End of the Global Wind Action System Saharo-Sahelian in Western Africa

Dumay F.[1] ***Mainguet M.***[1] ***Georges J.C.***[1] ***Fall O.***[2] ***Guang H.***[3] ***Lémine O.H.***[4] and ***Lehbib S.A.***[5]

[1]Laboratoire de Géographie Zonale pour le Dévéloppement, Univ. Reims France
E-mail : monique.mainguet@univ-reims.fr
[2]Ministère de l'Agriculture et de l'élevage du Sénégal
E-mail : fall_ousmane@hotmail.com
[3]Université Normale Supérieure Hunan, Chine
E-mail : hanguang@sparc2.hunnu.edu.cn
[4]Université de Nouakchott, Mauritanie
E-mail : dine@univ-nkc.mr
[5]Ministère de l'Environnement Rural, Mauritanie

The Global Wind Action System Saharo-Sahelian (SGAE) in the interface soil - atmosphere was defined as a set of currents of sand commanded on one hand by the topography: the méga-obstacles (Eglab, Tassili-Hoggar, Tibesti Ennedi, Djebel Marra, Aïr, Adrar des Ifoghas), by the fluviatiles paléo-deposits and the winds: Harmattan mainly, on the other hand (Mainguet and Guy,1975; Mainguet, Canon, Chemin, 1980; Mainguet, Dumay, 1995) Along these currents alternate areas of departure and areas of deposits (ergs) connected among them by areas of transit.

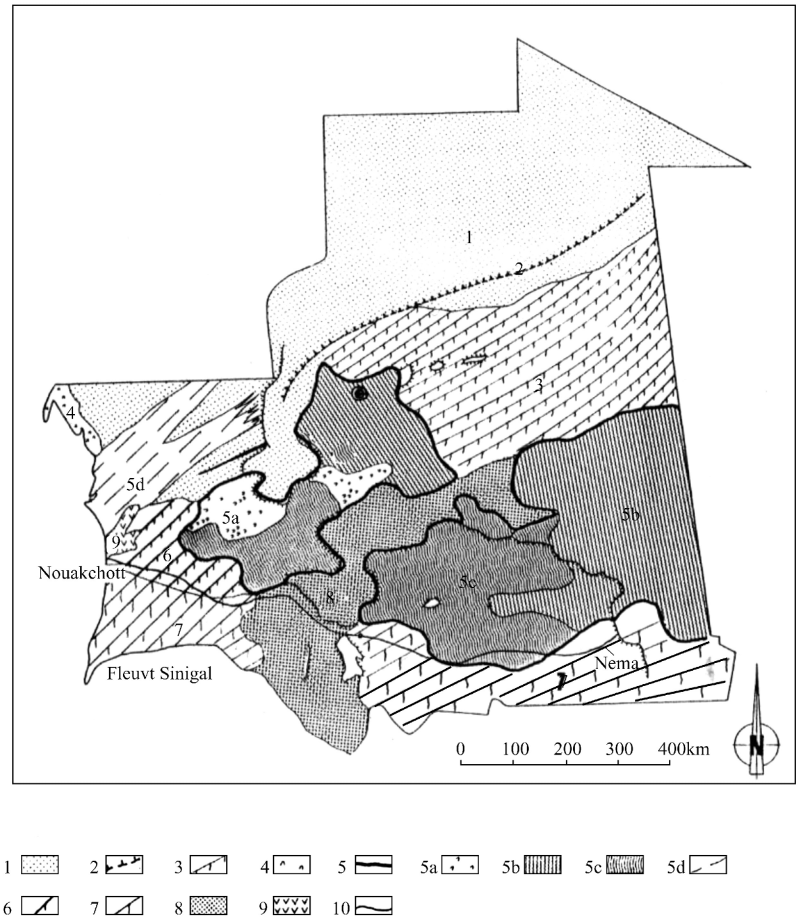
This work describes what we agree to call the continental terminus Mauritano-Senagalian of the Global Wind Action System. After a synthetic description of the SGAE and the regional sedimentary budgets, a diachronic study of the area of Nouakchott, its pluviometry highlighting the droughts and the increase of the transit notably by the winds of dusts during these dry fluctuations, the vegetation and the sifs, the sédimentological analysis will confirm the current effects of degradation of the sandy soils by the deflation and the impoverishment in fine particles and in organic matter.

1 Description of aeolian morphological units of mauritania and the north senegal

The whole system Mauritano-sénégalian divides according to the Sedimentary Budget in 3 units Fig.1: (1) a dry northerly unit : old and current area of departure and also area of current transit with a reorganization which is made in the form of transverses buildings; (2) a central unit, in the passage of the dry in the semi-arid, cover by an open Sahelian steppe to positive sedimentary budget (BS +). This unit is simultaneously an area of blocking sand in transit by the plant place setting steppic and an area of convergence fed by two currents of sand, the one NE-SW 45-55 ° resulting from Ergs Chech and Iguidi, the other one in zonal orientation 70 ° ENE-WSW obtained by and topographic maps 90°—105° E-W according to measures on the ground in January, 2001 (unpublished report); (3) a Southern unit, on the South of Mauritania and the North of Senegal with negative sedimentary budget (BS-), area of longitudinal dunes and recent reactivation in sif since the 1965’s.

1.1 The northern unit

The North of Mauritania to the isohyets 100 mm is an area of active sand where the transit of particles is made by saltation of isolated grains and in the form of trains of barchans. The north-south axis of these barchans, shaped by littoral current north-south, undergoes an inflection right during its meeting with harmattan current of direction NNE-SSW. The axis of these barchans, is NNE-SSW 10°—15 ° at the latitude 20°50′N, becomes NE-SW 40° at the latitude 20°43′N. This fall of axis comes along with an elongation in sif of the right wing of the barchans.



(1) Hyper-dry area of deflation and transit generalized with reorganization of allochtonous aeolian sandy material; (2) Steep slope of sedimentary rock with fall-out and ascents of aeolian sand; (3) Continental area of longitudinal dunes surmounted by sifs of reactivation already in place on the photographic coverage of 1958; (4) Littoral area with north-south current of aeolian sand more autochtonous 5. Continental area with Positive Sedimentary Budget; (5a) Fields of barchans; (5b) Area of akle; (5c) Area of transverses chains; (5d.) Semi-arid area characterized by the transit with genesis of some active dunes of type transverse on the thin dunes little differentiated in process of levelling; (6) Maximal area of degradation and exportation of soils : genesis of sifs and barchans; (7) Southern Sahelian area with reactivation of dunes : current austere deflation and genesis of sifs begun only since 1963; (8) Area of transit of sand (saltation and barkhanes) on rocky substratum (Tagant and Assaba); (9) Sebkha of Ndghamcha;10 Road of the Hope

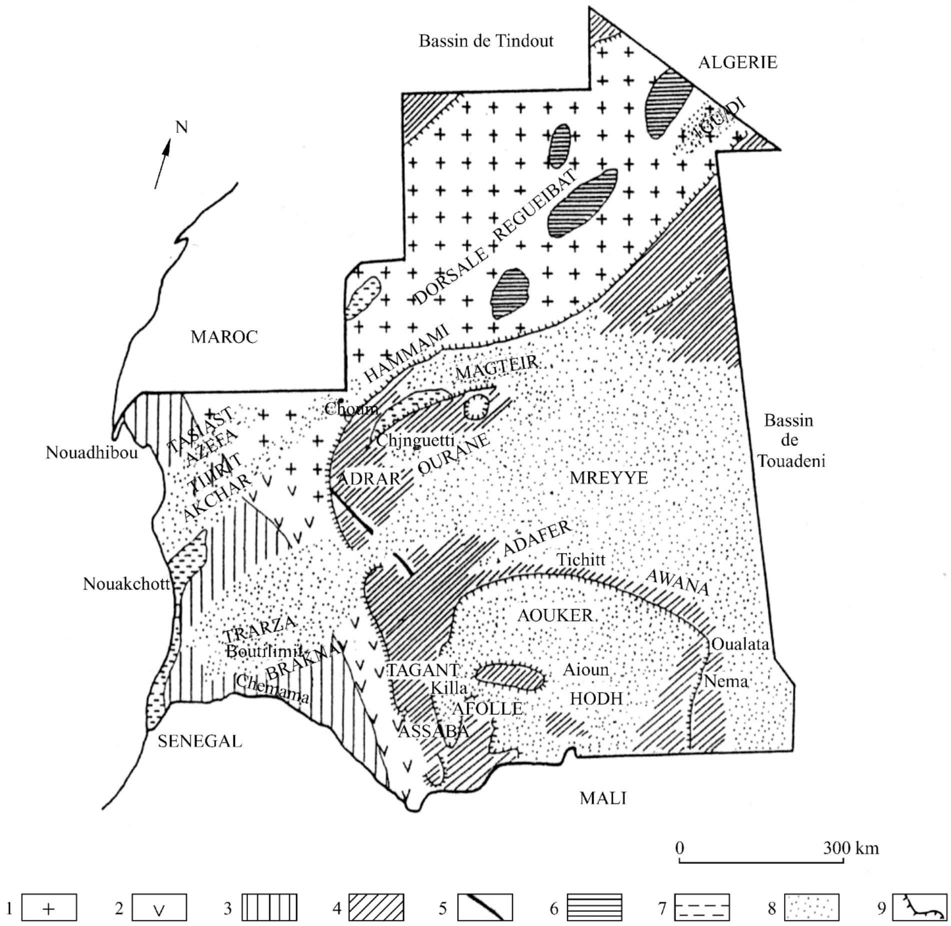
Fig.1 Vulnerability of aeolian morphodynamics units in Mauritania

In the south of this area of barchans, ergs Azefal and Akchar (Fig. 2), the other sectors of dominant transit, appear in the form of longitudinal dunes reactivated in transverse dunes with rare sifs. These dunes were formerly pédogénéisés and végétalisés: forests of Acacias, mentioned on topographic maps of 1970, disappeared leaving some vestiges of trees dying. All the sandy deposits of this vast area of transit is constituted by longitudinal buildings, perched with regard to the plains of Tasiast and Tijirit (Fig. 2), indicating an already formerly negative sedimentary budget, leaving in place a sandsheet of a thickness of 15 m measured in Azéfal at 40 km east of the coast.

The Erg Akchar is one of the active erg the most Southern of the South of the Western Sahara. He grows longer of the NE-SO 55° on more than 400 km since the steep slope of Adrar to the Atlantic Ocean (Pion *et al*, 1990). At present this erg is formed by longitudinal dunes very rubberised and covered at their summit by a thin layer of deflation. These dunes decrease by loss of their fine sandy material with means which migrates in interdunal corridors in the form of barchans and of rare sifs. According to the observations led during the mission of December, 2001, Azéfal is more degraded than Akchar. His exportation leaves some topographic convexities, in the up-wind part is much more advanced than in its southwest part in the contact of the Atlantic Ocean.

1.2 The central area of the system

The central and oriental part of Mauritania, Hodhs and Aouker (Fig. 2), consists of Aeolian deposits organized in transverses dunes, indicators of a positive sedimentary budget, in process of reactivation since 1962. Transverse méga-edifices complex are sometimes reactivated as in Tamcheket's village (17°13′N —10°39′W). The beginning of this reactivation is 1969—1970 and especially during the year 1973 when all the cattle was decimated. The beginning of the sand encroachment of interdunes can be dating, according to the mayor of Togba, years 1986-1991-1992 with the neogenesis of active dunes of type barchans in interdunes.



(1) Precambrian socle; (2) Bow of Mauritanides; (3) Sedimentary plain

(4) Sedimentary plateau; (5) Fault; (6) Hamadas; (7) Sebkhas; (8) Ergs; (9) Steep slopes

Fig.2 Geological map of Mauritania (according Pitte on 1975)

The vegetation was too a victim of this degradation in two step which are : a replacement of *Comifera africana* and *Acacia senegal* by *Acacia raddiana and Leptadenia pyrotechnica*, progressive disappearance of Euphorbes, increase of Calotropis procera and increase of Panicum turgidum areas, every vegetable evolution corresponding on the scale of a human generation. In interdunes and on the old rubberise dunes numerous gullies are the sign of an intense water erosion which participates actively in the supply of sand reshaped then by the wind. The other characteristic of the base of transverses dunes and interdunes: the numerous areas of glazing, proof of a water degradation.

1.3 The Southern area of the system

The South of Mauritania and the North of Senegal form a single morphodynamic unity characterized by a set of longitudinal dunes Trarza and Brakna (Fig.2) in Mauritania (in the North of the delta of Senegal) where dunes are directed NNE 30° (lat 19°45′ — long 16°) and the erg of Cayor in Senegal (Fig.3) where dunes are directed NNE 45° (lat 15°30′ — long 16°) and it to Ndandé's latitude (15°20′ — 16°30′).

In Trarza, the degree of reactivation is high and expresses himself by sifs of neogenesis of north-south direction which invade interdunal corridors where they become barchans of white sand. The graminean vegetation of Trarza disappeared, remain especially some *Acacia raddiana* and *Leptadenia pyrotechnica*. Brakna, differs from Trarza by a lesser reactivation, less high dunes and rich vegetative coverage, notably by its graminean stratum closed of annual. Here as in Aouker, the annual grasses tend has to colonize the hillsides of dunes. The degradation in this erg expresses himself by sheet erosion and the neogenesis of barkhanic domes which beginning to develop a crest and will become in short term a threat for villages

The exam of the satellite images reveals that, contrary to the descriptions of Tricart (1955) and Michel (1973), the dunes do not follow each other on both sides of the river Senegal, but undergo a deflection in the passage of the river.

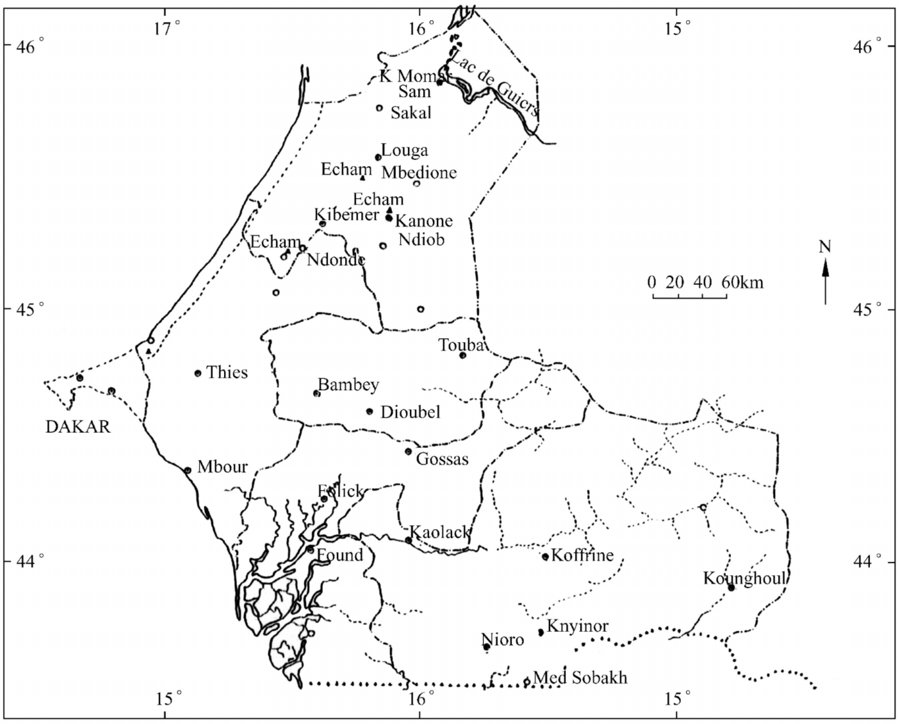


Fig.3 Map of northwest of Senegal

In Senegal, the wide longitudinal dunes of the North of Ferlo of direction NNE-SSO which achieve 125 km long and more of 5 km wide, become ENE-OSO in the South and on the West of the Lake of Guiers where dunes have a maximum length 50 km, a width of less than 2 km, a general orientation NNE and a height of only some metres. In the South of Louga, until Ndande's latitude, dunes are tighter and higher of direction NNE to NE.

Since the drought in 1970, begins a departure of material, the most effective aeolian mechanism of the desertification. The North of the groundnut basin became an area of sand reactivation with a stressed negative sedimentary balance. The aeolian erosion demonstrates itself by the sealing of interdunes and the mobilization of the sand on the summits of longitudinal dunes, further to the degradation of the very scattered vegetation which fixed them. The aeolian erosion becomes drastic for the sandy soils from 15°N. The strongly negative sedimentary budget is detectable on the soil by a layer of deflation and by a appearance of the root of *Balanites aegyptiaca*. The highest sandy dunes are the most affected. The aeolian erosion affects first and foremost the dune crest but the reactivation can affects the whole dune as it is the case to Ndiobène in about 3 km northeast of Louga; residual *Balanites aegyptiaca* is heightened on their roots and their surrounded feet of an alveolus of deflation which dig the soil on more than a metre deep and sometimes reaches a radius of 5 m. Villages are all surrounded by areas of degradation. On the Landsat imagery of 1994, the area of degradation achieves 4 km of diameter around Coki and 8 km to Darou Mousti (Fig.3). In the southwest of Guéoul, around Gad Mbirama (Fig.3), a more severe degree of aeolian erosion is reached, expressed by nebkas, ripplemarks and sand encroachment of fences of *Euphorbia balsamifera* who plays the role of comb towards the sand and heightened gradually on accumulations being able to exceed 1,20 m. Regrettably these fences are in process of degradation and their disappearance leaves accumulations rectilinear given “anthropological dunes”.

After clarification of the complex dynamic of this western African system, the diachronic study of the peripheral degradation of a capital of western Africa: Nouakchott allows to put this study to a local context.

2 Diachronic analysis of nouakchott

The diachronic study of the city of Nouakchott brings precision on the evolution of the climatic context from 1946 till 2000. The exam of the photographic missions IGN from 1954 till 1991 allows to follow the degradation of the plant and the dynamics of sifs from 1954 till 1991.

2.1 The climatic data

The annual average precipitation in Nouakchott classified by decades from 1946 till 2000 (Fig.4) put in evidence an humid decade 51—60, then three dry decades (61—70) — (71—80) — (81—90) with a brutal acceleration in the decade 81—90 during which was set up the sifs of reactivation.

The histogram of the annual average precipitation in Nouakchott from 1961 till 2000 (Fig.5) reveals the dry years: 1970, 1971, 1977, 1983,1984,1992,1994 with dry period marked from 1968 till 1987. Then, without being excessive, the precipitation of the last five years improved explaining the vegetative colonization to the base of dunes observed at the end of the year on 2001.

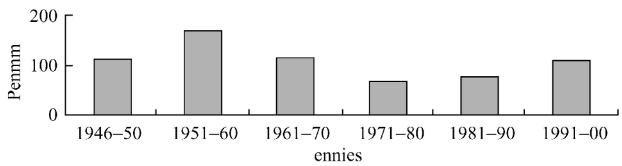


Fig.4 Evolution of the annual precipitation in Nouakchott by decades from 1946 till 2000 (Mainguet, Dumay, Lehbib)

The correlation between the precipitations and the winds of dusts and sand (Fig.5) allows to distinguish a rather favourable period until 1967 then a less favourable period with less precipitations and especially a strong increase of the winds of dusts and sand until 1996.

The genesis of numerous sif was only possible by increase of the number of the winds particles. The dry mists increased since 1963, year from which their annual frequency did not stop growing (Fig.5). Years 1998-1999-2000-2001 were years or frequencies of the aeolian phenomenon (dry mists, winds of dusts …) stabilized.

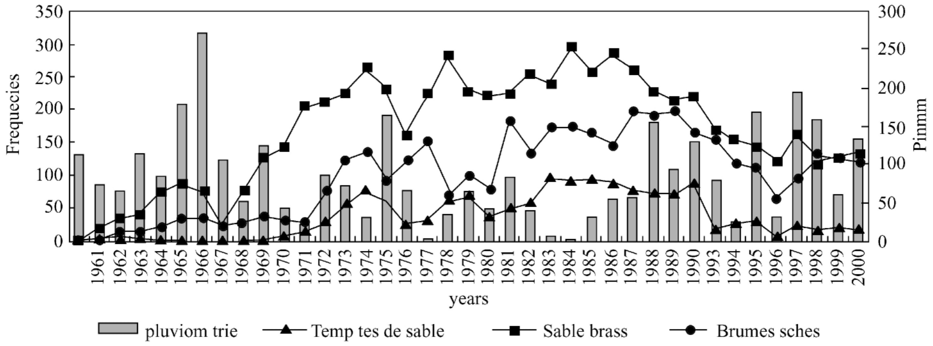


Fig.5 Correlation between precipitation and winds of dusts in Nouakchott from 1961 till 2000

2.2 The vegetation

To understand the degradation engendered by the wind in the GWAS Mauritano-Sénégalian under another lighting, an estimation of the degradation of the vegetative cover since 1963 in the suburb of Nouakchott was realized.

This site which occupies the higher part of a cordon, becomes in the 1980's a field of sifs threatening in the North of the city, is an area of favourable and relatively homogeneous vegetative density in the size of the individuals on at least 2 square kilometres. On the mission AOF 628/60 of 1963—1964, in the 1: 6,000 was deducted the raised vegetation because the mission AOF 096 of 1954 in the 1:50,000, however older, even enlarged was not able to be used for the evaluation.

After demarcation of a hectare witness (1.7 cm × 1.7 cm) on the triplet of aerial photographs AOF628 / 60 n° 50-51-52 in the North of a plot of land tracks down cultivated and lying below, was count, by the method of the slippery break, about 600 shrubs or small trees (between 0,5 and 1,5 m of diameter) of lesser reflectance answering in the black, or by extrapolating : 15,000 individuals for 25 hectares and 60,000 individuals in the square kilometre.

These measures give a quantitative proof of the anthropological action. The first eliminated are fragile herbaceous because they take nutriments in the first centimetres of soil. The small bushes are also more sensitive to the wood-cutting as far as they are frightening by sand encroachment, they are visible on AO 628/125 of 1963—1964 photos n° 27-28-39-40 where enclosures in cattle are numerous. Trees developed enough resist to the different outside attacks, so as "the slaughter", thanks to a vertical root system and swivelling which achieves, as we measured on June 12, 2000, humidity at 40—50cm of depth in the sand at the end of the dry season.

From 1963-64 to 1965 the general texture modified : was staked out black of the ligneous remains while the reflectance grey dark of the herbaceous areas tends to rise because of the shrubs disappearance. The average density of this dune is 580 shrubs/ha in 1963—1964 near to 600 of the previous station. In 1965, there is only 530 trees/hectare. This area accuses a loss of 40 trees by hectare which gives us 320 trees / ha.

On MAU 4/125 N 119-123 of 1980, the average density of shrubs on six kilometres North of Nouakchott, 2,5 kilometres of the first houses, is 160 shrub/hectare, 210 in four kilometres and 370 in six kilometres These values express the continuation of the plant decrease. It is difficult to quantify separately the parts human and climatic responsibilities but the pressure gradient put in evidence around Nouakchott is not obviously natural and proves again the anthropic impact.

2.3 The dynamics of sifs

In Nouakchott, sifs arises from the reactivation of the system of paléo-longitudinal dunes fixed by a tropical ferruginous paleo-soil and a steppic coverage. The erosion of the summits of longitudinal dunes determines the departures of sifs to this level. The embryon of sif gives a sandy comma, a “heap-reservoir” on the line of crest accompanied with a small arrow, beginning of the elongation. The particles which compose it migrate in a second stage on both sides of the crest on feet and hillsides of sifs (Mainguet speaks about a rail of sand) to reach at the end of the arrow where they accumulate and participate for the greater part in the elongation of the body of the dune unless they are re-exported farther by saltation

In the sector of Nouakchott, sifs by evolving takes an oblique north-south orientation of 20 ° in the two prevailing winds of north - northeast and north - northwest sectors to grow longer on the southeast hillsides of longitudinal dunes. By leaving the summit of the hillside W, the progress of sifs is made obliquely up to the hillside E longitudinal dunes. The genesis of sifs contributes has the levelling of longitudinal dunes by export of the sandy material of summits towards interdunes in filling where the material is reshaped in barchans. The genesis of sifs stresses the asymmetry of longitudinal dunes because they result from the aeolian erosion on the hillside NW and from the accumulation on the SE side.

3 Desertification and global wind action system

Several campaigns of samples were made during various missions, in Mauritania and in Senegal, allowing to have a transect N-S of Choum's latitude (N 21°18, W 13°04) in Mauritania to Medina Sabakh (N 13°36, W 15°35) in Senegal. Among the collected samples, were selected the most significant to expose the mechanisms of the deflation and the winnowing, the main causes of the impoverishment of soils. Granulometric analyses have for objective the obtaining the granulometric spectre of sand in transit and trapped in the wind of the obstacle and to determine the role of the deflation in the sorting and the winnowing of the aeolian material.

Granulometric analyses of aeolian accumulation (MAU 2001-03) in the NNE of a NW-SE wall and the Southern ending of a longitudinal dune (MAU 2001-04) in the North of Chemama (plain of Senegal) have a main mode of 160 µm, an aeolian mode and a secondary mode of 80 µm. A third sample (MAU 2001-05) of latitude hardly more Southern, taken in 10 cm deep too from a longitudinal dune also possesses these 2 same modes (80 and 160 µm) with however a loss of 10 % in the mode 160 µm. The fourth analyzed sample (MAU 2001-06) was taken in surface from a longitudinal dune in the South of Bouir Saïd. The distribution of this sample is more spread with three modes : 80 , 160 , 400 µm all of frequency lower than 20 %. In this sample, 400 µm became the main mode while the mode 160 fell in 10 %, what means an aeolian export. The mode 80 µm is not more than weakly represented by 5 %. The presence is due to its texture aggregated and to pseudo sands which allow a better resistance the aeolian erosion.

The decrease from 40 % to 10 % of the mode 160 µm results from the aeolian export of this mode entering exactly in the aeolian competence. The main mode became 400 µm irrefutable proof that the deflation plays its work leaving in place the most unrefined sands. Observation is confirmed by the sample MAU 2001-07a (Figure 6a) taken from a longitudinal dune levelled in process of denudation where particles lower than 50 µm disappeared, less than 5 % for the mode 80 µm and 7 % for the mode 160 µm: all the dusts were already exported. The strong increase of the unrefined modes 500 and 630 µm which are the residual modes of the aeolian winnowing represent 50 % of the sample in the form of pavement of deflation. In over where, when the taking is made in 5 cm deep MAU 2001-07b (Figure 6b) the modes 80 and 160 µm are still present because they were not yet affected by the deflation. The discovery of tools and numerous Neolithic potteries dug up in the North of the Road of the Hope and in the course of exhumation in the South of this road demonstrates well that the system is in phase of erosion.

In Senegal, studies of the texture of the sandy material of surface and in weak depth (5 cm — 7 cm) reveal that the limit size of the material mobilized in the thickness of the soil worked for the agriculture is more raised to the North (250 µm) than in the South (160 µm). The residue of winnowing forms sand sheet of deflation shaped ripplemarks to it. According to the granulometric analysis of three samples taken in the South of Louga (Fig.7): SEN 2000-03, material trapped by *Guiera senegalensis*, SEN 1999-03a, accumulation against *Euphorbia balsamifera* and SEN 1999-01, accumulation against a fence , sediments deposited by the wind are richer in fine mineral particles (fine sands, silt, clays), in light plant fragments (fertilizer, twigs of spices, seeds, etc.) and in organic matter that the superficial horizons of soil where from they result. The material accumulated against fences has a main mode of 200 microns. The finer grains of mode 125 microns are transported on a bigger distance and deposited against walls and fences in villages.

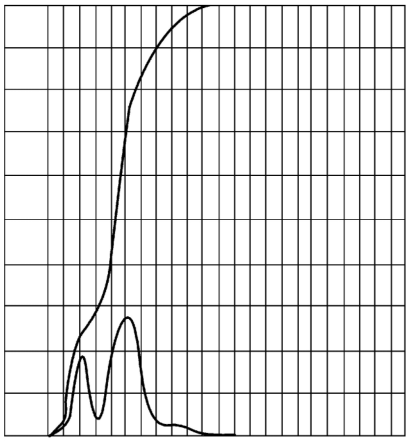


Fig.6a MAU2001 7a

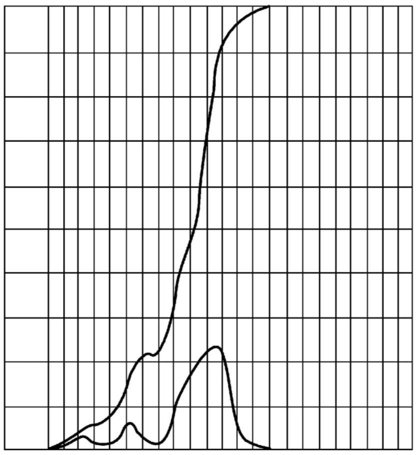


Fig.6b MAU 2001 7b

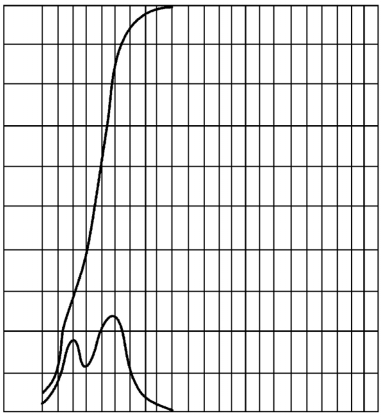


Fig.7 SEN 2000-03

In the southwest of Ngabou (14°45′ N—15°45′ O), an analysis compared by the rate of organic matter in a field and in a bundle of Gueira reveals : 0.15 % in the superficial horizon; 0,65 % in the bundle of *Gueira*. In a plantation of Eucalyptus of 3 years lined the field, rate of organic matter is 0.55 %, proving the interest of these plantations for the fight against the deflation. This difference underlines the loss of fertility when the ground is bare. Lehbib 2001 showed that for a sif fixed since 1990, the rate of organic matter increases from 0.25 % to 0.49 %.

This process leads to the transformation of the texture of the superficial horizons (called Ap) from 5 to 7 cm in thickness and in a change of the properties hydrodynamics of the soil by the ascent in surface of the less fertile and compact underlying horizons, in weak capacity of infiltration and keeping back in water. The work of the renewed soil every year through 2 or 3 hoeing makes go back up in surface a soft layer of the same thickness better for the cultures. In the North of the groundnut basin where the sandsheet are thick, this exportation of soils is not still perceptible. On the other hand, in the South, the combination of both processes of erosion ends quickly in the exhumation of the gravel horizon or armoured underlying, in weak depth.

Conclusion

The fight against the desertification requires to make the difference between the causes, the mechanisms and the consequences This work takes place at the level of severe mechanisms which are here especially aeolian: the deflation and the transport. These mechanisms concern all the system in Mauritania and the part of Senegal where deflation of soils was observed. The environmental degradation reached in Senegal the step of the degradation observed in Mauritania on the air photos of the 1960's.

The observations realized put in evidence the continuance of the regressive dynamics of the vegetative cover, the aeolian erosion and that the deterioration of the biologic conditions began in 1963—1964 of the only anthropological fact and without specific variations of the climatic data. From 1965 till 1980 the urban explosion becomes a reality and the determining factor of the degradation. The process of mineralization already engaged accelerates. The atrophy of the vegetative cover aggravated then without measures with the previous rhythms of degradation.

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