as in Case I) | 500 | 700 | 1,010 | 1,500 |
| 2. Food production (4% annual growth) | 90 | 135 | 200 | 300 |
| 3. Food requirement (as in Case I) | 100 | 160 | 250 | 410 |
| 4. Food gap (mtme) | 10 | 25 | 50 | 110 |
| *Case III* | | | | |
| 1. Population (millions) total fertility rate declining by 50% to 3.3 by 2020) | 500 | 680 | 890 | 1,110 |
| 2. Food production (mtme at 4% annual growth) | 90 | 135 | 200 | 300 |
| 3. Food requirement (mtme) | 100 | 150 | 220 | 305 |
| 4. Food gap (mtme) | 10 | 15 | 20 | 5 |

mtme=millions of tons of maize equivalent.

Source: World Bank data.



Note: Case I: a 2 percent annual growth rate in agricultural production and a constant fertility
Case II: a 4 percent annual growth rate in agricultural production and constant fertility ra
Case III: a 4 percent growth rate in agricultural production and a declining fertility rate.
Source: Word Bank data

**Figure 2. Projected food gap: alternative scenarios for sub-Saharan Africa (1990–2020).**

## Soil Transport

Wind erosion can become a problem whenever the soil is loose, dry, bare, or nearly bare, and the wind velocity exceeds the threshold velocity for initiation of soil particle movement (Fryrear and Skidmore 1985). In the Sahel, the farming systems and soil conditions are very favorable for wind erosion. Wind erosion is a set of processes that contribute to the motion of soil from its initiation until its final deposition.

The most comprehensive summaries on the movement of surface material by wind action were prepared by Bagnol (1941) for desert sands and by Chepil and Woodruff (1963) for agricultural lands. Wind erosion consists of initiation, transport (suspension, saltation, surface creep), abrasion, sorting, avalanching, and finally deposition of soil aggregates/particles (A/P). Soil transport by wind (Lyles et al. 1974). is commonly described in three distinct modes: suspension, saltation, and surface creep (Fig. 3).

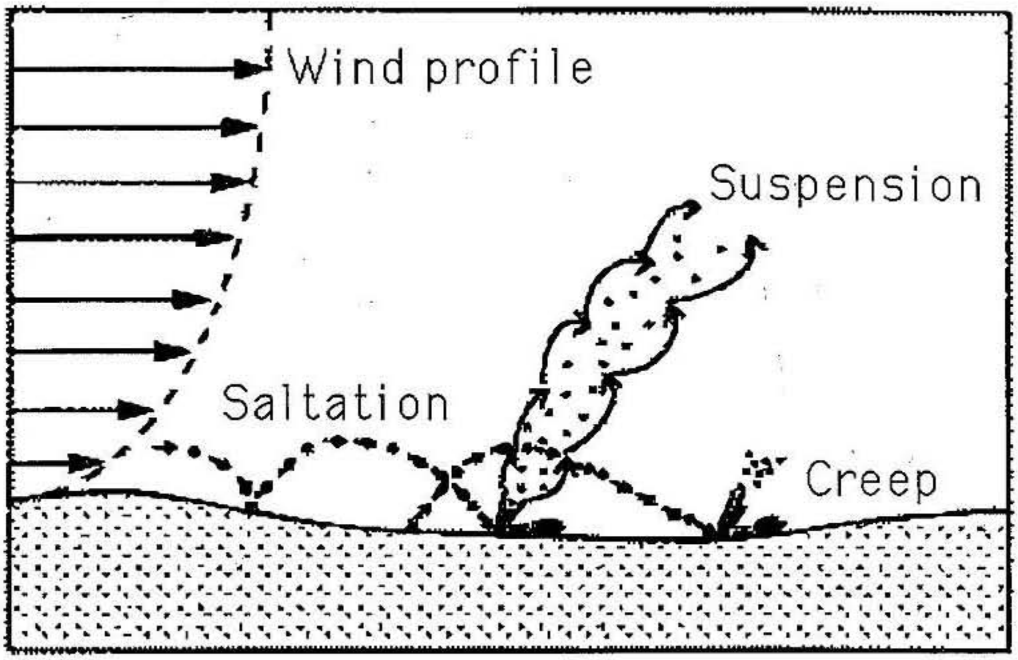


**Figure 3. Three modes of wind-blown particle transport.**

Particles transported by creep are too heavy to be lifted from the surface, and so they roll or slide along the ground. Particles transported by saltation are smaller than particles transported by creep. They move in a series of short hops at heights generally well below 1 m. The smallest particles move in suspension. These particles may be carried with vertical winds to great heights and are subject to long-range transport.

Under typical conditions, Hudson (1973) suggests that particle diameter varies from 0.5 to 2 mm for creep, from 0.05 to 0.5 mm for saltation, and is smaller than 0.1 mm for suspension. The overlap in diameters for suspension and saltation indicates that certain particles may be moved by different transport modes, depending on the particle density and the wind speed. So, the amount of material transported by the three modes depends on wind speed, particle density, and the texture of the topsoil. According to an estimate of Chepil (1945), the proportions vary from 50 to 75% in saltation, 3 to 40% in suspension, and 5 to 25% in surface creep. The smallest and slightest particles become suspended in the air stream and may be transported hundreds or thousands of kilometers.

Erosive winds that exceed the threshold wind-speed may occur during two distinct seasons (Sterk 1996). During the dry season (October–April), the area is invaded by dry and rather strong northeasterly winds, locally known as harmattan, that may result in moderate wind erosion (Michels et al. 1995a). The harmattan winds originate over the Sahara desert, and from January to March they usually carry large amounts of dust from remote sources. Part of the transported dust is deposited in the Sahel, enriching soils with nutrients. Dust deposits are particularly rich in sodium, potassium, magnesium, and calcium, but poor in phosphorus (Herrmann et al. 1996).

The second and most important wind erosion period is the early rainy season (May–July), when rainfall comes with heavy thunderstorms that move westward through the Sahel (Sterk 1996). Within a fully-developed thunderstorm, strong vertical downdrafts occur, causing a forward outflow of cold air that creates the typical dust storms of the Sahel. These events are usually short-lived, approximately 10–30 minutes, but the storms may result in intense soil movement (Michels et al. 1995a).

The major sources of present-day dust emissions are the subtropical desert regions and the semi-arid and sub-humid regions, where dry, exposed soil is subject to severe winds at certain times of the year. The major world dust-producing regions are located in the broad band of arid and semi-arid lands stretching from West Africa to North China, with the majority being in the Northern Hemisphere (Middleton et al. 1986). The Sahara Desert is the world's most important source of dust. The world-wide annual production of dust by deflation of soils and sediments has been estimated at 61–366 million tonnes (Hidy and Brock 1971). For Africa alone, it is estimated that more than 100 million tonnes of dust per *annum* is blown westward over the Atlantic (Middleton et al. 1986). The frequency of dust storms reaches a peak in regions receiving 100–200 mm of rain per year. As rainfall increases, the frequency of dust storms tends to decrease (Goudie 1978). Dust transported over long distances is composed of particles <16 μm in size, as only particles of that size can remain in suspension for long periods. Dust greatly decreases atmospheric visibility and may reduce the amount of incoming solar radiation by up to half that normally received at the ground surface when the air is clear. A persistent dust haze may therefore serve to reduce evapotranspiration rates.

## Aeolian Dynamics

The volume of sand moved by creep and saltation is a power function of wind velocity (Bagnol 1941). It is therefore highly sensitive to surface roughness and the presence or absence of vegetation or other obstacles, as well as antecedent precipitation.

The combination of areas of sand deflation, sand transport, and sand deposits detectable on satellite imagery allows for the concept of a Global Wind Action System (GWAS) in the Sahel (Maingret 1994). A GWAS is a dynamic aeolian system where, in a definite area, particles are imported and accumulated or re-exported as a consequence of wind activity. A GWAS can be an open or a closed system.

A closed GWAS is an area where particles are imported and accumulated but where export is negligible. An open GWAS is defined as a system where, after import and accumulation, particles can be re-exported out of the system. The Saharâ, which exports its aerosols towards the north as far as Greenland, towards the east as far as Kazakstan, towards the south as far as the tropical forest of the Gulf of Guinea, and towards the west over the Atlantic Ocean as far as Bermuda and the Nordeste (Brazil), is the best example of an open WAS.

The whole Sahara is one aeolian unit which cannot be separated from the Sahel. Studied on a synoptic scale, the Sahara–Sahel is considered as an open WAS, which delivers sand by saltation from the Sahara to the Sahel, and airborne dust, known as aerosol, in suspension throughout the world. Western Africa is the actual southern limit of this WAS. The system is open and its deflation effects are visible in cultivated land to 13° 50' N.

## Wind-erosion Control Measures

The two flow charts (Figs. 4 and 5) illustrate the processes and feedback involved in the natural stabilization of active sand dunes and the mobilization of dunes following destruction of their vegetation cover (Tsoar and Moller 1986). Any attempt at ecological restoration of degraded dune fields (Wolfe and Nickling 1993) will need to take account of these feedback loops.

Wind erosion is most effectively controlled by reducing the wind velocity at the soil surface or creating a non-erosive soil surface. Wind velocities over large land masses cannot be controlled, but it is possible to reduce the wind velocity at the soil surface with standing vegetation, wind barriers, or non-erodible materials on the soil surface.

Standing vegetation is several times more effective in reducing wind erosion losses than the same quantity of vegetation lying flat on the soil surface (Siddoway et al. 1965). However, weeds must be controlled, and in many developing countries crop residues are utilized by livestock, so it is not always possible to leave vegetation standing for extended periods. In many cropping systems, the entire plant is harvested and no residue is available for controlling wind erosion in the field.

The major objective of a wind barrier is to reduce wind velocity over the greatest distance from the lee of the barrier. The effectiveness of wind barriers depends on the porosity and shape of the barrier to the prevailing wind. The barrier should have about 40% porosity (Chepil et al. 1963) to protect a distance about 10 times the height of the barrier and to reduce wind erosion along the wind direction for a distance about 20 times the height of the barrier

(Hagen 1976). Dense barriers have the greatest wind reduction adjacent to the barrier but shorter protected distance.

Non-erodible elements are material on the soil surface that will not be moved or transported by erosive winds. These include stable soil aggregates, gravel, rock fragments larger than the maximum size that can be transported by wind, and even large sections of un-decomposed plant material. If 30% of the soil surface is covered with non-erodible material, soil loss is reduced by 80%.

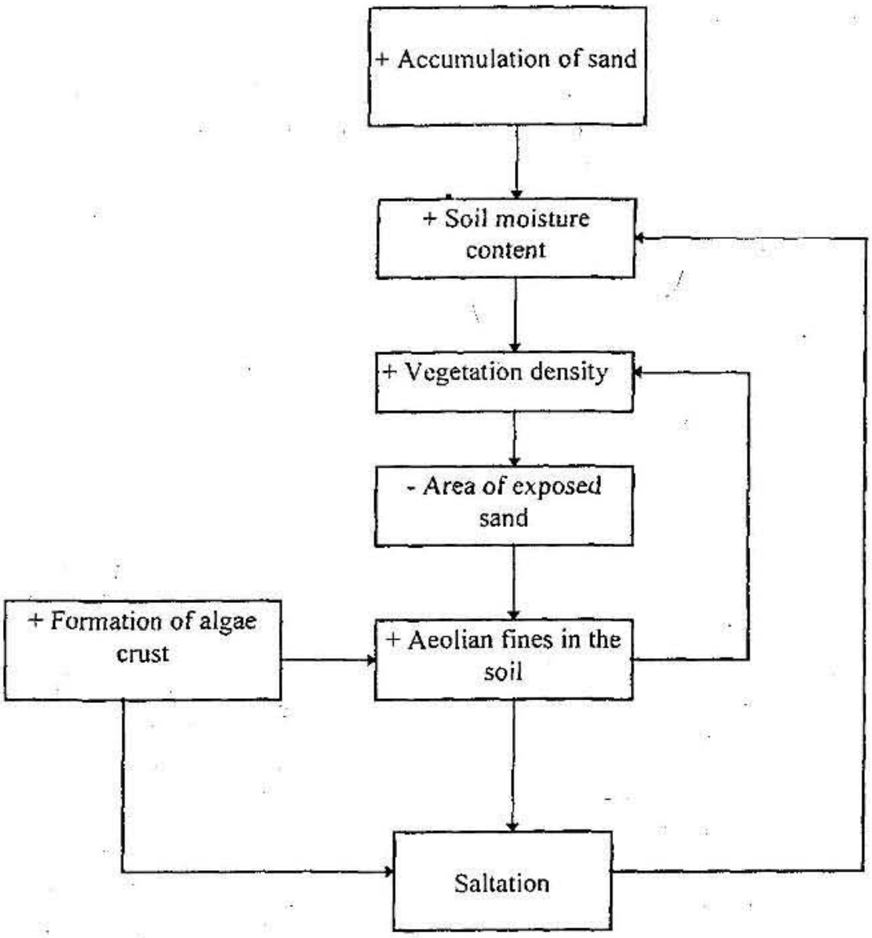


**Figure 4. Flow chart of the processes and positive feedback of the natural stabilization of desert sand dunes. (+) indicates an increase and (-) indicates a reduction (Tsoar and Moller 1986).**

A ridged soil surface reduces wind erosion losses on most soils. The larger the ridge the greater the reduction in soil loss, except for deep sands. Tillage will not control wind erosion on deep sands because the ridges are unstable after rainfall or irrigation.

Wind erosion during crop establishment can destroy young seedlings, reduce crop quality, or delay crop growth. All crops are not equally susceptible to wind damage. As crops mature, their susceptibility to wind damage decreases.

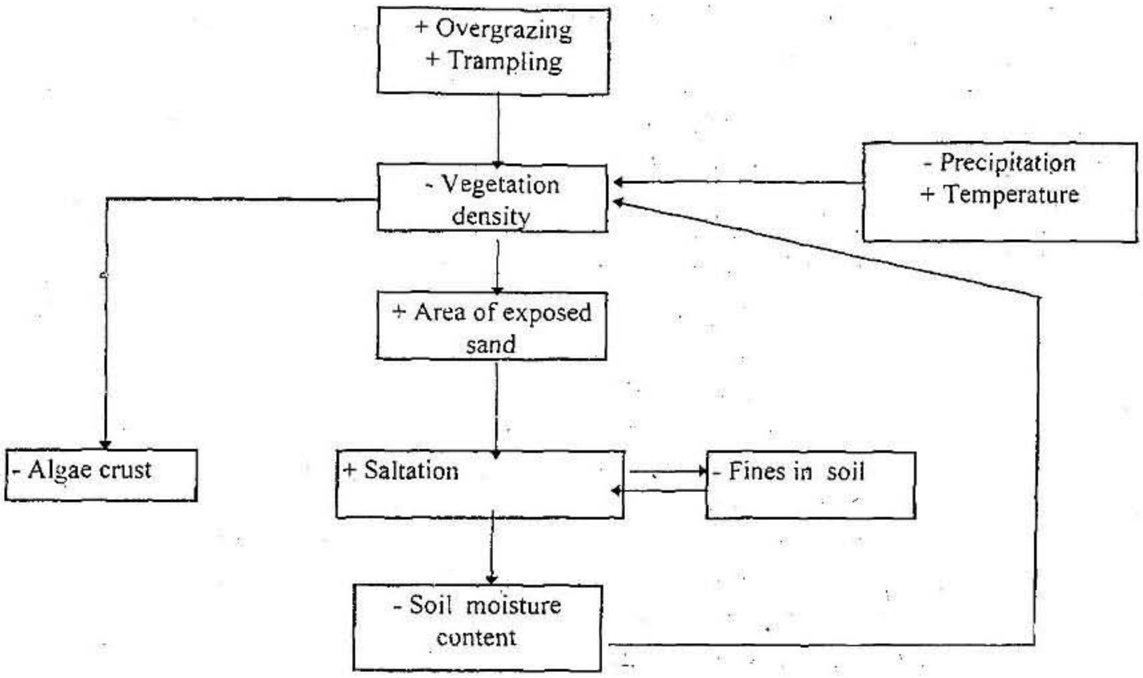


**Figure 5. Flow chart of the processes and positive feedback following the destruction of vegetation on desert sand dunes (Tsoar and Moller 1986).**

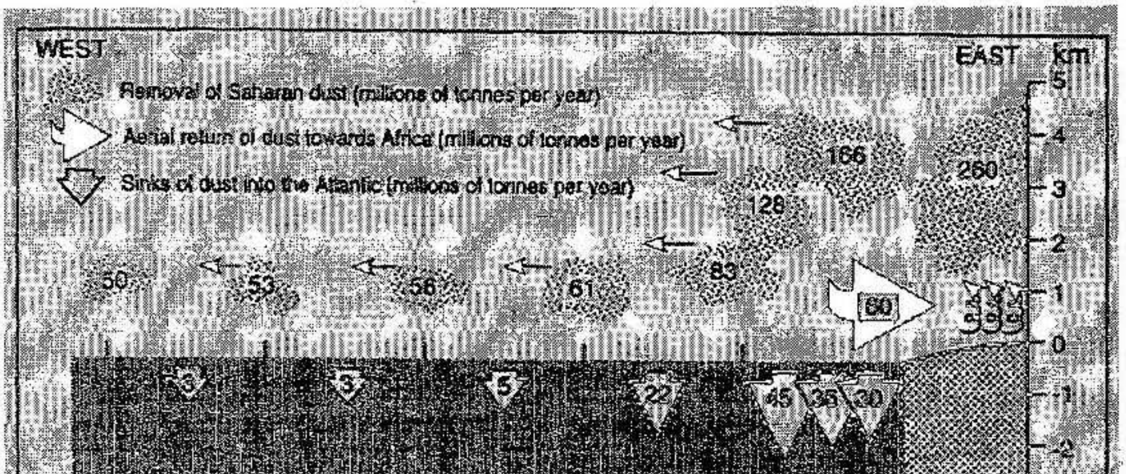


**Figure 6. Aeolian sand budgets for the Sahara. Barbados is roughly 5,000 km west of Dakar (after Middleton et al. 1986).**

## Conclusions

Aeolian translocation of soil material and sediments is a natural process in the arid and semi-arid regions of West Africa. It affects the properties, productivity, and constraints of the soils and ecosystems in the region.

Wind erosion is a major form of land degradation in the West African Sahel. It can be controlled by soil cover, such as a mulch of crop residues, soil roughening, or by the reduction of wind speed by annual or perennial grass barriers, artificial barriers, strip cropping, and windbreaks. The various control techniques can be used according to the scope of the problem. Their relative efficiency depends on: the susceptibility of the soil to wind erosion; drought, which can cause a reduction in vegetation; the prevailing wind direction, which is particularly important when establishing barriers; and the physical properties of the soil, which determine the susceptibility to wind erosion and suitable soil tillage techniques. Therefore the strong relationship between the incidence of wind erosion and soil properties suggests that it is possible to map the incidence of potential wind erosion in West Africa, and hence indicate to farmers where ameliorative measures can be used to best advantage.

## References

Bagnold, R.A. 1941. Physics of Blown and Sand Desert Dunes. Methuen, London.

Chepil, W.S. 1945. Dynamics of wind erosion: 1. Nature of movement of soil by wind. *Soil Sci.* 60(4): 305–320.

Chepil, W.S. and N.P. Woodruff. 1963. Physics of wind erosion and its control. *Adv. Agron.* 15: 211–302.

Goudie, A. 1978. Dust storms and their geomorphological implications. *Journal of Arid Environments* 1: 291–310.

Hidy, E.M. and J.R. Brock. 1971. An assessment of global resources of tropospheric aerosols. Pages 1,088–1,097 *in* Proceedings of the Second Clean Air Congress, Washington DC, USA.

Le Houérou, H.N. 1989. Grazing Land Ecosystems of the African Sahel. Springer-Verlag, Berlin.

Lyles, L., R.S. Schrandt and N.F. Schmeidler. 1974. How aerodynamic roughness elements control sand movement. *Trans. Am. Soc. Agric. Eng.* 17(1): 134–139.

Martyn, D. 1992. Climates of the World. Developments in Atmospheric Science 18, Elsevier Science Publishers, Amsterdam.

Middleton, N.J., A.S. Goudie and G.L. Wells. 1986. Frequency and source of dust storms. Pages 237–260 *in* Aeolian Geomorphology (W. G. Nickling, ed.). Allen and Unwin, Boston, Mass.

Sivakumar, M.V.K. 1989. Agroclimatic aspects of rainfed agriculture in the Sudano-Sahelian zone. Pages 17–38 *in* Soil, Crop, and Water Management Systems for Rainfed Agriculture in the Sudano-Sahelian Zone. Proc. Int. Workshop, 7–11 Jan 1987. Niamey, ICRISAT, Patancheru, India.

Sivakumar, M.V.K. 1986. Climate of Niamey. Progress Report 1. ICRISAT Sahelian Center, Niamey, Niger.

Trewartha, G.T. 1981. The Earth's Problem Climates. The University of Wisconsin Press, Madison, WI.

Tsoar, H. and J.-T. Moller. 1986. The role of vegetation in the formation of linear sand dunes. Pages 75–97 *in* Aeolian Geomorphology (W. G. Nickling ed.). Allen and Unwin, Boston, Mass.

Wolfe, S.A. and W.G. Nickling. 1993. Protective role of sparse vegetation in wind erosion. *Progress in Physical Geography* 17: 50–68.

World Bank. 1989. Sub-Saharan Africa: From Crisis to Sustainable Growth.