Farm Land Erosion: In Temperate Plains Environment and Hills
S. Wicherek (Editor)
1993 Elsevier Science Publishers B.V.

Erosion...a current environmental problem ? The GCES, a new strategy for fighting erosion to resolve this dilemna of a growing society

E. Roose

Director of Pedological Research at ORSTOM, Montpellier headquarters, BP 5045, 34 032 Montpellier Cédex 1, France.

SUMMARY

In Nature, as long as the soil remains covered, geological erosion is no more spectacular than rock weathering (1 meter per 100,000 years). But when population density increases over certain thresholds (40-100-800 inhabitants/km sq.) runoff increases as well and erosion is multiplied by 1000 so that soil is scoured within a

management. Soil erosion is no longer the main issue, but rather the consequence of improved water infiltration, soil capacity and increased biomass production - thus better cover - through better water and soil nutrient management.

RESUME

L'érosion est un phénomène de société. Dans la nature, tant que les sols sont couverts, l'érosion est lente (1 mètre en 100 000 ans). Mais, dès que la population dépasse certains seuils de densité, s'agglomère dans des villes ou que les pressions économiques provoquent des changements de systèmes de production, le ruissellement et les divers processus d'érosion s'emballent et les horizons humifères sont décapés en quelques dizaines d'années sur les pentes fortes ou sont vidés de leur substance par érosion sélective sur les pentes faibles (= squelettisation).

La lutte antiérosive est finalement plus complexe qu'on ne croyait car les processus en cause, les facteurs sur lesquels on peut jouer sont très divers et quelques fois contradictoires : par exemple, si on améliore l'infiltration sur les fortes pentes, on réduit les risques de ravinement, mais on augmente les risques de glissement de terrain. De plus, il règne une grande confusion de langage car les différents acteurs utilisent des termes sans en connaître la signification profonde et la philosophie qu'ils cachent.

Depuis des millénaires, les sociétés qui se sont succédées sur les quatre continents ont laissé des traces de leur lutte contre l'érosion. Ces *stratégies traditionnelles* sont intimement liées aux conditions économiques de ces sociétés. Ainsi, les gradins ou terrasses méditérranéennes se retrouvent sur les quatre continents mais toujours là où la terre cultivable manque, en dehors des montagnes, où la population est dense et où le travail est bon marché car on ne va pas investir 500 à 800 hommes x jour pour aménager un hectare si on n'y est pas acculé.

Plus récemment, ont été développées des *stratégies modernes d'équipement rural.* Pour faire face à des problèmes d'intérêt public, l'Etat par l'intermédiaire de ses corps d'ingénieurs (Ponts et Chaussées, Forestiers, Agronomes) a imposé au monde rural des équipements dont l'objectif est la restauration des sols certes, mais surtout la protection des routes, des ouvrages d'art, des barrages et de la qualité des eaux pour les citadins. Il s'agit de la RTM, Restauration des Terrains en Montagne (Alpes et Pyrénées, 1850-1900), de la CES, Conservation de l'Eau et des Sols des plaines américaines (Bennet, 1930), de la DRS, Défense et Restauration des Sols autour du Bassin méditerranéen (1940-1980).

Ces stratégies ont été rejetées par les paysans qui n'y ont pas trouvé leur compte (perte de terrain sans augmentation des rendements) et ont abouti dans plus de 80 % des cas à des échecs, tant aux USA qu'en Afrique et en Asie.

en soi, mais un préalable pour développer la production de biomasse, c'est à dire à

Catastrophic erosion occurs when geological causes are exacerbated by careless human management.
Erosion worsens in a most dramatic way, for ex. :
- gully erosion in the Mediterranean reaching *100-300 t/ha in one day.*
- Land slides moving *millions of cubic meters within one hour.*

The example of the Nimes storm on Oct. 3 1988 is spectacular. Within six hours' time, 420 mm of rain fell : torrents swept away the old village areas. Results : 11 deaths and 4 billion francs in damages! Worse still, in Columbia when the Nevado Ruiz volcano spitting vapor brought on an enormous torrent of lava that buried a city of 25,000 inhabitants in one single night !

In conclusion :

It is difficult to measure processes that are so temporally and spatially sporadic. Research is still not steady on its feet.
- The Press and the State only deal with catastrophes that elicit strong reaction from the public.
- As for us, we are particularly interested in the start of erosion processes - sheet and gully erosion - erosion accelerated by Man, because this is the stage where something can be done to prevent catastrophes.

1.2. Diverse logics: different spatial interests

Erosion is the result of three processes : washing-out, transportation and sedimentation. These three processes are ever-present , but their importance varies spatially.

In mountain environments : washing-out and therefore RTM is developed by foresters.

In Piedmont environments : both erosion and transportation are problems: the DRS tries to revegetate the upper valleys and to master torrents.

In hill and plain environments : Washing-out is less a problem than is sedimentation and pollution : the CES and control of sedimentation and pollution are strong imperatives.

In function of the space concerned, the strategies vary, and the actors involved as well :
- *On slopes*, erosion damages soil. The *"uphill logic" or farmer's strategy attempts to increase land productivity,* and seeks lasting results and insured productivity. The best methods seek to modificy poorly balanced production systems. The principal

1.3. Diverse processes, causes and factors (Tab. 1)

Land degradation can have numerous causes : Salinization of arid zones, compaction, during motorization, acidification by mineral fertilizers, mineralization of organic matter. It develops once land is cleared, before the preliminary symptoms of erosion(but not transportation), but worsens due to erosion.

Sheet erosion is dangerous because it often goes unnoticed (1mm=15 t/ha !) and is selective vis-à-vis organic and mineral colloids as well as absorbed nutrients. It wears out the land, i.e. it prevents the soil from stocking water and nutrients. This process is not clearly understood by peasants : to my knowledge, no African dialect includes a specific word for this pernicious process.

Linear erosion is better understood : even before Bennet, runoff speed was being slowed down by thresholds, waterfalls absorbed energy, damage was reduced , but infiltration and runoff volume related problems were still not under control.

Mass wasting is still not clearly understood (except by specialists) and is difficult to control : the presence of trees seems to reduce its frequency. However, cultivating on slopes causes progressive land sliding.

Dry mechanical erosion is often mistaken for sheet erosion. We don't know much about the intensification or reduction factors for this sort of dry creeping which is very active on overpopulated mountains. Research is starting to attack this problem!

Wind erosion only occurs when wind exceed certain speed thresholds (25 km/hour). Balancing factors are close to those for sheet erosion.

1.4. The underlying nature of the problem : the imbalance within the cultivated "converted" milieu. (Fig 1)

The dense humid forest has a biomass of 850 t/ha and produces 8-15 t/ha/year of litter perfectly protecting the soil from sun and rain. Roots are deep under the soil, but most roots dig into the first 25 centimeters, those richest in organic matter and nutrients. Under foliage, profiles develop over numerous meters, even tens of meters. Erosion is slow.

In the swamp environment, there is less protection : the canopy (50-150 t/ha) and especially the burnt or pastured litter, lets heat and rain penetrate, which crusts the soil surface. Runoff can reach 40-70 %, especially if fires come late. Water penetrates more superficially and soil is leached, and more clayey between 50-100 cm.

But under cultivation, the atmosphere is even dryer : the canopy is less dense (2 to 20 tons depending on agriculture) and litter is often inexistent, burnt, used elsewhere, valorized by livestock or artisans.

From a vegetal point of view, we can observe :

- simplification of the agrosystem,
- reduction of the biomass.

The pedo-climate is hotter, more arid than the forest, especially since rooting is limited to 25-50 cm in depth.

The soil is characterized by :

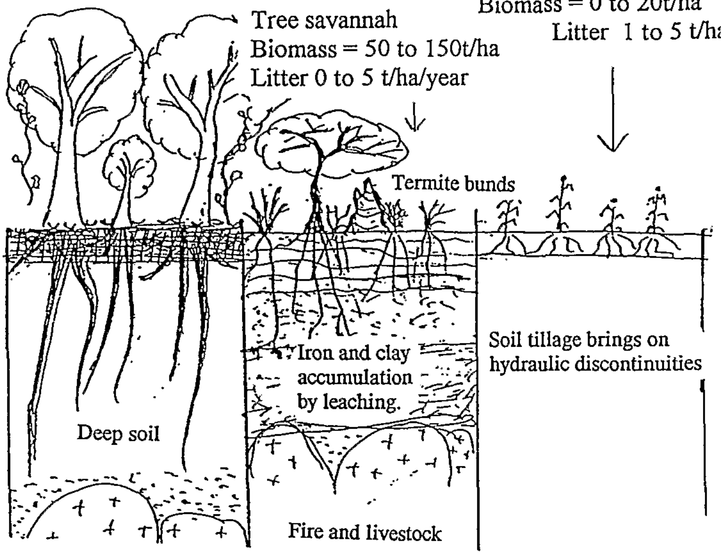
- reduced biological lifting (feeble rooting)
- decrease in litter supply, and therefore decrease in organic matter in the soil and biological activity.
- structural degradation: crusts, damage to microporosity and decrease in infiltration capacity.

TABLE 1 - Diversity of Erosion Processes, Causes, Factors and Consequences.

Process	Causes	Factors	Consequences
Soil degradation	- Mineralization of organic matter - Salinization, motorization, etc...	- Temperature - Humidity - Litter turn over	**decrease :** ↓ OM Content decrease ↓ Water + nutrient storage capacity ↓ Porosity, infiltration **increase :** ↑ of runoff and Erosion risk
Sheet Erosion	Splash = - setting - shearing - projection	- Vegetal cover 1000 - Slope 200 - Doil 30 - Structure A.E 10	Sealing crust + Setting Runoff - Selective Erosion - Scouring
Dry mechanical	Tillage practices	- Frequences - Intensity - Slope steepness - Soil fiability	- Scouring - Humiferous - Horizon
Gully Erosion	Runoff energy $E = \frac{M.V2}{2}$	- Runoff - volume = f {surface, rain, intensity - Speed = f (slope, roughness) - Resistance of the soil × vegetation - A.E structures : weir, etc.	- Deep gullies - Imbattance of slopes - Alluvial fans
Mass mouvements (Sliding) on hillslopes	Gravity > Cohesion of the soil	- Cover weight {soil+water+vegetation - Humectation of sliding plane - Slope + drainage	- Hillslope scouring - Mud slides.

CONCLUSIONS :

1 - Diversity of forms, causes, factors and means for fighting erosion.
2 - Temporal and spatial variability of erosion intensity.
3 - Great importance of the soil surface state.



Green cover evolution ...... { - Simplifying the ecosystem, biomass decrease.
- Soil protection against sun and rain energy decrease.

Climate evolution ...... T° increasing ⇒ Dryer situation

Soil evolution ..... {
- Reduction of soil thickness exploitation
- Reduction of biological turn over
- Reduction of litter supply → decrease of O.Matter content in soil.
→ decrease of biological activity.
- Soil structure degradation : - sealing crust, compaction + clay pan,
- decrease of macroporosity,
- reduction of infiltration capacity.
- Runoff + Erosion + Leaching risks increase.
- Nutrient losses increase ↑
- Decrease water + Nutrient storage capacity → "TIRED SOIL"
- Decrease water disposal for biomass production.

Figure 1. The soil degradation causes : The imbalance of cropping systems.

Risk of runoff increases, as erosion and leaching of nutrients by drainage and runoff water increase. Nutrient and organic matter losses are accelerated, especially in forest soils rich in surface litter : water and fertilizer storage capacity is reduced. The soil becomes "worn out" and is incapable of valorizing the water and nutrients it receives : productivity decreases to a stable limit, taking into account the production system of biological lift and supply hindered by rain and dust. Traditionally, without fertilizer, 4 to 8 quintals of cereals is produced! Just enough to maintain a state of relative survival !

1.5. Economic consequences of erosion

Erosion brings on soil production losses and downhill damages. This economic aspect is currently the object of extensive research.

a) On-site loss due to erosion.

Water loss :

- runoff brings on decrease in drainage in humid zones and increase in river debit, but little change in production.
- however, in semi-arid zones (if only during dry season) runoff brings on a decrease of "ETP" and of the biomass.

The anti-erosion combat (LAE) should be even more spectacular concerning productivity in semi-arid areas.

Loss of fertilizer : is calculated in terms of tens of kilos of "NPK" by hundreds on silting of reservoirs, canals and ports. Mudslides encumber ditches and poorly placed village roads. The cost of damage from erosion during storms of rare frequency (1/1 to 1/10) is increased, and attracts the media, provoking reactions from the government more often than does soil degradation. This explains the traditional approach consisting of stopping first the erosion from the badlands, which are worn-out lands.

c) Major consequences of economic analysis of the LAE (Fig 2)

- If investment is made in the fight against erosion on degraded soils, whether or not the soil is deep, productivity of the land is not altered (thus this does not interest the farmers) but transportation of solid matter is reduced. This is the case for RTM and DRS.
- If investment is made on good land being damaged :
- if the soil is deep, no improvement in profitability can be reached,
- but if the soil is superficial, productivity can be restored (in the interest of the farmer).

This is revolutionary in relation to the classic LAE which deals with damaged land, while farmers prefer to invest in better land...except if they can recuperate acidentally damaged land. This was experimented in very different ecological conditions : the Nord-Pas de Calais region (5) Mali (6) and Yatenga (7) Rwanda (8) and especially Algeria (9).

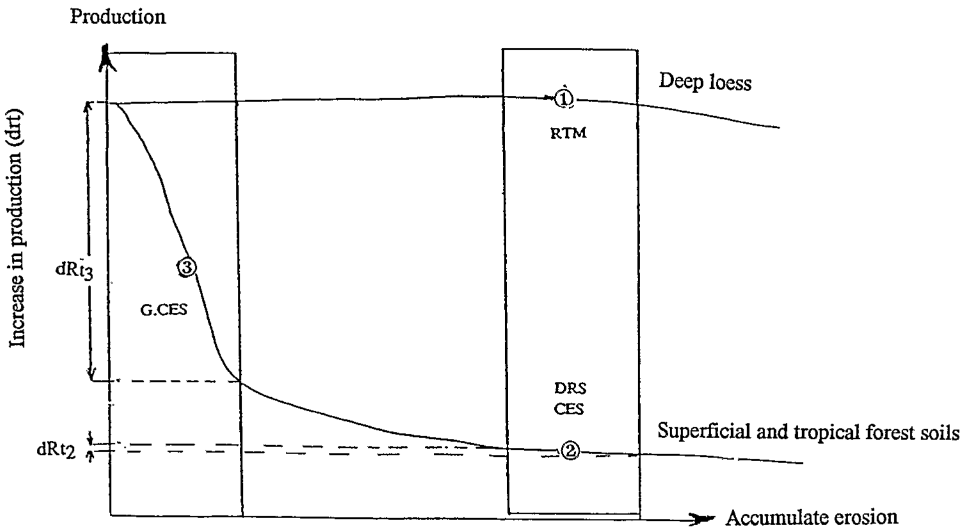


Figure 2. Effect of cummulated erosion or soil scouring on their productivity. Interest of rural equipment strategies (RTM, DRS, CES) and rural development strategies (G.CES) in relation with two different soil situations.

1.6. Conclusions

a) Inconsiderate use of the same terms by different disciplines in speaking of erosion while there are at least five different processes at work, with varying gravity in function of different factors and thresholds according to temporal and spatial scales, has brought about quite a bit of confusion, both on the research level (where links between lab tests, plots, fields, on slopes, on catchment areas are desperately sought) and between those involved in fighting erosion.

In spite of thousands of years of empirical practice fighting erosion, research is still not progressing in certain domaines such as that of dry mechanical erosion, fighting crusting, simultaneous management of water and nutrients, socio-economic aspects of the LAE, acceptation by farmers and cost of LAE techniques.

b) Analysis of economic policy of anti-erosion combat clearly distinguishes two objectives and two different actors involved :

- if the problem in conservation - or better still, restoration of soil fertility - means of modifying production systems should be proposed to farmers in order to resolve immediate problems of valorizing work, improvement and security of production of the best lands (this is the GCES) : only the farmers can manage the rural environment ;
- if it is a question of conserving water and reducing solid transportation from rivers, only the State can take charge of major mechanical and biological projects for stabilizing gullies, torrents, land slides and rivers, reforestation of upper valleys, protecting banks, routes and other works.

2. ELEMENTS FOR A SOLUTION

2.1. Traditional or modern strategies

Man has not given up on handling erosive phenomena which hinder his projects and development: we have found traces of his ingenuous attempts in this domaine over thousands of years (ex. stepped terraces in 1800 around the Mediterranean basin - in 1200 in Crete - in 1400, by the Incas in Peru and even earlier in China, Bali and Latin America).

These traditional methods are often described, but we don't understand their functioning very well or their limitations. Engineering studies have considered them inefficient and not worthy of modern times. However, many of these methods, even if they have been abandoned for economic reasons (the factory pays more) are quite efficient, and inform us about the socio-economic conditions of a certain age in history, indicate extreme ecological conditions in specific regions and can be improved and serve as a starting point for farmers in taking charge of their environmental problems. (ex. the Zaï and stone bas in Yatenga, Burkina : 7).

Since 1850, "modern methods for rural equipment" have been developed :

- the RTM (1850) "Restoring Mountain Land" in the Alps and Pyrénées by foresters who restore vegetation in degraded mountain slopes and remedy torrents ;
- the CES (born in 1930 in the USA) "Conservation of Water and Soil" by agronomists charged with providing both financial and technical support. for farmers wishing to protect their lands' productivity - and the quality of water indispensable to city-dwellers (thus explaining the State support for the project) ;

the DRS (developed in the Mediterranean area between 1940-1980) "Defense and Restoration of the Soil" (damaged by erosion) proposed by State forestry engineers to protect land, restore vegetation on damaged land and more importantly, to reduce the silting up of dams, water being a precious asset in arid areas.

All these approaches, carried out by the centralized power of different States, have often succeeded in realizing admirable projects, but most often have met with failure at long-term, because farmers do not feel concerned. This equipment does not improve productivity, on the contrary, it reduces exploitable surface without attacking the heart of the problem: sheet erosion and degradation of organic matter in the soil.

Since 1987 and the Puerto Rico (WA.SWC) (10) , Niamey (ICRISAT) Medea (INRF) Butare (ISAR) and Bujumbura (ISABU) seminars, a new strategy is developing which attempts first of all to resolve farmers' problems, double profitability over 20 years, improve stability of production systems, and intensify agriculture without destroying the environment. These methods have been described in a pamphlet entitled "Land Husbandry" or the art of caring for land, and a series of articles and conferences on the GCES (11). The FAO should be putting out a volume on the application of this strategy tied to lasting development of agriculture in different countries of Europe and Africa.

In short, the process is the following :

a) *Diagnostic :* Where does run off and erosion start ?

- Is it due to degradation of the soil? When ? How ?
  If so, the production system should be improved with the help of farmers involved.
- Is it a case of untimely, excessive water input from uphill ?
  If so, then the drainage and water management system should be improved with the help of engineers.

b) *Water management function of the region hydric balance*

There are four means of managing water corresponding to anti-erosive structures and adapted agricultural techniques.

c) *Managing the biomass and nutrients*

Conservation of the soil often discourages farmers for it demands great effort, investment in labor and "intrants" without providing immediate improvement in profitability since soil is often already damaged.

Restoration of physical and chemical qualities must therefore be envisaged.

A means of exploitation of the available biomass must be chosen, through breeding and manure production, (foresee and coefficient of profitability of 30 % and heavy azote waste), through composting (much labor and same profitability as manure, but without animal production), direct removal of agricultural residue (much work and slower degradation of the soil) or straw protection of the surface. Production systems increasing the available biomass are imperative (agroforestry, cultivated fallowland, concealed green fertilizer etc). In any case, airation of the soil has to be provided, as well as correction of the pH factor (aluminic toxicity if pH is over 4.8) and soil deficiency (mineral supplements directly brought in to valorize labour and available water).

Finally, infrastructures must be developed (routes, markets, schools, dispensaries) in order to valorize the surplus in rural production by using it to feed cities.

We often use the individual case as a starting point for developing an exploited slope by a small rural community before carrying the projects to the level of a field, and then to that of a catchment area. This involves more than does a simple equipment project because it also a question of changing mentalities, of liberating the creative spirit in peasant farmers, but this is the only way to avoid imminent disaster: farmers must take their environment into their own hands.

Table 2.
Antierosive structures and cultural practices in relation with running water management.

Management type	Antierosive structures	Cultural practices
Runoff farming in arid and semi-arid areas	- Impluvium, sistern, - Soil dykes on wadies - Discontinued terraces	Deep plowing,pitting Microcatchment
Total infiltration in semi-arid (less 400 m) or sub tropical areas on highly permeable soils	- Pitting - Beuch terracing	- Rough plowing - Tied-ridging - Mulching
Water diversion Humid areas on slow permeable soils	- Channel terraces with lateral drainage	- Oblique ridging - Ridging paralelly to the slope
Runoff energy dissipation in all climat, permeable soils on slopes < 60%	- Stone bunds or walls - Grass lines, grassed embrankment - Hedges	- Agroforestry - Rough tillage - Crops alternating with meadows - Mulching

2.2. A few solutions have emerged through research

a) The major importance of biological methods, vegetal cover and in particular, at the soil surface, litters, self-propagating vegetation, even cover plants introduced under agriculture : canopies are less efficient than litter.

b) The ambivalent role of working the soil which, on one hand, temporarily improves infiltration, rooting and profitability, but which, on the other hand, speeds up mineralization, imbalances and degradation of soil. To be used with a certain carefulness: minimal labor along with mulch permits a serious reduction in degradation risks.

c) The role of inclination of the slope seems more important than its length except when linear erosion is developing.
The topographical position is especially important: the bottom of the slope is often more quickly saturated and eroded than the upper segments. Complete revision of classic plans for installations must be done and use of mathematic formulae defining - empirically - the space between terrasses, should be left aside. Only observation of the land on early rills and gullies and discussion of economics with farmers will lead to definition of the spacing between anti-erosive structures.
d) major effect of soil surface state upon runoff - particularly litter biological activities and crustings : must mode us revised the notions of deep/superficial work, heavy clods or powdery. Function of runoff generation we must try to improve infiltration by a production system or to drain water excess with out increasing solid transportation. Cultural profile often makes clear the plant development but rarely elucidates infiltration ! Soil surface state is much more significant.
e) Treating gullies is costly, but is not complicated if one respects a dozen or so elementary rules. Costs can be reduced and water and lost sediments valorized by transforming gullies into a kind of " linear oasis" so that each ecological nitch is used by well adapted productive species.
f) Modelization of runoff has made great progress using surface states, evolution of infiltration capacity and water stockage in diverse horizons. We still have to try to better understand the redistribution of water at the catchment area level during different seasons.
g) Modelization of erosion is much more complicated. There is no universal model. The USLE model is an empirical approach adapted to field engineers who need markers to choose different modes of LAE. It can be useful if rainfall energy and danger of sheet erosion are greater that runoff and gully or mass erosion. Studying the functionning of slopes is a prerequisite to using the model.
h) Sociological aspects of erosion (property problems, typology of exploitations, motivation and available resources for undertaking property investments) has hardly been approached. Economic problems are handled first : economic conditions for erosion, influence of the regional and world markets, cost of erosion, loss in short and long-term productivity of eroded land, cost of fighting erosion. We have trouble classifying different soils according to their erodability for each type of soil is a dynamic entity, evolving over time in function of the production system applied and the type of erosion.

We are advancing in the domaine of theoretical and practical knowledge... but the next generation will still have a lot left to deal with.

3. GENERAL CONCLUSIONS

a) *Erosion is a societal problem, in constant growth.*
- In developping countries, water has to be managed along with soil fertility in order to meet the challenge of doubling productivity over 20 years' time, along with the increase in population.
- In industrialized countries, quality of water, a natural resource as precious as soil, must be conserved, or restored, - water is a resource whose renewal, and restoration are often possible, but costly.

b) *Today this complex problem interests many people*
- Researchers from diverse disciplines who seek to understand and modelize the process.
- Developpers, because mastering erosion is one of the keys to lasting agricultural development.
- Politicians... because environmental problems are a contemporary issue: those who pollute should pay, which is not the case today.

c) Today, possibilities for action are opening up
- The problem is evident, urgent : we're backed into a corner, there is no way out. Everyone is concerned.
- Demographic pressure is enormous.. but production is stagnating.
- We're starting to find a way out: there are already a few results showing that it is possible to intensify agricultural production without degrading the environment.

This is a fascinating area of study because it integrates physical and human environments.

However, French research institutes do not have any major research program on fighting erosion. Technical higher education on erosion processes is not plentiful and is more or less nonexistant concerning ways of fighting erosion. It is difficult to do serious doctoral research on quantified erosion in the field and especially so concerning development of anti-erosion strategies, because erosion varies so greatly according to space and time.

Evidently, the problems are many and frequent... but devoting a whole career to this area is difficult.

I would like to conclude on an optimistic note - once the problems of world

8. Roose, E., Ndayizigiye, F., Nyamulinda, V., Byiringiro, E., (1988) : La GCES, une nouvelle stratégie de lutte antiérosive pour le Rwanda. Bull. Agricole Rwanda, n° 21 (4) : 264-277.
9. Arabi, M., Roose, E., (1989) : Influence de quatre systèmes de production et le ruissellement en nappe en moyenne montagne algérienne. Bull. Réseau Erosion n° 9 : 30-51.
10. Roose, E., (1987) : Water efficiency and soil fertility conservation on steep slopes of some tropical countries. Communication Workshop WASWC, Puerto ¤ico, 22-27 March 1987. Edit. Moildenhauer (W.C.) and Hudson (N.W.), S.W.C. Soc. Ankeny, USA : 296 p.
11. Roose, E., (1991) : Introduction à la Gestion Conservatoire de l'eau et de la fertilité des sols (GCES) : bilan et perspective. CRPA Ouahigouya, ORSTOM Montpellier : 188 p.