الجمهوريـــة الجزائريـــة الديمقراطيـــة الشعبيـــة

وزارة التعليـم العالــي والبحـث العلمـي

جامعة محمد بوضياف بالمسيلـــــة

كليـــــة العلــــــوم

قسم العلـوم الفـلاحيـــة

2.3.6./ق ع ف/2024

جامعة محمد بوضياف - المسيلة
Université Mohamed Boudiaf - M'sila

المسيـــلة في: 17-09-2024

شهادة موافقة علمية على مطبوعة بيداغوجية

يشهد رئيس اللجنة العلمية لقسم العلوم الفلاحية بجامعة محمد بوضياف بالمسيلة، أنه بعد الاطلاع على تقاريـــر الخبـــــــرة الواردة من طرف الخبــــراء من صف الأستاذيـــة:

- السيد زدام عبد الغني، أستاذ التعليم العالي بجامعة محمد بوضياف بالمسيلة.
- السيدة حيواني فطيمة، أستاذة محاضرة أ بجامعة بسكرة

وتم تعيين أيضا

- الأستاذة شريط ايمان، أستاذة محاضرة "ب" بجامعة المسيلة قسم اللغة الإنجليزية للتدقيق في اللغة

والمعينيـــن من طرف اللجنـــــة العلميـــة في الاجتماع المنعقد في دورته العادية يوم 2024/05/23 لإجـــــراء الخبــــرة لمطبوعـــة بيداغوجيـــة خاصة بالأستاذة **مداني جميلة** - أستاذ محاضر ب- بقسم العلوم الفلاحية وهي معنونة كالآتي: "Conservation des sols" **مقدمة باللغة الانجليزية**

والمقررة في برنامج تكوين التكوين السنة الثالثة تخصص تربة وماء المفتوح بقسم العلوم الفلاحية.

<u>تــمت الموافقــة عليها شكــلا ومضمونـــا</u>

رئيس اللجنة العلمية لقسم العلوم الفلاحية

رئيس اللجنة العلمية لقسم العلوم الفلاحية

د. بعة عبد الحميد

Algerian People's Democratic Republic

Ministry of Higher Education and Scientific Research

Mohamed BOUDIAF University of M'Sila

Faculty of Science

Department of Agricultural Sciences

Educational handout

Course: Soil Conservation

Degree: Bachelor

Level: 3rd year LMD (Semester 6)

Major: Soil and Water

In accordance with the Bachelor's curriculum: Soil and Water 2017-2018

Subject of UEF with a total hourly volume of 67 hours 30

Debts: 6   Coefficient: 3

Dr. MADANI DJAMILA

Academic year: 2023-2024

The pedagogical objectives of the course

The soil degradation results in the erosion and loss of the fertility. Today, it has many types, which impoverish the ecosystems and endanger the life quality. Thus, the fight against it is necessary. The main objective of this course exceeds the mere description of the phenomenon, as we aim at collecting all the information about its factors and mechanisms to find solutions that limit the erosion risk and preserve the water quality. This course is meant for the 3rd year Bachelor students majoring in “soil and water”.

Table of contents

Contents

List of figures

List of tables

The list of pictures

CHAPTER 01

SOIL DEGRADATION: PROCESS AND FACTORS

1. Introduction:

The soil is the interface of the dynamic exchange between the atmosphere, the biosphere, the hydrosphere, and the geosphere. It intimately links the organic and the mineral, what exceeds the simple addition of the geological and biological properties (Gobat et al., 2010). One of the functions of the soil is holding the plants that benefit the humans. Besides, it can transform all the series of the products that we put in it, mainly the products we want to get rid of, thanks to the physical support, the fluids circulation, and the living organisms. In addition, it is a support and a room for storage as it contains water and the minerals needed for the plants. In this regard, when one of these functions is affected, we face the risk of the soil degradation (Coll et al., 2012).

The excessive exploitation of the soil by the human has increased with the demographic growth that requires an intensive use of the agricultural lands. In this regard, Badraoui et al. (2000) pointed that the degradation of the soil and water quality due to the irrigation is a serious issue for the durability of this system. Few decades ago, economic and demographic pressures led to a rapid and massive degradation of the soil worldwide. Today, this problem impoverishes the ecosystems and threatens the life quality.

2. Soil degradation: process and factors

2.1. Definition:

Soil degradation is the process that reduces the potential of the soil productivity and of the utility of the natural resources (Barrow, 1991). Besides, it is the change in all the natural or biophysical aspects of the environment due to an anthropic activity, on the detriment of the vegetation, the soil, the surface, the surface water, the ground water, and the ecosystems (Conacher & Sala, 1998). The degradation of the environment or of the land surface is tightly related to the soil degradation. In fact, a degradation of the vegetation accelerates the soil erosion and, thus, the decrease of the productive value of the lands (Hill et al., 1995; Shrestha et al., 2004). It is a situation where the balance between the climatic hostility and the potentials of the soil resistance is cut by the human actions (FAO, 2014).

Picture 01: Example of the good fertile land that is dried and cracked due to the lack of rain (According to Mathieu, 2009)

2.2 The different types of the soil degradation:

Generally, we have two aspects of degradation: the pullout and the movement of the soil surface elements by the hydric or eolian erosion, and the soil degradation due to the chemical or physical elements:

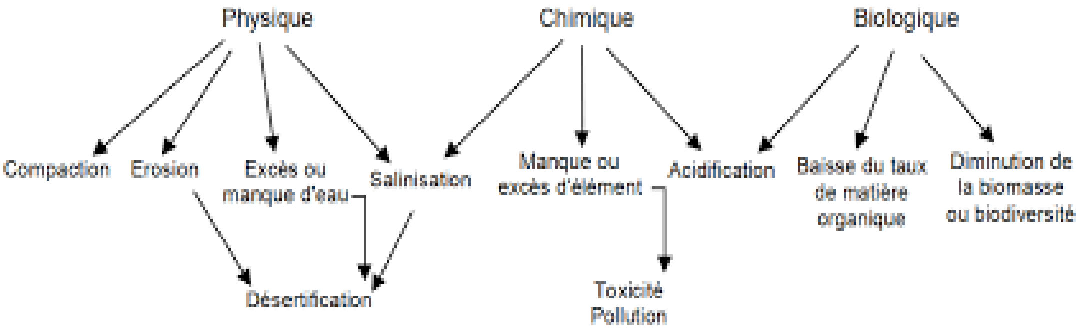


Figure 01: The main types of the soil degradation (According to Mathieu, 2009)

2.2.1 The physical degradation:

It weakens the soil structure, the crusting, the compaction, and the erosion (Mathieu, 2009).

- The compaction: it results from the animals trampling in the humid conditions, or due to the passage of heavy machines. The soil porosity, thus, decreases and the air and water movement changes. Besides, the rooting is limited, if not possible. The vertical water flows are disrupted and the run-off starts, leading to the erosion (figure 02)

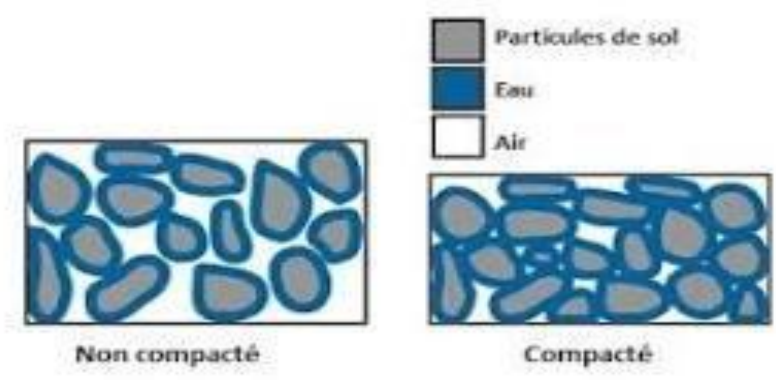


Figure 02: The difference in porosity between a compacted and non-compacted soil (According to Baize, 1984).

- The excess of water in the soil: it takes place when the speed of the water infiltration is lower than the flows. Thus, the water temporarily or permanently stagnates in the soil, hindering the good aeration and the development of the normal biological activity (vegetal and animalistic). The anaerobic conditions cause chemical transformations. Besides, the compaction leads to the water excess; more widely, anything that hinders the lateral circulation of the water causes the engorgement and, then, the hydromorphy (picture 02).

Picture 02: The potential case of the water excess in cereal parcels in spring (According to Baize, 1984).

- The crusting and the soil surface waterproofing: these phenomena are the results of the vegetation that does not protect the soil surface from the effects of the raindrops. The soil aggregates decrease; the liberated thin particles clog the surface porosity and a soil crust (name given to the state of surface where the soil loses the porosity and does not allow the infiltration) emerges, causing the run-off (figure 03).

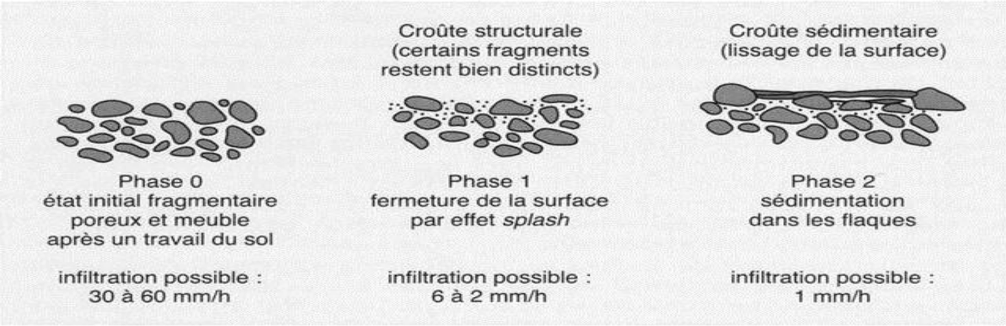


Figure 03: Stages of the degradation of the soil surface and the formation of a "soil crust" under the rain action

The erosion by water (hydric erosion): It happens when the water, which cannot get infiltrated, runs off and cannot strip the soil of its superior horizons; i.e., of its richest part with the organic substance. If the erosion is a natural phenomenon that rejuvenates the soil and allows the continuity of life, the hydric erosion that is caused by the human activities is harmful because it may even lead to the complete stripping of the soil and outcrops the mother rock (picture 03)

Picture 03: The erosion in one winter period in a loamy region (According to Mathieu, 2009).

The eolian erosion: it may take place everywhere, mainly when the vegetation is absent or incomplete, the soil is dry and thinly divided, and the aggregates of the soil have been destroyed or absent (sand, if not peats). The first consequence of the eolian erosion is the exportation of the thinnest particles (clay and organic substance), which impoverish the soil. Besides, the transportation and the deposit may affect the sand, which migrates and accumulates so much that it evades the cities, the oases, and the roads. This form of erosion is important in the desert regions (photo 04).

Picture 04: The eolian erosion on a sand loamy formation and a bare soil in an Atlantic climate (According to Mathieu, 2009).

2.2.2. The chemical degradation:

It happens in the mineral and organic phases. The main manifestations are (FAO, 2014):

- The loss of the nutritional elements and the organic substance: This phenomenon, generally, occurs when the exportations of this substance during the harvest of the crops are not compensated by the fertilizers, compost, etc. The rapid decease of the rates of the organic substance in the soil after the deforestation are part of this degradation.

- The salinization: In the arid and semi-arid regions and the naturally salty soils, due to the saline mother rock for example, we usually notice a secondary salinization due to a mismanaged irrigation (salty irrigation water or absence of the drainage of the irrigated particles). In the coastal regions, the salinization may be due to the intrusion of the seawater or salty groundwater in the good quality groundwater. When the mother rock or the groundwater contains salt, the evapotranspiration of the cultivated vegetation may salinize the soils.

Picture 05: The concentration of the salt above a ridge in the beet plantation (According to FAO, 2014).

- The acidification: The excess of acidizing fertilizers may lead to the soil acidification, which weakens the soil structure and causes the loss of the clay (as there are no enough cations to link the clay particles), a difficulty for the plants to assimilate the mineral elements, and a slow microbial activity.

- The pollution: The industrial pollution generates acid rains that contribute to the acidification of the soil. Besides, the cars are the main source of the lead, the zinc, and the cadmium in the atmosphere. The accumulation of the urban garbage, the spread of the sewage sludge, and the excessive use of the pesticides provoke the chemical degradation of the soils, as they lead to the accumulation of toxic elements.

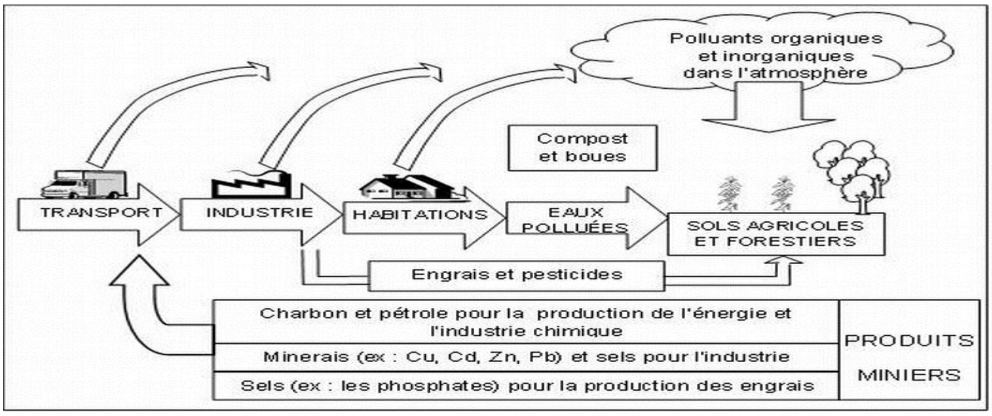


Figure 04: soil pollution by the urban and industrial activities (according to Girad, 2011).

2.2.3 The biological degradation

It affects the vegetation and leads to the decrease of the biomass quantity, the decline of the quality and composition of the species, and to fires, which decrease the fauna of the soil (or the pedofauna). These organisms that live in the soil are a good indicator of the functioning and fertility of the milieu. In fact, they influence and improve the soil structure, as they maintain a porosity that allows the infiltration of the rainwater and, thus, reduce the superficial flow and the erosion.

2.3 The process of soil degradation

In the natural state, without the human intervention, the soil is normally covered by the vegetation. Besides, the leaves and the branches protect it against the rain, the wind, and the drying. The dead leaves and the broken twig make a superficial litter that protects it and holds an important population of macro and micro-organisms. The roots, in the surface or the depth, open the soil and ensure its cohesion. The soil that is covered by a natural vegetation for a long time has a thick layer that is rich with vegetation (horizon A). It has a dark color due to the high content of the organic substance, and contains a high amount of nutritional elements and a stable and very developed structure that allows absorbing and storing a big amount of rain.

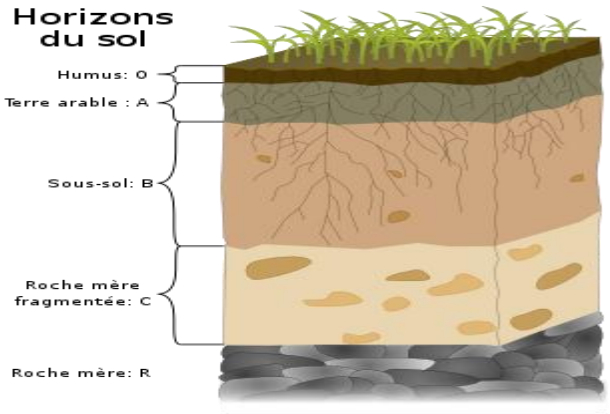


Figure 05: A profile showing the different horizons of the soil formed by the alteration from the mother rock (according to Mathieu, 1990).

If the vegetation disappears, either for the crop or due to the overgrazing, the fires, climatic changes, and other changes shall take place on the soil. The change speed depends on the temperature, the topography, the precipitations, the soil itself, and the development mode. In general, and under the hot climates, mainly when the animalistic manure does not go back to the land, the content of the organic substance decreases under 0.5%, the soil structure and fertility deteriorate, the rainwater clogs the soil surface, the infiltration decreases, and the run-off and the erosion start and then accelerate.

The soil degradation degree is the intensity of the land degradation process (Ruelle, 1990). It can be:

- **Light:** when some degradation indications are visible, but the process is in its initial phase.
- **Moderate:** when it is apparent, but the control and rehabilitation of the soil are possible with considerable efforts.
- **Strong:** when the change in the land properties is important and the restoration is difficult.
- **Extreme:** when the degradations exceed the possible restorations.

In fact, soil degradation is a complicated phenomenon where many elements intervene and cause the loss of the agricultural potentials, the erosion, the soil deterioration by the water or the wind, and the loss of the fertility, leading to chemical, physical, and biological modifications. Thus, we can find different types, factors, and processes of the soil degradation.

CHAPTER 02

THE HYDRIC EROSION

1. Definition

The soil erosion is a phenomenon where the materials move to the soil surface by the water action; thus, it is a hydric erosion. Besides, it can be by the wind action and, thus, is an eolian erosion (Stengel & Gelin, 1998). The hydric erosion is the detachment, transport, and sedimentation of the soil particles by the rain which runs-off on the soil surface, or the water flow in the snow melt. It results when the pullout forces are bigger than the soil particles' resistance forces.

2. The mechanisms of the hydric erosion

According to Lagacé (2015), it is the process where the soil particles are pulled out from their milieu and transported by the water to another milieu, as shown in this figure:

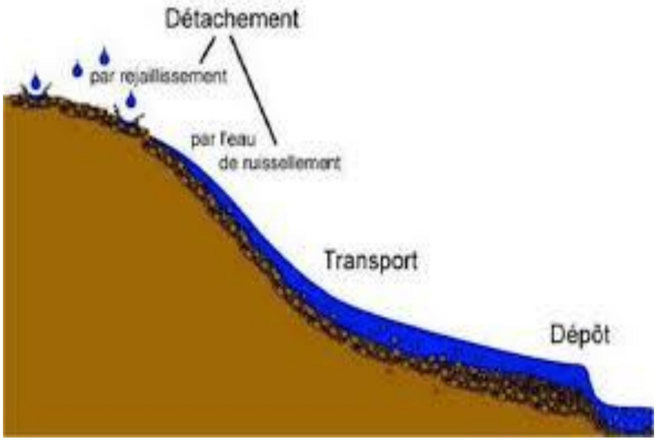


Figure 06: The mechanisms of the hydric erosion (According to Bigi, 2012).

The erosion is so important that it causes a high disequilibrium. The deposition takes place when the transport forces are weaker than the particles weight (Ritter, 2012).

2.1. The detachment

The particles detachment takes place on the soil surface due to the raindrops, when the aggregates splash, or when the shearing force of the run-off is superior to the resistance (Yvio, 2008). Thus, we must point that there is a detachment by the run-off when the force of the water friction on the soil particles is superior to the soil shearing, as shown in the figure:

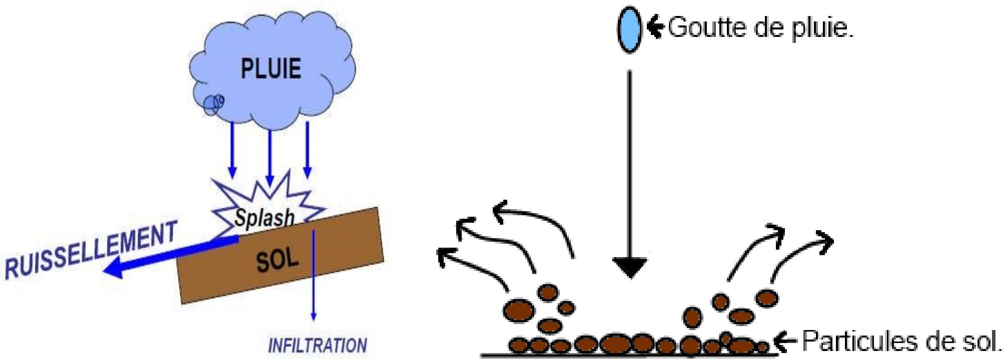


Figure 07: The effect of the raindrop

2. The transportation

The particles resulting from the dissociation ultimately move to the downstream by the gravity. Some screes directly fall. The thin ones are moved by an agent, generally the water. The pulled out particles may be transported through three ways by the flow:

- **In suspension:** the raindrops effect on the water blade provokes a turbulence that maintains the thin particles in suspension. These particles are transported for long distances.
- **In roll:** when the flow increases, it may pull out bigger particles, but cannot put them in suspension. The flow force rolls them on the bottom.
- **By saltation:** when the particles have average size, they can be transported by successive jumps (saltation).

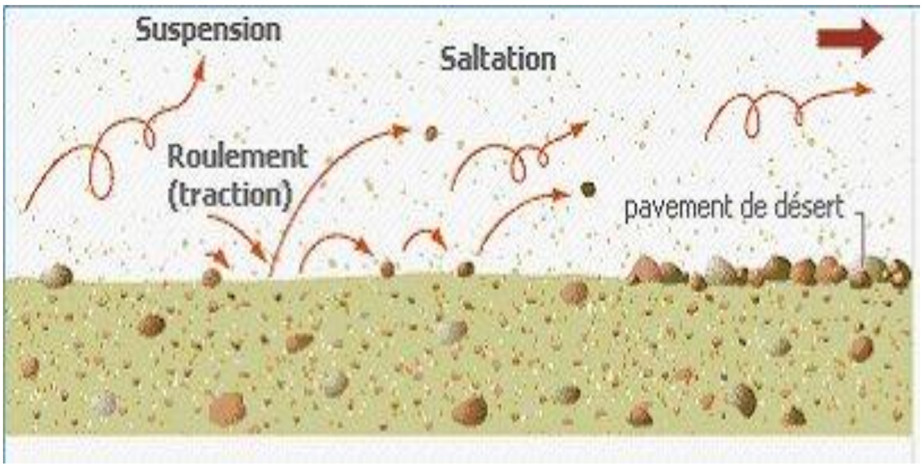


Figure 8: The mode of transportation through run-off (According to Tidjani, 2008).

2.3 The deposit

The main factor for the sedimentation is the water run-off. The soil particles that are pulled out arrange themselves between the original place and the downstream according to their dimension, density, and the transportation capacity of the run-off (Lagacé, 2015). The particles follow this order: sand, thin sand, and loam. The clay and the colloidal humus are generally transported from the watercourse until the downstream (Bigi, 2012).

3. The causes of the soil hydric erosion

3.1. The intensity of the precipitation or the rain erosivity

The rain is the main factor for the hydric erosion, which depends on the duration and the intensity of the precipitations, or on the kinetic energy that results directly from the drop diameter and speed (Roose & Noni, 2004). According to Stone (2000), the increase of the precipitations intensity increases the erosion and run-off risks. Besides, according to Arnold et al. (1989), the raindrops impact may hurt the aggregates, disperse the soil particles, and makes them more subject to erosion. In addition, the run-off increases if the infiltration decreases by the compaction and the formation of crust or gel during the rainfall (Roose & Noni, 2004).

3.2 The topography

Three topography aspects must be considered, namely the inclination of the slope, the length of the slope, and the presence of concavities and convexities. These factors are not completely independent. According to Stone (2000), the long slope increases the risk of the erosion. In fact, the increase of the inclination of the slope increases the water run-off speed and decreases the infiltration rate; this increases the run-off quantity. The relief influences the speed of run-off on a parcel. The low speed increases the pullout of the soil particles. The soil erosion risks according to the slope are evaluated as follows:

- Between 0 and 1%: water run-off with no erosion.
- Between 1 and 3%: erosion starts and gullies are formed.
- Between 3 and 5%: strong erosion with gullying.
- More than 5%: very strong erosion with a deep gullying.

These numbers must be relativized according to the soil type.

3.3 The vegetation

The erosion risks increase when the soil has a weak vegetation or residuals, which protect the soil from the raindrops and the splashing. They slow the speed of water run-off and allow a better infiltration. According to Girard (2011), the type of the vegetation plays an important role in the process of erosion. A forest vegetation protects the soil and has a good influence on the structure and capacity of the soil infiltration. According to Lagacé (1980), the erosion risk increases when the vegetation and the rate of the residuals on the agricultural lands decrease. The relation between the vegetation and the erosion is not simple (Stone, 2000):

- It depends on the density of the vegetation. The protective effect of an agriculture is not generally efficient before around 40-50% of the vegetation, and there is a difference beyond 80-90%.
- It depends on the type of vegetation: the plants with high leaves are less efficient because the water drops that fall on the leaves have the time to reach a speed that equals that of the rain. Even the shape of the leave may play a role in altering the drop that falls on the soil (the kinetic energy of the drop that falls on the surface is approximately proportional at ms2, where m= mass and s= speed). The leaves that concentrate the water on the surface to increase the size of the drops may provoke an erosion under the crown if the soil is bare.

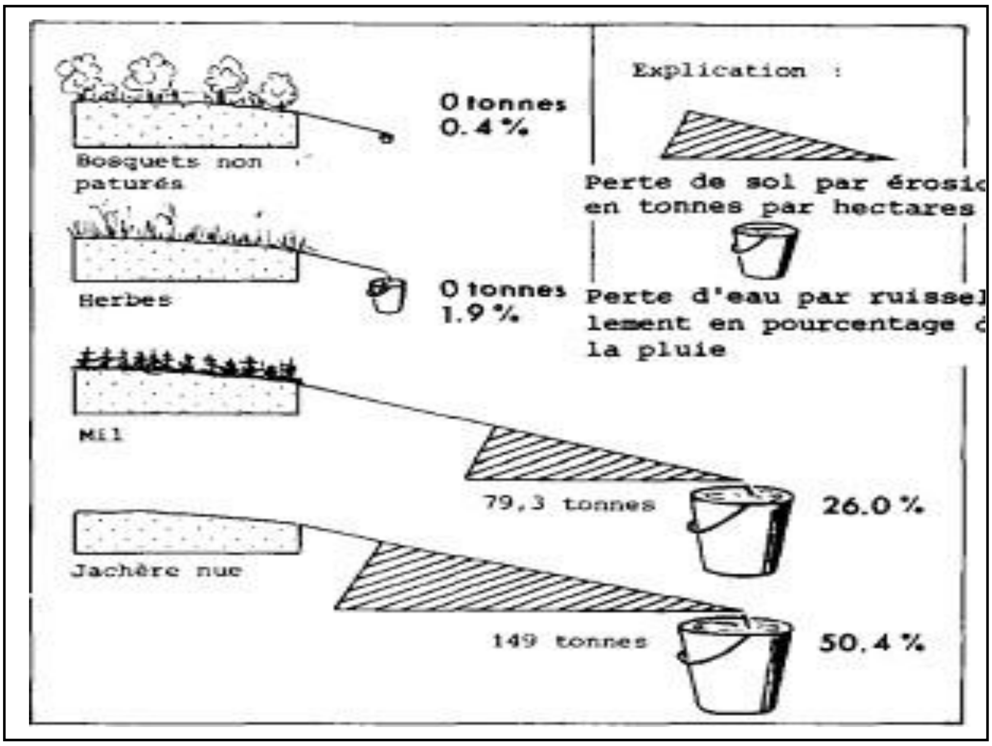


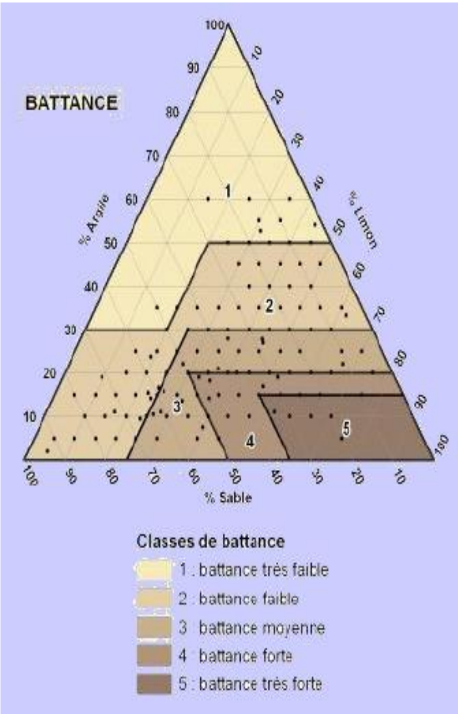
Figure 9. The results of the soil erosion assays on the lands with different vegetation in MPWAPWA, Tanzania (according to Rapp-Berry-Temple et al, 1973).

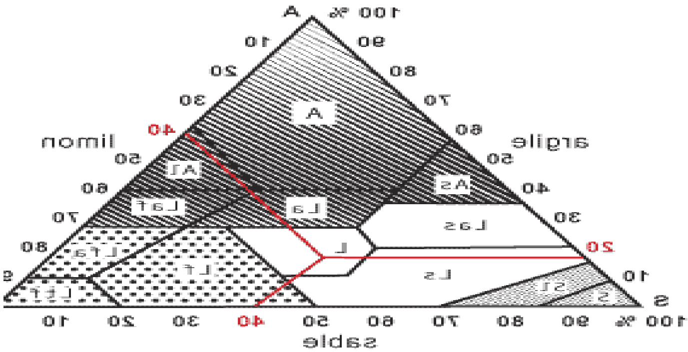
3.4 The soil texture

The texture is the main factor that influences the sensitivity of the soil to the erosion.

Some elements such as the structure, the organic substance level, and the permeability of the soil play a role (Stone, 2000). According to Arnold et al. (1989), the compacted clays and gross sand erode less than the loams, the very thin sands, and some clay loams

The textures with very little clay have a low cohesion and, thus, a weak structural stability. Under 10-15% of clay, the structural stability is weak. These soils may form a soil crust on the urface: a thick and little porous layer that limits the infiltration.





	L : loamy
C :clay	Ls : loamy-sanded
SC : clay-sanded	LtC : loamy thin clay
LC : loamy-clay	TL: thin loam
CL : clay-loam	VTL: very thin loam
LtC : loamy-thin clay	Sl : sandy-loam
CsL : clay-sanded loam	S : sandy

Figure 10. The relation between the texture and the soil crust (Zaher, 2010), B (According to USDA in Gadrat, 1997).

3.5 The soil erodibility

According to Ouattara et al. (2003), an erodibility is a base that tallows determining the level of facility with which the soil was eroded. This is linked to the sensitivity of the soil or the superficial materials to being moved by the run-off. If this sensitivity is very linked to the structural stability, it depends on the physical state of the surface, compaction, work of the soil, crusting, etc. The erodibility is the yield of the soil and rocks intrinsic non-resistance to the erosion. A very big erodibility may lead to the washout (followed by a dangerous leaching). The soil erodibility is a parameter that represents the integrated annual value of the soil profile reaction to the detachment and the soil transportation by the raindrops and the surface flow.

3.3.6 The human activities

The human inadequate practices are the main factor for the erosion intensity. The deforestation the human causes, the overgrazing, the unplanned agriculture, the mechanical work in the big slopes, and the non-restitution of the nutritional elements of the soil facilitate the run-off and, thus, the erosion with its undesirable effects that harm the environment and agriculture (Fournier, 1960; Ouattara et al., 2003).

a. The cultural techniques: Each cultural system includes a repetition of the cultural process that causes discontinuities in the evolution of the soil physical properties. The farmers may accelerate or slow down the soil superficial degradation (Boughalem et al., 2013). The cultural operations modify the structural state of the soil, and the consequences on the infiltration differ according to the used techniques and their date regarding the rainy periods. All the works on the soil that aim at the agriculture, such as the fight against the adventitia immediately increase the infiltration capacity. These works limit the run-off speed and traction force. When the soil work direction is perpendicular to the direction of the biggest slope, the created roughness may contribute to storing an important amount of water. We can consider that the cultural operations that modify the physical characteristics of the soil have an immediate effect (Lawani, 2012).

b. The overgrazing: the pastoral space gets weak due to the overgrazing. The disappearance of the vegetation leaves important surfaces unprotected and exposed to the erosive effects of the rainwater and to the run-off.

c. The mining: We consider that the mining plays an important role in the hydric erosion due to the works where the machines transport big amounts of land. The exploitation of carbon and schist in open spaces is the cause of the main sedimentological and hydrological problems. The exploitation in open spaces removes the cover soil, the rocks, and other layers covering the deposits of the ore. The big mining exploitations cut the natural drainage net and modify the basins erosions and run-off (Gac, 1980).

d. The urbanization: The urban zones generally have a specific erosion that exceeds that of the rural regions. The biggest amounts of sediments are produced during the construction phases, mainly when the vegetation and the cover soil are temporarily removed. The construction works may increase the erodibility and decrease the stability of the slope radically. The drainage net may get full of sediment, and its flow capacity decreases.

e. The deforestation

It causes a rapid degradation of the chemical and physical properties of the superficial horizons. It is the outcome of the climate hostility, the soil fragility, and the rapid mineralization of the organic substance, accelerating the damages of the erosion.

f. The fires: because the fires damage the vegetation, they imply a high risk of erosion. In fact, the zones without vegetation are subject to the risk of strong erosion.

4. Forms of the hydric erosion

The raindrops on a bare soil detach the particles that are jot in all the directions. This is known since a long time (De Ploey et al., 1991). The land resistance to the erosion mainly depends on the soil texture (cohesion, strength, grains size,…) and the vegetation. The relation between the erosive forces and the resistant forces is influenced by the agriculture practices (chemical weeding, grassing, labor, scratching,…) and the soil occupation.

4.1 The sheet erosion

It is the initial stage of the soil degradation by the erosion. The sheet erosion causes the soil degradation on its surface and is a common form of erosion. Thus, it is less visible from one year to another (figure 11).

4.2 The rill erosion

This happens when the run-off water concentrates and forms nets or rills (figure 11). These well-defined depressions resulting from the soil removal by the water force do not harm the work of the machinery. In many cases, these rills are compiled each year due to the soil work.

4.3 The gullying

It is an advanced state of the sheet erosion. The soil is deeply notched that the depressions that result harm the normal operations of the soil work. The superficial flow that leads to the formation or the widening of the gullies is generally the result of a misconception of the outlets of the surface and underground drainage nets (figure 11).

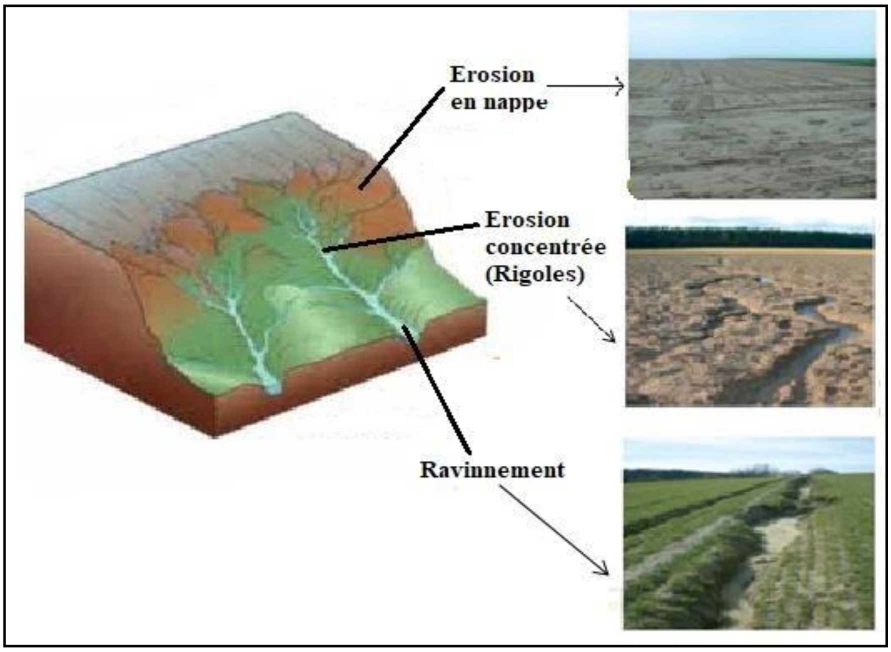


Figure 11. The different forms of the hydric erosion

5. The types of the damages

There are two types of damages:

The damages in the eroded zones and the damages in the deposit zones.

5.1 The damage in the eroded zones

a. The degradation of the water balance

It is the most important effect. Rain-fed crops are subject to erosion faces the risks of the decrease of the efficient rain. In fact, an important fraction of the rain runs off and is no more suitable for the plant. Besides, we notice a decrease of the good soil volume:

$$RU = q\ n\ Z.$$

The soil departure deprives, in this case, the crop from an indispensable water reserve. For example, if RU: 60 mm on a normal soil

® Due to 4mm/ day ® 15 days of drought are supportable for the crop. If the same soil is half denuded: RU: 30 mm.

® Due to 4mm/ day ® only 7/8 days of drought are supportable for the crop.

b. The soil impoverishment

The soil's content of humus and nutritional elements, the water retention capacity, and the structural stability decrease. This impoverishment is due to the double effect of the superior horizons stripping, which are the most fertile.

c. Other consequences

Other consequences include receding, carried plants, crop coverage, an increasing heterogeneity in the parcels, and a decrease in the deep drainage, leading to less supply of the groundwater.

Table 01: The order of the soil losses

Sheet erosion	1 t/acres/year
Rill erosion	10 t/acres/year
Gully erosion	100 t/acres/year

We must point that a simple rill that is formed during a storm of 2 cm in depth and 5 cm in width causes a land loss of 120 g/100 m of rill.

5.2 The losses in the deposit zones

The sedimentation and the solid transportation disturb the majority of the development. They manifest in:

- Accelerated siltation of the drainage ditch, the irrigation canals, and the reservoirs (the basins).
- A decrease in the capacity of the riverbeds and a risk of flood in the neighboring lands.
- An increase in the costs of consumption water treatment.

5.3 The effect on the agricultural production

Through this stripping, two consequences on the decrease of the vegetal production manifest:

- The decrease of the hydric balance.

Due to the provoked crusting, the rain becomes less profitable for the plants. In fact, an important break-in of the rain run-offs. The decrease of the volume of the exploitable soil by the roots increases the sensitivity of the crop to the dry periods.

- A soil poor in the fertilizing element:

The soil fraction caused by the erosion is often richer than the soil as a whole. The soil left in its place disintegrates and becomes hostile (no biological life, high heterogeneity, and low production).

- Inaccessible land (bad lands)

The formation of the gullies makes the land bad and hinders access to it. To avoid this, we need the coherent fight methods. The role of the vegetation comes on the top. The erosion must be stopped since its reversible form, i.e., before the start of the gullies.

6. The estimation of the hydric erosion and the prevention method

6.1. Estimation of the land damages

The methods used in the evaluation and cartography of the erosion differ according to the objectives, the tools, and the work scales. The quantification may be made through the direct measures and the indirect evaluations.

6.1.1 The direct measures

6.1.1.1 The measure through roughness tester: we estimate the variation in the soil height based on a reference plan. This is an example of the tool used to test the roughness (picture 6):

Picture 06: Roughness tester (according to Nord, 2006)

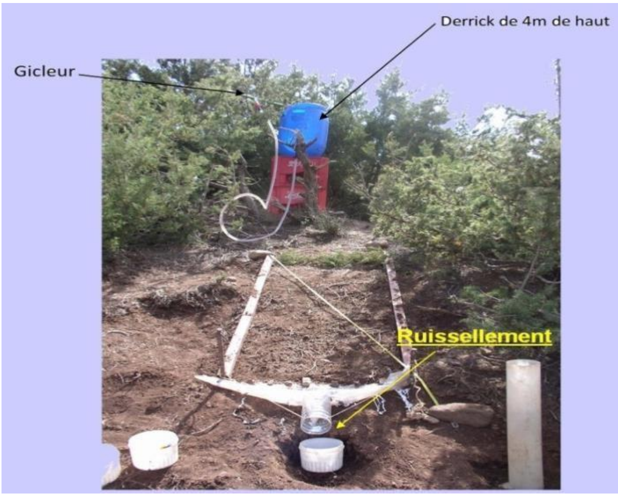
The main measure is following the evolution of the gullies: we measure the variation of the dimensions of some sections of the gully after each rainy event.

6.1.1.2 The rain simulation

The aim is to determine certain hydrodynamic characteristics of the soil under diverse conditions of the soil and the rain. The use of the rain stimulators has many advantages because (Zaher, 2010):

- It is mobile.
- It can produce intensive rain with height and energy similar to the natural.
- It allows simulating rainfall with rare frequencies that cause big losses.
- It saves the field observation time.

The tester has many types, from simple to complicated. The simplest is the minisimulator. It can even be confectioned by the user. Picture 07 shows ORSTOM minisimulator:



Picture 07: Rain simulator (According to Zaher, 2010**).**

6.1.1.3 Measure through the study of the sedimentation in the reservoirs

The estimation of the amount of the sediments in a reservoir depends on the density and the volume of the sediments (Flageollet, 1989). The sediments density changes according to time and position in the reservoir. It varies according to the granulometry, the mineralogical composition, the deposit thickness, the level of the water in the reservoir, and the age of the depot. Regarding the sediments volume, it is determined based on the comparison of the topography of the basin before and after the flow of the water into the dam (Fonier, 1960

6.1.2 The indirect measures

6.1.2.1 The universal equation (Wischmeier model)

The universal equation of the land losses is an empirical model based on the statistical analysis of 100 experimental parcels. It allows predetermining the average annual losses in a given land under specific conditions. The equation takes the form of a 06 independent factors product; each represents a parametric equation with many variables.

The model is written in its simplest form as follows:

A = 2,24 R. K. L.S. C. P.

A= the loss of the lands (ton per acre).

R= the factor of the climatic hostility.

K= the soil factor.

L: the factor of the slope length.

S: the slope factor.

C: the agronomic factor.

P: the anti-erosive developments factor

The model has some weaknesses, mainly:

It cannot estimate the losses of the land in a short period (isolated rainy season). Besides, it considers the erosion factors as independent while there are many interactions among them.

6.1.2.1 The description of the different terms of Wischmeier equation

a. The climatic hostility factor:

It is defined as the product of the kinetic energy (E c) and the maximum intensity in 3 minutes (I 30).

R= E c x I 30with E c= 11.9 + 8.73 log (I)

E c in D/m^2/mm of the rain

I: the average intensity of the rain (mm/h).

R: may be determined for the variable periods (1 averse in 1 year).

When it is used as a parameter of Wischmeier model, the index R is generally calculated as the average of many years.

b. The soil factor K:

It is characterized with the soil erodibility; i.e. its sensitivity to the erosion. It measures the big relative resistance of the soil to the erosion.

Wischmeier suggests a model to calculate K based on the following parameters:

For a first approximation:

The sum of the thin loam and sand percentages.

The percentage of the sand

The level of the organic substance

And for a more exact approach:

The structure

The permeability

We can also determine K using the following formula:

100 . K = 2,1 . 10 -5 . (12 – O.S) M 1,4 + 3,25 . (S - 2) + 2,5 (P - 3)

K: the erodibility factor

O.S: the percentage of the organic substance

S: a structure code

P: class of the permeability

M: the product (% thin sand + % loam) . (100 - % A)

c. The topographic factors LS

The factors L and S respectively characterize the effect of the slope and of its length.

The relations established by Wischmeier allow determining L and S:

L= (1/22.15) et S =(0.43 - 0.30 s+ 0.043 s)/6.613

L : the length of the slope factor

l : the length of the slope (m)

22,13 : the length of the standard parcel (m)

m : exponent depending on many parameters of the slope.

m = 0,5 when the slope is < 10 %

m = 0,6 when the slope is > 10 %

S : the slope factor

s : the slope (%)

d. The crop index: C factor

The factor C allows considering that the rain acts more on the bare soil than on the covered.

It characterizes the crop and the soil fertilization level.

It represents the balance of the soil losses of the cultivated lands in well-defined conditions.

Roose calculated the values of C for many plants in West Africa (See table 01).

e. The anti-erosive developments

The P factor is defined as the relation between these land losses of a field where we apply the conservation practices, and of a slope-cultivated field.

The observed P values for different development types are on the table:

Table 02: The influence of the vegetation on the erosion in West Africa (Roose, 1996)

Cultural techniques and plants	C annual average
Bare soil	1
Dense forest or abundantly mulched crop	0,001
Savana and prairies in good state	0,01
Burned and/or overgrazed savanna and prairies	0,1
Cover plants with a slow development or late plantation - 1st year 2nd year	 0,3 to 0,8 0,1
Cover plants with a rapid development and early plantation since the 1st year	0,01 to 0,1
Maize, sorghum, mil (according to the yield)	0,4 to 0,9
Rice in intensive crop	0,1 to 0,2
Cotton/ tobacco (in 2nd cycle)	0,5
Peanut (according to the plantation date)	0,4 to 0,8
Manioc (1st year), yam (according to the date of plantation)	0,2 to 0,8
Dates, hevea, coffee, cacao with cover plants	0,1 to 0,3
Pineapple in flat (according to the slope), slope 4 to 20% Burned residuals Landfilled residuals Surface residuals	 0,1 to 0,5 0,1 to 0,3 0,01
Pineapple on tied ridges (slope 7%)	0,1

Table 03: The “anti-erosive practices” factor in West Africa (Roose, 1996)

	P
U.S.A	
Isohypse labor	0,75
Isohypse ridging and labor	0,50
Isohypse grassed bands and labor	0,25
West Africa	
Tied isohypse ridges	0,20 to 0,10
Anti-erosive bands of 2 to 4 m of width	0,30 to 0,10
Straw mulch	0,01
Curasol mulch (60 gr/l/m2)	0,50 to 0,20
Temporary prairies or cover plants	0,50 to 0,10
Armed buldge or dry stone little walls (climb: 80 cm). - Isohypse hoeing and labor, and balanced fertilization	0,10

6.1.2.2 The use of Wischmeier equation

Once these parameters are well-known in a given region:

We estimate the land losses and determine the anti-erosive measures to be applied. The maximum values are set according to the type of the soil and the target production.

Very often:

K and S are imposed by the field and R by the geographic position.

Thus, the human intervention is limited to the factors L, C, and P--> and allows defining the anti-erosive methods.

6.1.2.2 The limits and advantages of the universal equation of the land losses

a. The limits

This empirical equation requires exploiting many results. Thus, it is necessary to have a big number of experimental results to fix the values of different factors. The obtained results on the parcel cannot be transposed on various surfaces in the light of general programs of combatting the erosion.

b. The advantages

The equation of Wischmeier allows evaluating the advantages of the actions in CES. To decrease the erosion A, an action may be made to reduce the erosivity index K through improving the structure and permeability. We can act on the factor C through covering the soil during the critical periods (strong rains). Besides, we can act on the factor P by preconizing the crops in isohypse, or in alternated bans. After making these three possibilities of the combatting the erosion, we can move to the slope factors through appropriate anti-erosive factors.

6.1.2.3 The use of the satellite images

The increasing advantages of the pluri-kilometric studies and the related environmental problematic stimulate the use of the teledetection in the studies of the natural resources and the environment. Based on knowing the states of the surface and their behavior regarding the run-off and the erosion, the cartography of the erosive risks is possible, even in surfaces that reach thousands of Km^2 thanks to the spatial model (Touazi, 2001).

The acquisition of the satellite images (Landsta TM or SPOT), a technique and tool that is highly used today, allows making the cartography of the erosive risks. The method cannot replace the field studies in understanding the phenomenon. However, it remains the most rapid and less costly regionalization and updating method. Currently, we can reach a cartographic precision that suits the scales of 1/25000 and 1/50000.

In fact, the direct cartography of the erosion marks is not possible currently. Nevertheless, we can study the indirect criteria that reveal the presence of erosive phenomena. The choice of the structural degradation of the soil surface, that provokes the run-off and the erosion, may be beneficial for estimating the gravity of the erosion on a big surface (Okoth, 2003).

6.1.2.3 The use of the radioisotope: the cesium- 137

^{137} CS is a radioelement brought to the terrestrial surface through the atmospheric deposition. Once incorporated in the soil, it is fixed in the particles and allows following their future. Making an inventory in the profiles of a non-disturbed soil allows evaluating the erosion rate on a given site. Then, with the help of different methods, the loss in the land may be estimated based on the losses in the radioelement. The major advantage of this technique compared to the field observations or experiments is that the erosion is estimated in a given moment and during a period of time that may reach the last 40 years in the case of 137 Cs. Thanks to its advantages and precision, the method is increasingly being used. In addition, we must point that the method is very costly.

7. The prevention methods

7.1 The physical methods

7.1.1 The stone line

They are mechanical barriers that stop the run-off water on the isohypse to reduce the erosion and increase the soil humidity (See picture 09 and figure 12).

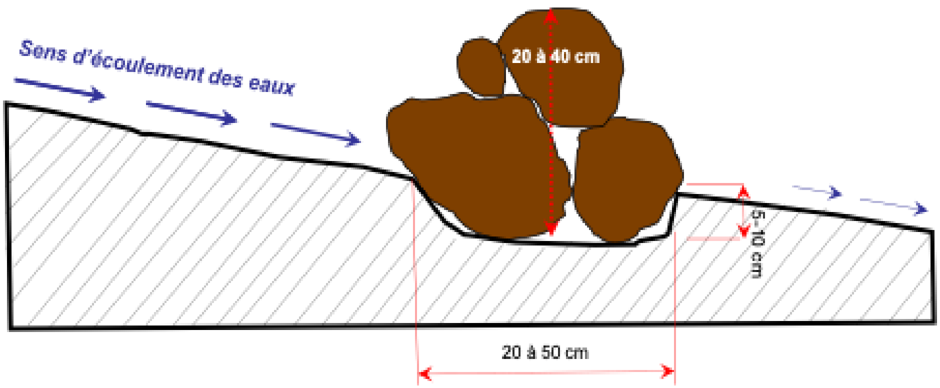
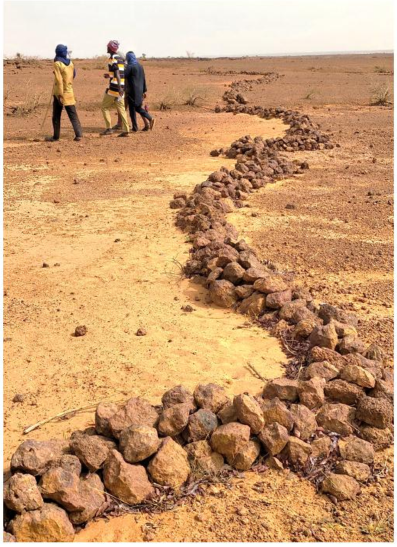


Figure 12. Longitudinal view of putting a stone line (According to SPONG, 2012)

The objectives of the stone line according to Spong (2012) are:

- Reducing the run-off speed through the spread of the groundwater on all the surface of the parcel.
- Improving the water infiltration on the entire parcel surface (mainly in the line upstream).
- Decreasing the slope and provoking the progressive formation of the micro-terraces.
- Provoking the sedimentation of the particles and the debris of the upstream line.
- Improving the soil fertility.
- Restoring the bare soils.




Picture 09: A close view on a low wall (According to SPONG, 2012)

7.1.2 The low walls

The construction of low walls in stone following the isohypse is an obstacle that decreases the speed of the water flow on the slope, and is a filter that retains the materials dragged to the zone between two constructions; it gets clogged slowly upstream. The low walls exceed 50 cm upstream of the soil level. The stones must be carefully piled. The choice of the stones is extremely important; they can be flat, angular, and big (20-25 cm maximum). The space between the stones must be filled up with the small stones (Ruelle et al., 1990).

Picture 10: a close vision on a low wall (according to HCEFLD, 2014)

7.1.3 The terraces

The aim of the terraces is decreasing the length of the flow slope through building an intercepting ditch that safely leads the water outside the parcel

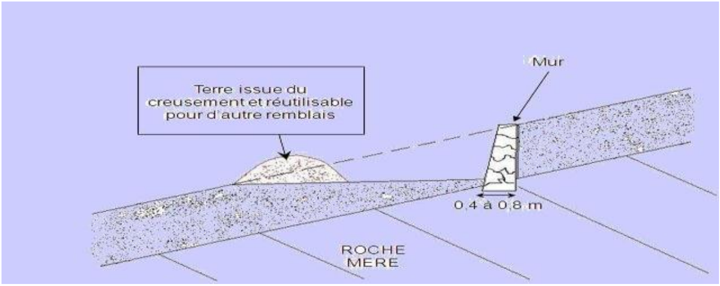
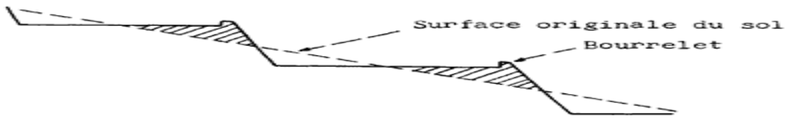
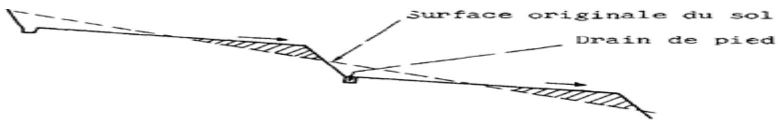


Figure 13. Cross-section of a terrace in construction (According to FAO, 1977).

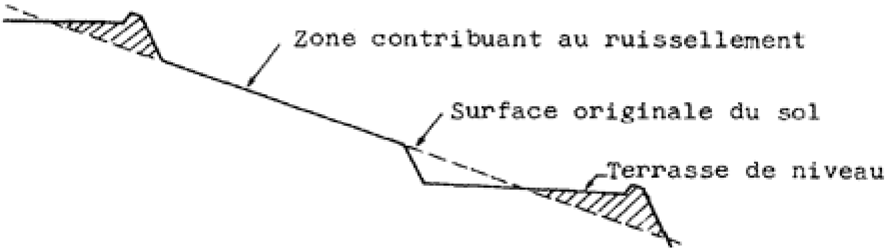
There are various types of terraces: the stairs terraces, terraces with an interception ditch, and the conservation terraces. They reduce the erosion to 89-90% in a parcel (fig. 14)



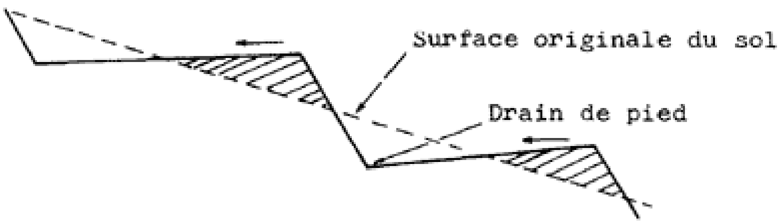
1. Horizontal stairs terraces



2. Terraces with a profile directed forward



3. Horizontal terraces in a discontinuous net



1. Terraces with a profile directed toward the downstream

Figure 14. Types of the terrace (according to FAO, 1977).

7.1.4 The gabions

They are stones put on each other. Their dimensions are sufficient not to fall between the meshes, and are well distributed. We must not put the small stones in the middle and the big in the outside (picture 11). Thus, it is better to fill the gabions by hand to reduce the risk of an important deformation in the structure in the average-term. In this regard, the meshes may be hurt by the tree trunks and other materials that may be brought by the stream. The gabions are meant to stop the speed of the water flow, allow filling the water ground, irrigate the surrounding terraces with part of the runoff, and reduce the erosion and flood risks in the downstream zones (Melalih, 2012).

Picture 11: The limits of gabion use in the fixation of the gully

7.1.5 The benches

They are constructions with a rectangular form in stone, compacted land, or both (figure 15). They may be permeable or waterproof. The main dike of the construction may be 80m long. The “arms” of both sides have a width of 15 m. The benches are made according to the isohypse and are opened to the upstream. The distance between the benches is about 6 m in the same line and, according to the slope, of about 25 m between the lines (Biji, 2012). As for the downstream of the construction, we dig a ditch to receive water. The ditch is about 0.50 m long and 0.30 m deep. The excavated and rammed soil can be used for the construction of the main dike (Bielders, 2004).

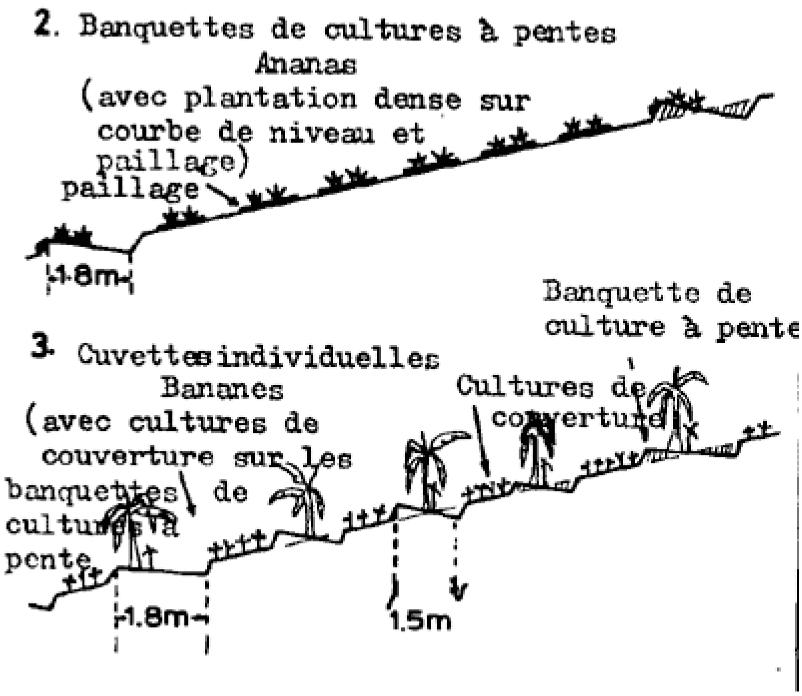


Figure 15: The benches of the slope crop (according to Biji, 2012).

Picture 12: Benches on sharp slope that is not repaired and gullied. (According to Bielders, 2004)

7.2 The biological methods and the cultural practices

7.2.1 The forestation

Setting fast growing plants such as *Eucalyptus*, *Acacia*, *Pins*, *Atriplex*, *laurier rose*, cactus, etc allows the improvement of the soil cover and gaining the organic substance (Catinot, 1994).

7.2.2 The mulching

It is about spreading the harvest residuals in the parcels that are sensitive to the erosion.

The mulch absorbs the kinetic energy of the raindrops and contributes to the protection of the recovered surface against the precipitations hostility through limiting the effects of the splash erosion (FAO, 2010). The mulching acts in different ways through the organic substance it brings; it enriches the soil, improves the physical quality, and increases the permeability (Ganaba, 2008).

Picture 13: The mulching; a: mulched manioc plantation, b: maize plantation on the crop residuals, c: the soya plantation (According to Roose, 2010).

7.2.3 The ridge tillage

The work followed by a ridge tilling may store an important quantity of water, sandy materials, or loam materials. The ridge tillage in isohypse is twice better than the simple construction in isohypse (picture 14).

Picture 14: The ridge tillage (according to FAO ,2010)

7.2.4 The agricultural rotation

It is an agronomic practice that alternates the different crops (cereals, vegetables, etc) on the same parcel. This plan may take place in one year, or in many years (FAO, 1976). The pluri-annual rotation of the crops is part of the European biological agriculture regulation and the main element of the system of the biological vegetal production management to preserve and increase the biological fertility and activity of the soil, and to prevent the losses caused by the pests, the diseases, and the bad herbs (Darboux, 2009).

The diversity of the crops in one parcel ensures the coherent use of the soil nutritional resources because the plans need different nutrients. Thus, a prairie allows enriching the soil with the organic substance, stimulating the biological activity, and improving the soil structure. The vegetables agriculture enriches the soil with azote. On the other hand, some crops require the nutritional elements. The crop rotation in the same parcel reduces the erosion and strengthens the soil resistance through the humiferous intakes, the action of different root systems on the soil structure, and the soil work.

7.2.5 The crop rotation

It is a localization and distribution of the crops on the parcels in a given year with a rotation of the crops year after year (Ganaba, 2008). The size and distribution of the parcels reduce the erosion. In fact, a divided parcel allows diversifying the crops all along the same slope and the change between the parcels where the water shall be infiltrated and dispersed, and the parcels where the situation is critical. A good management of the parcel avoids the degradation of the surfaces and generates runoffs during the preparation of the seeds in the parcels downstream. A divided parcel allows choosing the crop rotation according to its characteristics (sensitivity to the erosion, position on the slope,…) (FAO, 1983).

CHAPTER 03

RUNOFF CONCENTRATION TECHNIQUES AND RUNOFF RATES

1 Introduction

Modeling terrain and using biological techniques do not solve all water and soil conservation problems. As soon as precipitation becomes insufficient to support vegetation growth, and when the slope becomes significant, it is essential to consider new techniques requiring earthworks. These techniques help control runoff.

There are three categories for runoff control:

- Runoff concentration systems.

These are used when rainfall is moderate, typically between 400 to 500 mm. In such climates, rain-fed crops cannot be guaranteed every year. Horizontal structures are built along contour lines to collect runoff from an upper slope. Only the portion of the surface collecting runoff is cultivated. The water balance of the cultivated area is improved by the infiltration of runoff from the upstream slope.

- Absorption or infiltration systems

These are used when rainfall allows for dry farming with sufficient yields (rainfall less than 750 or 800 mm). They consist of horizontal structures (built along contour lines) designed to promote the complete infiltration of precipitation received by the portion of a slope between two contour lines. They are only suitable for permeable soils with gentle slopes.

- Diversion systems

These are suitable when rainfall is abundant. They consist of sets of structures with very low longitudinal slopes (less than 0.3%). Each structure is designed to break the momentum of the runoff, infiltrate some of the temporarily retained water, and channel the rest towards a properly designed outlet. Evacuating excess water during the rainy season helps prevent excessive soil leaching problems.

2. Common structures

2.2.1. Terraces (bench terraces)

These are platforms of earth arranged like stair steps. The fill soils are supported downstream, either by a wall or by a grassy slope. They allow cultivation on steep slopes but require significant, non-mechanizable work. Their use is becoming less frequent. They are now being replaced by the technique of progressive terraces or curtains (I explained this in detail in previous courses).

2.2. Curtains or progressive terraces

Curtains result from field shaping, achieved less by earthworks than by a progressive evolution due to plowing or natural downslope movement of soil. They form whenever two fields, one upstream and one downstream, are separated by a boundary perpendicular to the slope (plow line, grassed stop strip, low wall, etc.). Through continuous plowing downhill or due to soil slippage, the upstream edge of this boundary rises while the downstream edge deepens. The overall terrain profile then offers a succession of less steep fields, separated by a series of setbacks or curtains.

2.3. Benches

These are structures used to divide plots according to contour lines with horizontal obstacles (ditches, embankments). They break the energy of runoff, increase infiltration, and channel water towards outlets (I explained this in detail in previous classes).

2.4. Dikes

This is a technique developed in areas with low slopes (a few percent). Subject to sheet erosion.

They consist, depending on the projects:

- Of compacted earth ridges 40 - 50 cm high, impermeable.

This method presents technical risks (dike settling, leading to preferential erosions) and cultural risks (suffocation of crops upstream of the dike). They are difficult to maintain and require significant resources, either in equipment or labor (compaction).

- Alignment of permeable rubble stones 2 to 30 cm in size.

In areas where stones are abundant, this technique can be developed by farmers without external intervention. Otherwise, it is necessary to provide farmers with trucks for stone transportation. It is essential to adopt inexpensive and reproducible techniques for farmers: notably, the possibility of advantageously replacing topographic site surveys with the water level technique should be noted.

2.5. Runoff concentration techniques

These processes utilize the following principles:

* A portion of the plot is left uncultivated. It forms a small watershed allowing runoff development.

* The remainder of the plot is dedicated to crops. Runoff is concentrated and infiltrates there.

These techniques are particularly suited to silty soils, with poor structural stability and high water retention capacity.

3. Sizing of runoff control devices

To size runoff control devices, several approaches are used:

3.1 . Empirical approach: This method relies on historical data and past experiences to estimate the dimensions of the devices.

3.2 . Calculation of spacing between structures in a CES (Erosion and Sedimentation Control) network: This step involves determining the optimal distance between different control devices to ensure maximum effectiveness.

3.3 . Sizing of structures based on the water balance: This approach takes into account local hydrological conditions, such as precipitation and runoff rates, to calculate the dimensions of devices necessary for the proper management of surface water.

4. Fighting erosion in Ravines

The use of different types of waterways or drainage systems. Runoff rates can be controlled through techniques such as building retention basins or installing energy dissipation structures. As for the types of waterways or drainage systems, they may include rock-lined channels, gabions, reinforced concrete linings, or stormwater drainage systems."

4.1 Runoff Rates

In the absence of precise hydrological data, sizing runoff rates must be approximated using empirical formulas. This is the most common case, as the watersheds considered are often very small.

The formulas mainly used in French-speaking Africa are:

- The Rodier-Auvray method, for estimating decennial flood rates for watersheds with an area of less than 200 km² (Rodier and Auvray, 1965)
- The rational formula:

$$Q = a.\ i.\ A$$

where:

- Q is the peak flow rate
- a is a reduction coefficient
- i is the rainfall intensity for a chosen recurrence interval and for a duration equal to the basin's concentration time
- A is the area of the basin (basin smaller than 1300 ha)."

4.2 Types of Waterways or Drainage Systems

a) Diversion or Protection Ditches or Guards

Diversion ditches are dug across the slope to protect downstream cultivated lands subject to CES development and divert water from the upstream to a chosen outlet.

b) Talwegs or Waterways and Falls

In principle, these are natural pathways that are adapted and developed (see figure 12). They allow for the removal of excess water from diversion ditches of anti-erosion structures (benches, low walls, etc.). Located in cultivated areas with low slopes:

- with very low transverse slopes (4/1 to 6/1) to reduce the thickness and flow velocity to levels compatible with grass protection.

- while retaining or creating a lawn. When the pathways become significant, natural shrubby vegetation can be left, but cultivation tools should not be used on them.

The construction and consolidation of the channel must, except in exceptional cases with very resistant soils, occur before the opening of the structures in the tributary network and upstream guard ditches.

Temporary consolidation structures used to restore already ravined waterways, such as fascines, logs, gabions, and dry stone walls, must be replaced over time by permanent stabilizing vegetation, with or without permanent structures.

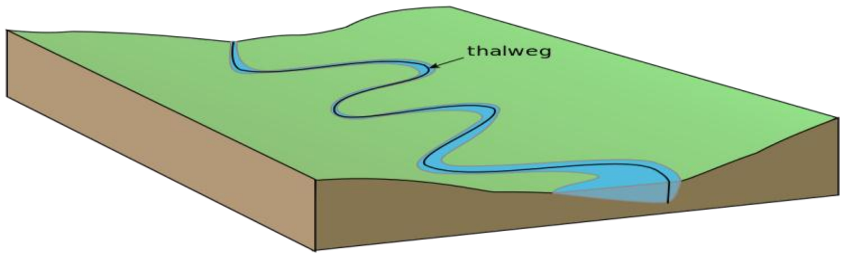


Figure 16: Correction of the cross-sectional profile of a ravine (adapted from Chevallier et al., 1985).

c) Correction of gullies (ravines, koris, ...).

The main objectives of gully treatment are as follows:

- slowing down the water flow to stop regressive erosion, which is the cause of gully formation and its evolution.
- inducing sedimentation upstream of the structure to reduce the slope of the gully.

when possible, allowing water spreading to promote the establishment of efficient agriculture. Although diverse, gully treatments employ similar principles. It is always desirable to adhere to these principles as closely as possible while adapting to the terrain configurations.

4. 3. Treat the gully from downstream to upstream.

Erosion by runoff is regressive. Gully management should begin from a stabilized area (absence of erosion due to a decrease in slope or the presence of a rocky threshold: for example, a weathered rock outcrop). The structures are then built moving upstream. Failure to adhere to this principle can result in undermining of the downstream structure, followed gradually by all structures.

The stability of the structures is increased by implementing step-like adjustments: the foundation of a structure is at a lower elevation than the spill elevation of the structure immediately downstream.

4.4. Treat the upstream watershed.

In order to reduce runoff in the valley bottom or gully, it is necessary to treat the slopes using the usual CES techniques (check dams, grass strips,).

The effect on high-frequency floods will be significant and will greatly reduce the ongoing maintenance of the structures.

The effect on low-frequency floods (decadal, centennial) will be limited and may not prevent the eventual destruction of the structure.

4.5. Treating small watersheds.

In the development of a large watershed, the devices must be implemented through successive sub-watersheds, increasing in size.

Spreading water over large surfaces

Whenever possible, correction structures should spread water over large surfaces. The benefits are threefold:

- reducing the flow of runoff water and thus flow velocities,
- reducing the flow of water pouring onto the structure and thus the risk of erosion at the base of the structure,
- facilitating infiltration upstream of the structure. Coupled with significant sedimentation, this spreading of the flood promotes the development of efficient agriculture where crop water supply and soil fertility are improved. The possibility of agricultural production motivates local farmers to maintain the structures.

CHAPTER 04

THE EOLIAN EROSION

1. Definition

The eolian erosion manifests in the arid climates where the rain is less than 600 mm in bare soils with the presence of the winds of a speed that exceeds 20 km/h, or 06 m/s in dry soils. It may, also, occur in the humid climates where some months are dry and the soil is prepared by the cultural techniques that pulverize the soil surface (Mainguet, 1983).

Picture 15: The eolian erosion (according to Mainguet, 1983).

2. The eolian erosion factors

The strong winds are the cause of this erosion. The pullout, the transportation, and the deposit of the soil particles depend on the wind speed, the size and density of the particles, and the humidity of the soil and the vegetation (Bagnold, 1954).

a. The erosive intensity of the wind power

It affects the soil surface. The speed and duration of the wind affect the size of the soil erosion. The particles pullout is determined by the wind forces on the soil surface. The speed of the wind that passes on the soil surface is important.

b. The soil nature (texture, structure, and organic substance level)

They are risk factors. The sandy soils are fragile and sensitive to the eolian erosion. However, some particles with small diameters may resist the erosive action of the wind thanks to their cohesion. The soil structure is the arrangement of the individual particles in aggregates, which are heavier than the individual particles and cannot be easily moved by the wind. The aggregation process tightly depends on the climatic conditions and the mechanical phenomena that intervene on the surface. The structure constantly changes. The decrease of the substances that improves the structure (organic substance, metal, lime, and free alumina) makes the soil fragile.

c. The topography

It is dependent on the increase of the roughness of the field in the presence of ridges, where there is an intervention to reduce the eolian erosion effect. Besides, the stoniness on the soil surface, through making a "pavement", reduces the eolian erosion risks, such as the case in the regs.

d. The vegetation

Most of the soils need a vegetation of at least 30% to prevent the destructive effects of the eolian erosion. Besides, we must point that the culms and the residuals of the crop on the soil make an alternative that reduces the wind speed.

e. The soil humidity

It increases the cohesion of the soil particles and makes them temporarily unavailable for the pullout.

3. The mechanisms of the eolian erosion

3.1 The mechanisms of the eolian movement of the particles

There are three different modes of particles addition; the saltation, the distribution on the surface, and the suspension (FAO, 1988) (figures 16, 17, and 18).

a. The saltation

The initial movement of the soil particles is a series of jumps. The diameter of the particles under saltation is between 0.5 and 1.1 mm. After jumping, the particles fall due to the gravity. The descending part of the trajectory is very inclined towards the soil and, practically, rectilinear. Some particles reach an altitude of more than 1 m, and about 90% of them make jumps of less than 30 cm. the horizontal amplitude of a jump is generally between 0.5 and 1m. The phenomenon of saltation is necessary for absorbing the eolian erosion. It is the cause of the two other modes of the soil elements transportation by the wind (the surface crawling and the suspension in the air).

b. The surface crawling

The particles with big dimensions roll or slip on the soil surface because they cannot be taken and their movement is caused by the impact of the particles in saltation, not by the wind. The diameters of the particles that move are between 0.5 to 2 m, according to their density and the wind speed.

c. The suspension

In general, the thin dust cannot be taken unless by the impact of the thicker grains. Once they reach the turbulent layer, they may be taken to high heights by the ascending air and, then, form dust clouds that often reach altitudes of 3 to 4 m. Even if their aspect may be impressive, the main mechanism of the eolian erosion remains the saltation because without it, such clouds cannot emerge.

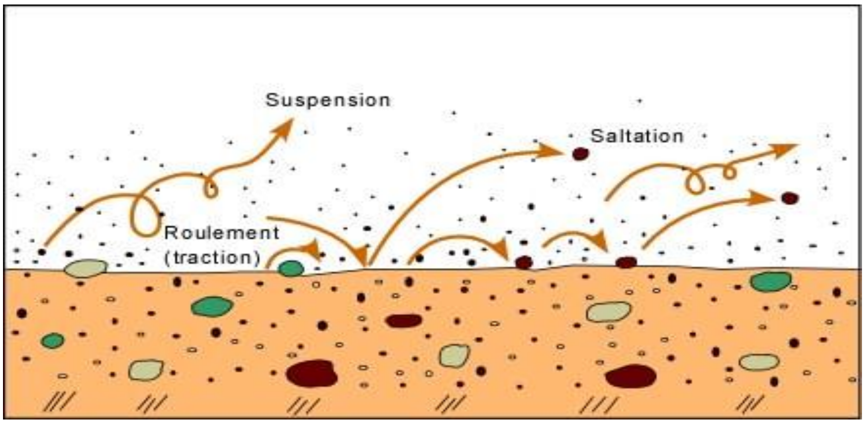


Figure 17. The transportation of the particles (according to Pierre, 2010).

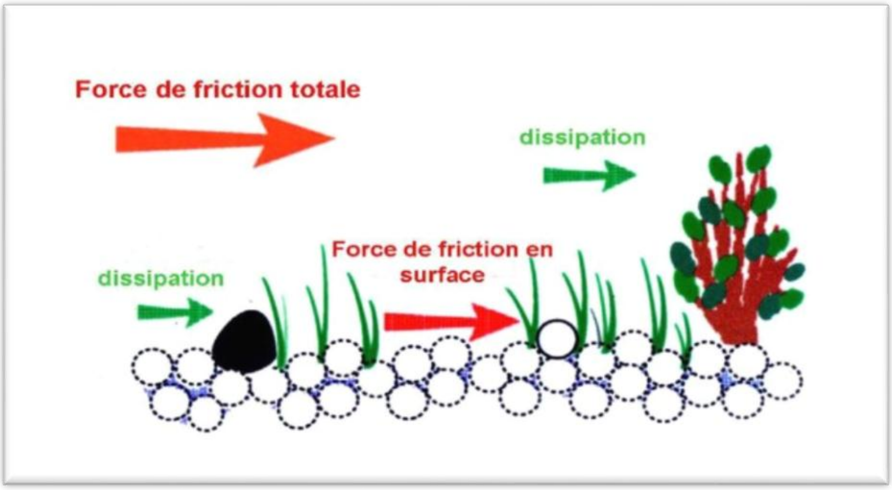


Figure 18: The distribution of the energy coming from the wind action, between the smooth surface and the roughness elements (According to Marticorena, comm. pers)

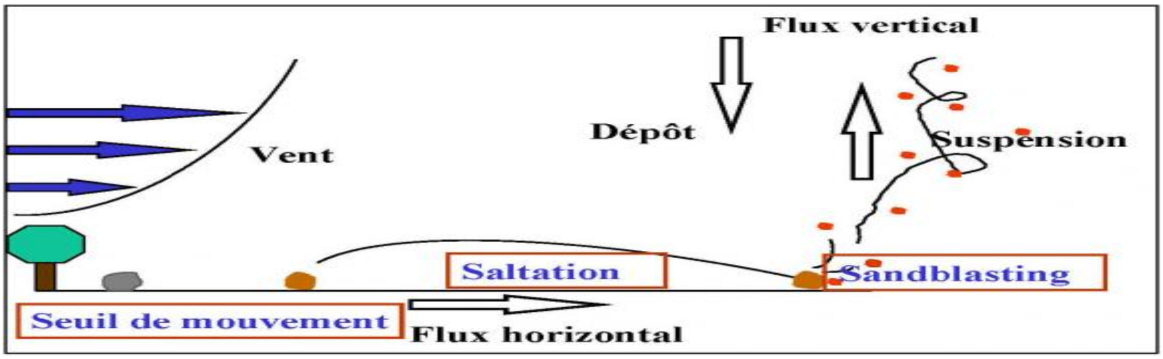


Figure 19. The main modes of particles transportation by the wind and the flows associated when the wind speed exceeds the limit of the particles mobilization (according to Pierre, 2010).

3.2 The mechanisms on the global movements scale

The moving particles are the interaction field, from which we mention (FAO, 1988):

3.2.1 The avalanche effect

This phenomenon is the outcome of saltation. The particles that jumped provoke the departure of an important quantity of the particles. Besides, when the wind increases on a bare soil, its particles load increases unceasingly until reaching a maximum. The wind maximal load of particles is the same for all the soil types and equals that one found on the sand dunes. The necessary distance for reaching this saturation depends on the sensitivity of the soil to the erosion. In addition, on a very fragile soil, it may be produced in 50 meters and require more than 1000 m on a soil with a good cohesion.

3.2.2 The arrangement

The wind moves the very thin and light particles more rapidly than the big ones. The thin particles are moved in long distances and heights. The wind separates the different elements of the soil into categories according to their dimensions, non-erodible clump, gravel, sand, clay, and loess. Besides, it takes the thin elements and leaves only the big ones. Another consequence of this arrangement is the progressive sterilization of the soil because the organic substance itself is made up of thin and a bit dense elements and is to be taken.

3.2.3 The corrosion

It is the mechanical attack on the surface where a wind loaded with particles blows. It is a cause of the soil erosion in the arid region. In a coherent and homogenous material, the corrosion manifests in parallel streaks or a remarkable polish. The polishing affects the outcropping like the regs stones that are more or less dimpled or shaped in facets. The sand winds associated with the effects of the thermal amplitude give the shape of mushroom to the residual mounds cut in the sandstone covers. In the loose rock, mainly in the agricultural lands (clay and loam), the wind digs parallel furrows, which make the roots of the young plants bare. When this phenomenon is pushed away, the corrosion delimits the elongated mound to longitudinal and aerodynamic profiles, which are sometimes many meters high and called “yardangs” (figure 19).

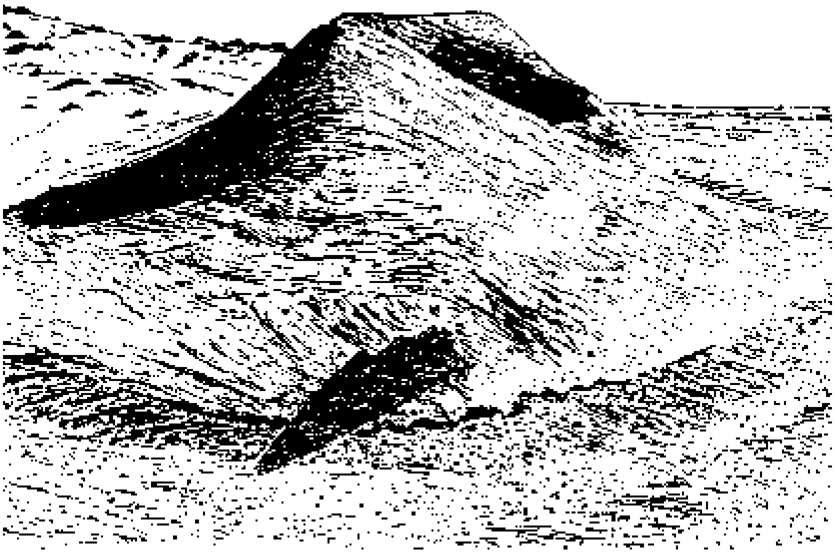


Figure 20. Yardang

4. The effects of the eolian erosion

The first effect is the winnowing of the light particles. The eolian erosion is very selective. It exports the thinnest particles to long distances, mainly the organic substance, the clay, and the loam. The accumulation of the pulled out loam by the wind in the periglacial steps gives birth to the loess, which are fertile lands that cover large spaces in Europe and North America, where a very performing agriculture emerges. The most spectacular forms are the dunes and the accumulation of the more or less sterile sand that migrates by the wind to the oases and the ancient cities. The sand groundwater that circulates in a low altitude (30 to 50m) may degrade the vegetables (mainly the young millet seeds or cotton in the semi-arid regions). Finally, the eolian erosion effects cause a drought in the milieu due to the loss of the capacity of storing the nutrients and the land water.

5. The estimation of the eolian erosion and the prevention method:

5.1. The direct measures

- It may be directly made by the qualitative measure of the effects on the decrease of the soil productivity.
- It may be estimated by the quantification of the infrastructure sanding.
- It may be made by the collection of the particles using mobile sensors put in different levels above the soil.

5.1.1 The stake method

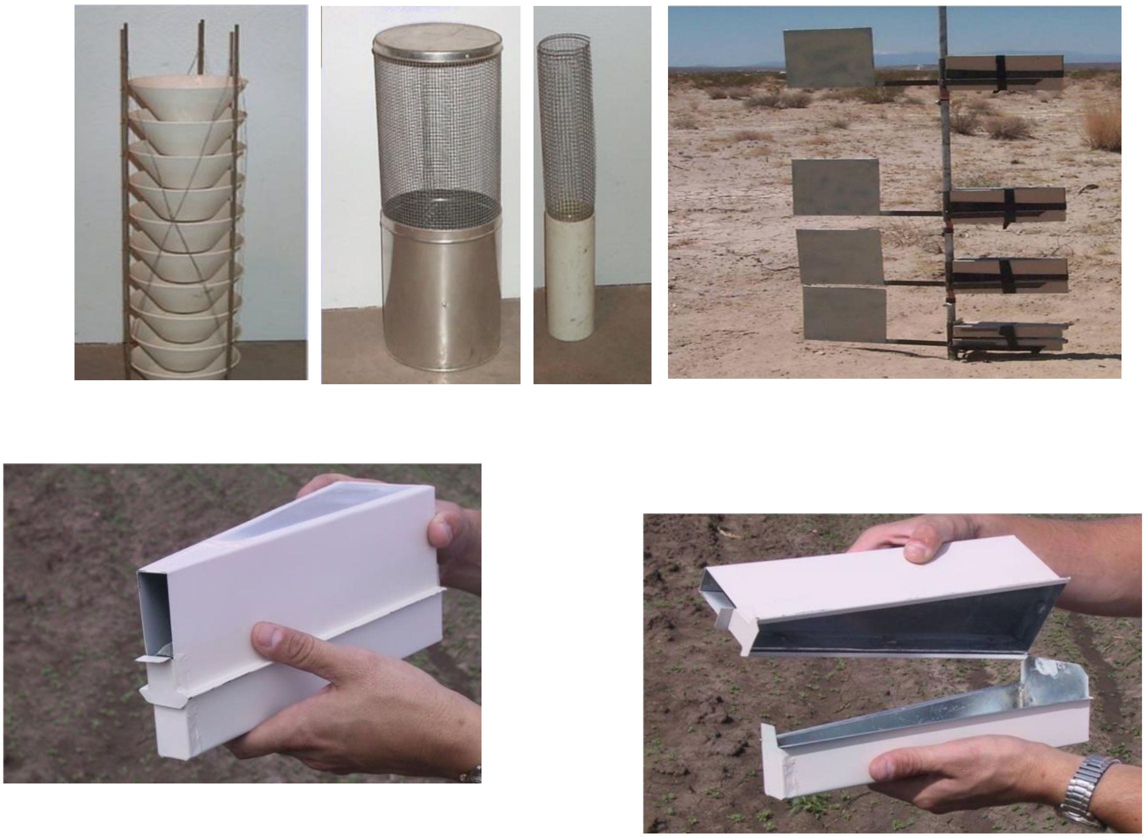
It is a net of round metallic stakes, sometimes graduated, whose distribution on the land depends on the experimental setup and the aim of the study. This method quantifies the intakes/losses in the soil (sanding/erosion) expressed in heights or mass, and determined from the natural evolution from the soil surface level. This quantification is calculated based on the fluctuation balance sheet in the soil starting from an initial state taken as the origin.

Picture 16: The stake method used in the lands to quantify the eolian erosion

The technique does not give approximate ideas on the movement of the sand at in the parcel.

5.1.2 The sand trap method

To evaluate the moved sand quantities, the sand is caught with traps, as shown in the pictures below. The collectors can be put in different heights from the soil.



Picture 17: The mobile sand collectors

5.2. The indirect measures (the modelling)

They may be made directly by the qualitative measurement of the effects on the decrease of the soil productivity or the sanding of the infrastructure. Besides, they may be made through the use of the universal equation of the eolian erosion.

E=IRKTCADB (t /ha/an)

(l) I= the erodibility index according to the structure texture (easiness of the soil desegregation).

(2) R= the superficial cover (vegetation, harvest residuals).

(3) K= the land roughness index.

4) T= the texture.

(5) C= the climate index according to the temperature wind.

(6) A= the dimension of the field in the parallel direction of the wind.

D= the orientation r/r to the wind direction.

(7): B= the windshield artificial protection, culms.

5.3. The anti-erosion methods

a. Windshields and hedges

They reduce the speed of the wind to reduce the evaporation and the eolian erosion (figure 20). Their action reduces 20% of the wind speed and takes place on 10 to 12 times the height of the windshield downstream and upstream (Combeau, 1977). This protection depends on the windshield permeability. A low permeability provokes a big speed reduction. According to Pons (2007), if we reduce much the speed (very dense plantation), the temperature increases and the plants burn out all along the windshield. It is better to reconstitute a park of 40 adult trees to regularly decrease the wind speed.

In general, the windshield decreases the evapotranspiration to 20%. Nevertheless, this effect may be counterbalanced by the water consumption of the windshield itself. To be used as windshield, the trees must have:

- Persistent leaves.
- Rapid growth.
- Low cluttering.
- A radicular system to have a limited concurrence of the roots.

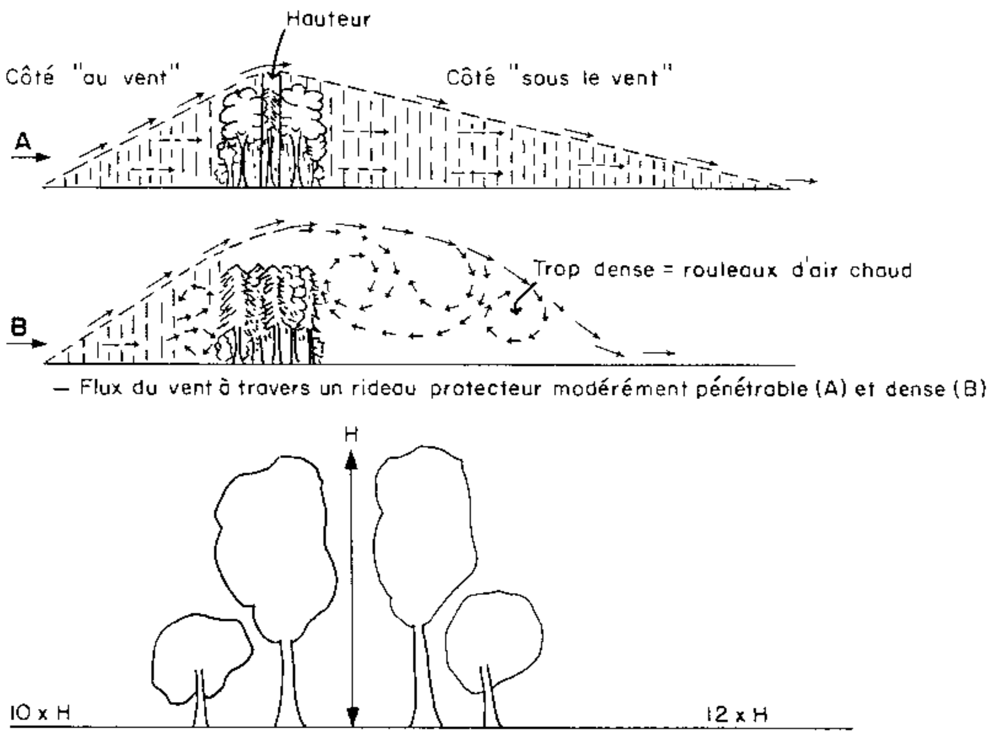


Figure 21. The influence of the windshield on the wind (according to Combeau, 1977).

b. Soil cover

- Mulching.
- Living cover during the dry season, as long as the climate allows.

c. The dunes fixation

The dunes fixation in the hyper-arid zones is a process that stabilizes the moving sand through simple mechanical and biological techniques. In a context where the rains are quasi-inexistent and the main source of the water is the groundwater, we use the vegetal material that exists locally to strongly reduce the winds (FAO, 1988). When we want to fix the dunes, we must make prior studies, such as:

- The sand composition
- The force, frequency, and direction of the wind
- The height, duration, and distribution of the rain
- The existence of the natural vegetation on the dunes

The aim of the dunes fixation is hindering the sand movement for a longtime to allow the natural or planted vegetation to grow (Mainguet, 1983). In this context, we irrigate the picket fences, which are made in branches, mats, planks in the dunes, etc. To help the fixation, we use a light net of branches or all other debris on the sand. The picket fence must be monitored until the vegetation grows.

Picture 18: The sanding and the dunes fixation in Djado oasis

REFERENCES

Références

Arnold, J.B., Wall, G., Moore, N., Baldwin, C.S., et Shelton, I.J. (1989) . Fiche technique : L'érosion du sol - Causes et Effets », Ministère de !'Agriculture, de l'Alimentation et des Affaires Rurales de]'Ontario, Division Agriculure et Affaires Rurales, Guelph, 7 p.

Badraoui, M., Agbani, M., & Soudi, B. (2000). Evolution de la qualité des sols sous mise en valeur intensive au Maroc. Séminaire 'Intensification agricole et qualité des sols et des eaux', Rabat, Maroc, 2-3.

Bagnold, R. A. (1954). The Physics of Blown Sand and Desert Dunes. Chapman and Hall, UK. 265 p.

Baize D. (1984). Fonctionnement hydrique de planosols en Champagne humide. In : C.R. colloque *Fonctionnement hydrique et comportement des sols*, Dijon, 22-25 mai. AFES, Orléans : 21-32.

Barro, S.E.(1995). Notes de cours sur la conservation des eaux et des sols. EIER. 48pp.

Barrow, C. J. (1991) Land degradation: development and breakdown of terrestrial environments, Cambridge University Press, 295p

Bielders, C. (2004). Les mécanismes de l'érosion hydrique, Antoing 16 décembre 2004 - Unité de Génie Rural, UCL.

Bigi A.(2012) . Guide de référence sur les pratiques de conservation et de lutte contre l'érosion dans le département de sud d' Haiti. 144p.

Biji, A. (2012). Guide de Référence sur les Pratiques de Prévention de Lutte contre l'érosion dans le département du Sud d'Haïti.

Boiffin J. (1984).*La dégradation structurale des couches superficielles du sol sous l'action des pluies.* Thèse de doctorat, INA-PG ; 320 p + annexes

Boughalem, M., Mazour, M., Grecu, F., Abdellaoui, A., Hamimed, A. (2013). Evaluation par analyse multicritères de la vulnérabilité des sols à l'érosion : cas du Bassin versant de l'Isser-Tlemcen – Algérie », Annale Universităţii Bucureşti, Geografie, LXII, 5-26

Catinot ,R. (1994) Aménager les savanes boisées africaines un tel objectif semble désormais à notre portée. Bois et forêts des tropiques, 241, 53-70.

Chevallier, P. et al. 1985. Pluies et crues au Sahel - Hydrologie de la mare d;Oursi (Burkina Faso). 1976-1981. Collection Travaux et Documents no. 190. Paris. 251 p.

Coll, P., Le Velly, R., Le Cadre-Barthélemy, E., & Villenave, C. (2012). La qualité des sols: associer perceptions et analyses des scientifiques et des viticulteurs. Etude et Gestion des Sols, 19(2), 79-88

Combeau ,A. (1962). Erosion et conservation des sols. Cours ORSTOM, Paris, 85 p

Conacher, A. J. &Sala, M. (1998) Land degradation in Mediterranean environments of the world: nature and extent, causes and solutions. Wiley & Sons, 491 p.

Darboux ,F.(2009). L'érosion, un acteur majeur de la dégradation des sols et de l'environnement dans « Le Sol » - Dossier INRA – p.128-131.

De Ploey J., Imeson A., Oldeman L.R.(1991). Soil erosion, soil degradation and climatic change. In : Brouwer F-M., Thomas A-J. ,Chadwick M-J.,editors. Land use change in Europe,Kluwer Academic Publisher, Dordrecht, 275-292

FAO .(2010).Evaluation des ressources forestières mondiales 2010. Rapport principal. Rome, Étude FAO Forêts 163, 348 p.

FAO. (1977).Aménagement des bassins versants. CAHIER FAO CONSERVATION 1 https://www.fao.org/3/AD071F/AD071f00.htm#cont

FAO.(1976). La conservation des sols dans les pays en voie de développement. Bulletin pédologique, vol. 30, 92p

FAO.(1983). Garder la terre en vie : L'érosion des sols, ses causes et ses remèdes. Bulletin pédologique, vol. 50, 62p.

FAO.(1988) . Manuel de fixation des dunes, cahier FAO conservation 18

FAO.(2014). Word Reference Base for Soil Resources. Food and Agriculture

Flageollet , J.C. (1989) . Les Mouvements de terrain et leur prévention. Collection Géographie, Masson Éditions, Paris, 224 p.

Fonier , C.F. (1960). Climat et érosion. Paris, PUF, 201 p.

Fournier C.F. (1960). Climat et érosion. Paris, PUF, 201 p

Fournier ,C.F. (1960). Climat et érosion. Paris, PUF, 201 p

Gac J.Y. (1980). Géochimie du bassin du lac Tchad. Bilan de l'altération de l'érosion et de la sédimentation. Trav. Doc. ORSTOM, 123: 251pp

Gadrat B.(1997). Argile plus sable = ?. https://www.designvegetal.com/gadrat/s/sol/argilesable.html. Consulté le 02/10/2016.

Ganaba ,S .(2008).Caractérisation, utilisations, tests de restauration et gestion de la végétation ligneuse au Sahel, Burkina Faso. Dakar, Univ. Cheikh Anta Diop, Fac. Sc. et Techniques, thèse, 287 p. + ann.

Girard, M.-C. (2011). Sols et environnement, 2e éd., Dunod, Paris, , Les Principaux sols du monde. Voyage à travers l'épiderme vivant de la planète Terre, éd. Tec & Doc-Lavoisier,

Gobat M.G., Aragnon M., & Matthey.Y. W. (2010). Le sol vivant: bases de pédologie, biologie des sols. 3ème édition .s. l: Presse Polytechnique et Universitaire ROMANDES. 817p

HCEFLCD.(2014). Haut-Commissariat aux Eaux et Forêts et à la Lutte. Contre la Désertification. Maroc.

Hill, J., Mégier, J. &Mehl, W. (1995) Land degradation. soil erosion and desertification monitoring in Mediterranean ecosystems. Remote Sensing of Environment, vol.12, p. 237-260

Lagacé, R.(1980). "Erosion et conservation des sols", Compte-rendu des conférences, 8e colloque de génie rural, Ed., Université Laval 135 p.

Lawani A. (2012). "Etude du ruissellement et de l'érosion à différentes échelles spatiales sur le bassin versant de Tougou en zone sahélienne du Burkina Faso : Quantification et transposition des données ". Thèse de Doctorat, Université de Montpellier II. 319 p.

Mainguet, M. (1983). Dunes vives, dunes fixées, dunes vêtues: une classification selon le bilan d'alimentation, le régime éolien et la dynamique des édifices sableux. Z. *Geomorph. N.F. Suppl. Bd* 45: 265-285.

Mathieu C. (2009). Les principaux sols du monde, voyage à travers l'épiderme vivant de la planète Terre », *coll. Tec et Doc, 233 p., Lavoisier, Paris.*

Mathieu, C. (1990). Itinéraire de la dégradation des terres de savanes soudano-guinéennes à très faible de densité de population, l'exemple de la République Centrafricaine », Tropicultura, 8,4, pp. 175-184, Bruxelles.

Melalih ,A.(2012). Analyse des techniques de conservation de l'eau et du sol dans la zone aride cas bassin versant d'AIN SEFRA, Mémoire de Magister - Université de Tlemcen, Faculté des SNV – 144p.

Nord , G. (2006) . Modélisation a base physique des processus de l'érosion hydrique à l'échelle de la parcelle. Thèse doctorat Hydrologie. Université de Joseph-Fourier - Grenoble I, France. 324p.

Ouattara T., J-M. Dubois et J. Hugh . (2003). MEH-SAFER : un nouveau modèle d'érosion hydrique pour les milieux semi-arides de forte énergie à partir d'images multisources et de données auxiliaires. Télédétection, 2-3-4, p. 151-163.

Pierre, C.(2010). Variabilité interannuelle des émissions d'aérosols minéraux en zone semi-aride sahélienne, THESE DE DOCTORAT DE L'UNIVERSITE PIERRE ET MARIE CURIE, 214p

Pons, A. (2007) . Le sable et le vent. Projet bibliographique.19p

Rapp, R.R., Berry, L., Temple ,P. (ed). (1973). Studies on soil erosion and sedimentation in Tanzania. Geogr. Ann. 51 A, Stockholm

Ritter J. (**2012**). L'érosion du sol — Causes et effets, fiche technique, 8p.

Rodier, J.A. et Auvray, C. 1965. Estimation des débits de crue décennale pour les petits bassins versants de superficie inférieure à 200 km^2 en Afrique Occidentale. Publication CIEH, Orstom, Paris. 46 p.

Roose , É .(2010). Agro-pédologue, chercheur, DR. émérite, IRD, UMR Eco&Sol, Montpellier, France. Eric.Roose@ird.fr

Roose , E. (1996). Méthodes de mesure des états de surface du sol, de la rugosité et des autres caractéristiques qui peuvent aider au diagnostic de terrain des risques de ruissellement et d'érosion, en particulier sur les versants cultivés des montagnes. Bull Réseau Erosion 16: 87-97

Roose, E., & De Noni, G. (2004). Les effets d'actions incitatives de lutte contre l'érosion en Afrique du nord et en Amérique Latine/The effects of incentive schemes in the fight against erosion in North Africa and Latin America. Revue de géographie alpine, 92(1), 49-60.

Ruelle P., Séné M., Juncker E., Diatta M., Perez P.(1990). Défense et restauration des sols. Dakar: ISRA, 50 p.
Ruelle P., Séné M., Juncker E., Diatta M., Perez P.(1990). Défense et restauration des sols. Dakar: ISRA, 50 p.

Secrétariat Permanent des Organisations Non Gouvernementales (SPONG), (2012). Fiches techniques des bonnes pratiques en matière de gestion durable des terres, d'adaptation aux changements climatiques et de conservation de la diversité biologique dans les régions du plateau central, du centre nord, du nord et du sahel. Ougadoudou Burkina Faso. 113 p.

Shrestha, D. P., Zincka, J. A. & Van Ranst, E. (2004) Modelling land degradation in the Nepalese Himalayas. Catena, vol., p.135–156.

Stengel, P., & Gelin, S. (1998). Sol : interface fragile. Paris: Editions INRA.

Stone, R.P. (2000) .Equation universelle des pertes en terre (USLE) », Ministère de l'Agriculture, de l'Alimentation et des Affaires Rurales de l'Ontario, Division Agriculture et Affaires Rurales, Guelph, 9 p.

Tidjani ,A .D .(2020). Cours sur la lutte contre l'ensablement d'origine éolienne, Master gestion intégrée des sols et des eaux, 120 diapos

Tidjani, A.D. (2008). Erosion éolienne dans le Damagaram Est(Sud-Est du Niger) : Paramétrisation, quantification et moyens de lutte. Thèse de doctorat Université catholique de Louvain, 171 pages.

Touazi , M. (2001). Evaluation des ressources en eau et acquisition de bases de données à références spatiale et temporelle en Algérie du Nord". Thèse doctorat, Université de NiceSophia Antipolis, 300 p

Okoth, P.F.(2003). A hierarchical method for soil erosion assessment and spatial risk modelling,Thesis Wageningen University 232 pages.

Yvio G.(2008). Evaluation de l'Erosion dans le bassin versant de la rivière Grise (Haiti). Faculté universitaire des sciences agronomiques de Gembloux, Belgique - Master en gestion des Risques Naturels.

Zaher H . (2010= . Cours CES. Ecole Nationale Forestière d'Ingénieurs Département Sol Eau Biodiversité. www.ma.auf.org/erosion/Sommaire.html