New Data Concerning Erosion Processes and Soil Management on Andosols from Ecuador and Martinique

***Bounmanh Khamsouk*[1], *Georges De Noni* and *Eric Roose*[2]**

[1]CIRAD-FLHOR, BP 53, 97200, Fort de France Martinique.
[2]IRD (Institut de recherche pour le développement), BP 5045, 34032 Montpellier - France
E-mail: khamsouk@wanadoo.fr, denoni@mpl.ird.fr, roose@mpl.ird.fr

Abstract: Because of their remarkable physico-chemical properties andosols are considered generally as fertile soils, well aggregated and very resistant to water erosion. Nevertheless recent measurements in cropped andosols under bananas plantations in Martinique Island and cereals in Ecuador steeplands have shown that its is necessary to moderate this opinion. In Martinique Island, intensive banana crop systems could seriously damage the environment by water erosion and chemical pollution because of the use of high inputs, aggressive tropical rainfalls and steep slopes. Therefore a field study with 10 runoff plots (200 m²) was located on 10-25-40 % slope of clay volcanic nitisol. In Ecuador, steep slopes of Andean Mountains are densely covered with little crop fields without any water management, therefore rills and gullies are abundant. 6 runoff plots (100 to 1000 m²) of 20%—40% slope were installed in the farmers fields with traditional crop rotation (barley, beans and potatoes). In each situation, under natural forest and savannah vegetation and under well mulched crops, runoff and erosion were negligible, but as soon as soils are denuded and compacted by grazing or by farmers or desiccated by the sun, it was observed in each situation moderate increase of runoff (5% to 20% of the rain amount) and severe erosion from 80 to 150 t/ha/year.

Looking to soil surface features, its was observed very few sealing crust, very stable aggregates but high susceptibility to compaction. As soon as fields have more than 15%—20% slope, runoff is collected in rills and gullies. Erosion is not a selective process because runoff is able to take off aggregated topsoil as a whole. In opposite to general opinion runoff does not increase with the slope steepness but erosion increase strongly, so that from 20%—40% slope erosion processes change from sheet and rill erosion to rill and creep erosion. Between 10 and 40 % slope, when cropped plots are mulched by crops residues or mulched by strips, runoff and erosion are insignificant.

In conclusion, simple anti-erosive measures can be used by farmers when they are obliged to crop very steep hillslopes. First, to increase infiltration rate, soils must be covered by intensive cropping system including crop residues mulching. Secondly, to reduce runoff velocity and energy, grass strips and earth bunds are managed each 10 to 20 meters depending of slope steepness and soil erodibility. These strips must be productive of forage, fire wood and poles for building to be acceptable for poor farmers.
Keywords: Ecuador, Martinique island, volcanic soils, erosion risks, slope effect, soil and water management, soil surface features

1 Introduction

In the world, volcanic soils are very cultivated because of their remarkable physico-chemical properties and their fertility characteristic. These soils are generally considered well aggregated and very resistant to water erosion. Nevertheless, recent assessments in cropped andosols under banana, pineapple and sugarcane plantations in Martinique island and under cereals in Ecuador steeplands have shown that it is necessary to moderate this opinion (De Noni *et al.*, 1996—2000; Khamsouk, 2001). Because of their aggressive climate conditions (high rainfall intensities such as irregular heavy storms or hurricanes) and volcanic mountainous landscapes, water erosion in andosols steeplands could induce great damages over soil degradation and water pollution in these countries. This paper will deal with volcanic soil erosion and its processes through these countries and then it will propose some soil management for soil loss reduction.

2 Site, saterials and methods

2.1 Site

Our study is made in two volcanic countries: Ecuador and Martinique island. Although these countries are different by their geographic position, climatic conditions and cropped farming systems, some similarities are found in soil erosion processes.

Ecuador (latitudes: 1°25 N — 5° S; longitudes: 75°12 — 81° W) is a country located on the South-American continent. It contains a remarkable mosaic of landscapes which is the result of the presence of the mountain barrier of the volcanic Andes, called the “Sierra”. This mountain show striking variations in altitude, long and steep slopes, heavy farmers population pressure (“minifundio”) on the lands and very active soil erosion in the little crop fields. The Sierra is made up of two parallel ranges (the Cordilleras, up to 3,200 m) with a depression between them formed by a succession of basins (interandean corridor: from 1,500 m to 3,200 m). The climate is equatorial of mountain, rainfalls are included between 1,000 and 2,000 mm and temperatures fluctuate according to the altitude: average is around 10° C up to 3,200 m and 20—22°C down to 3,200 m (De Noni *et al*., 1996—2001). There are two wet seasons: from September to November and, from February to June.

The experimental station is located at two levels of altitude: at Mojanda (3,300 m) in the cordillera on a barley cultivated soil and at Tumbaco (2,600 m) in the Andean corridor where maize is the principal crop. The soils are mollisols with a low bulk density, a low clay content, a moderate organic matter content and a satisfactory erodibility index K (table 1).

Martinique island is a volcanic andesite island (1,080 km² area) of the West Indies archipelago, surrounded by the Atlantic Ocean on the east and the Caribbean Sea on the west (latitudes: 14—16° N; longitudes: 60—62° W). Its relief is irregular with volcanic mountains in the north and in the south which are separated by small plains. The climate is tropical moist, characterised by an important average rainfall near 500—5,000 mm a year from south to north and the average temperature is around 25°C, with some peaks reaching 18° or 34°C (Khamsouk, 2001). Two seasons usually occur: the dry season from January to June and the wet season from July to December with important weather disturbances (tropical storms, hurricanes).

The experimental station is set up in a banana plantation in the island’s central area. The soil is described as an acid nitisol (Colmet-Daage & Lagache, 1965), with a low bulk density, a high clay content, a high organic matter content, a strong resistance to sheet erosion and a low erodibility index K (Table 1).

Table 1 Some characteristics of superficial (0-10 cm depth) volcanic soils coming from Ecuador and Martinique island

Soils characteristics	ECUADOR	MARTINIQUE
Soil classification	Mollisol	Nitisol
Slope inclination (%)	20—40	10—40
Bulk density ($g.cm^{-3}$)	0.9	0,77—0,92
Acidity pH water	5,4—7,4	4,9—5,7
Clay content (%)	14,5—24	62—74
Organic matter content (%)	2—2.3	2,7—3,3
Erodibility index K*	0.30	0,08—0,1

* according to the K index nomograph (Wischmeier & al., 1971)

2.2 Materials and methods

In both situations, experimental stations formed by runoff plots are set up in cropped steeplands to assess the water erosion and to determine its processes under natural rainfalls. The soil loss processes are not only variable in time, but also in space (Roose, 1994). To understand the origin of water erosion and its explanatory factors in cropped fields, we need to operate measurements with runoff plots which areas are 100—200 m² in Martinique Island and 100—1,000 m² in Ecuador, according to the references (Wischmeier & Smith, 1978). Besides, regarding other erosion methods, Hudson (1996) underlines the interest of runoff plots to assess and show soil loss damages and to determine a predicting erosion model. Therefore, the runoff plot's scale seems the most suitable because it integrates studied cropped systems characteristics: farming and soil conservation practices, cropped density, sheltering surface effect, etc.

On a 20—25 m long linear-shaped slope, these runoff plots are built with a closed studied area to avoid that superficial water comes out but into calibrated storage tanks of runoff and erosion sediments according to some references (Wischmeier & Smith, 1978; Roose, 1980; Rishirumuhirwa, 1997). Runoff and erosion are directly measured in the field after rainfall and results often are accurate for small to average rainfall episodes but become more approximate for great storms like hurricanes.

2.3 Treatments

The studied treatments which are repeated over two years in Martinique and five years in Ecuador in runoff plots are as follows:

- Bare soils: In the two countries, the "cultivated bare soil" (100 m²) is a standard treatment for the assessment of soil erodibility under aggressive rainfalls (Wischmeier & Smith, 1978). In Ecuador, there are one bare soil 100 m² plot at Tumbaco (Tw) on 20% slope and one other bare soil 100 m² plot at Mojanda (Mw) on 40% slope; and in Martinique, there are three runoff plots set up on three different slopes 11% (Bs11 plot), 25% (Bs25) and 40% (Bs40). In all the plots, soil tillage is made in 20 cm deep and soil surface is smoothed off each year before measurements;

- Traditional and improved crop systems: In Ecuador for cereals treatments, the studies has been carried out on two 100 m² plots cultivated with maize at Tumbaco (Tt) and annual crops rotations with barley, potato, beans at Mojanda under traditional farming methods. There are also two other larger plots (20 m x 50 m = 1,000 m²) under improved soil conservation methods to develop gradually into pseudo-terraces: grass strips at Tumbaco (Te) and low walls made of clods of earth at Mojanda (Me). In Martinique, three main crop systems are tested in 200 m² runoff plots: two repetitions of "lasting banana plantation" (Ba9 and Ba11) located on 9% and 11% slopes, with mulched strips of crop residue, a "classical mechanised and furrowed pineapple" (Pa7) on a 7% slope, a "superficial tillage with mulched strips pineapple" (Pa9) on a 9% slope and three "mulched sugarcanes" (Sc11, Sc25 and Sc40) respectively on 11%, 25% and 40% slopes.

2.4 Measured parameters

Some parameters of rainfall, runoff and erosion are measured after each erosive episode. Rainfall is determined by its maximal rainfall intensity in 30 minutes *Ipmax*30 (mm/h) according to an automatic meteorological station. Runoff is defined by the mean annual runoff coefficient *Cram* (%) which corresponds to the annual runoff water depth divided by the average rainfall and by the maximal runoff coefficient *Crmax* (%) which is the maximal runoff depth divided by its generated rainfall episode. Annual erosion *E* ($t.ha^{-1}.year^{-1}$) is determined by the total dry weight of whole soil loss (coarse and suspended sediments) of every eroded episode. For the most eroded treatments, four wet sieving operations are done from their coarse sediments and the mean eroded macro-aggregates content (aggregate diameter > 200 µm) is determined. Other parameters linked to cropped systems properties such as weight soil moisture content and the sheltering surface ratio by mulch and crop cover are monthly assessed (Khamsouk, 2001; De Noni *et al*., 2001).

3 Results

3.1 Rainfall parameters

In Ecuador, in a high tropical mountains like the Andes, the mean average rainfalls is lower than in the plain: 700 mm/year at Tumbaco and 900 mm/year at Mojanda. Rainfalls intensities are also lower, generally under 40 mm/h during 30 mn. There are each year a few stronger rainfalls intensities, from 40 to 80 mm/h at Tumbaco and 40 to 60 mm/h at Mojanda, which are responsible for more than 80% of annual soil losses (De Noni *et al*., 1990; 2001).

From 1978 to 1998, the mean average rainfall is 2,420 mm/year and the mean aggressive R index, which is characteristic of moist tropical climate according to Wischmeier and Smith (1978) and Roose (1980), rises to 915 J/m²/h. For the two years of measurements, the mean average rainfall reaches 2221 mm/year and the mean R index is around 546 J/m²/h. During these two years, three tropical storms with 74 to 190 mm rainfalls and with 37 to 76 mm/h induced great eroded events. Nevertheless, runoff and soil loss risks are active, especially during the wet season when rainfalls and their aggressiveness increase (Khamsouk, 2001).

3.2 Crop systems parameters

For the sheltering surface ratio, there are four different situations along the year: (1) the“bare soil” treatment with a weak sheltering surface ratio in both country (less than 20% of runoff plot’s area are essentially due to stones and litter) ; (2) the “lasting banana plantations” treatment with moderate and constant mulched sheltering surface ratio in Martinique (40%—60% of the plot’s area are laid by mulched strips of crop residue) ; (3) treatments like “classical furrowed pineapple” in Martinique and cereals in Ecuador with a growing sheltering surface : the pineapple leaf growth gradually covered from 35 to 80% of the plot’s area and the cereals took up more than 80% of the plots areas after three months of seedbed ; iv) treatments like “mulched sugarcane” and “superficial tillage and mulched pineapple” with a strong sheltering surface ratio : more than 60% of the plot’s area are regularly mulched by crop residues.

For the soil moisture, there are different situations between the two countries along the year. In Martinique, we have the following data: (1) the “bare soil” treatment with a constant weight soil moisture, around 45% because of no cultivated plants; (2) the treatments such like the “lasting banana plantation” and the “mulched sugarcane” which have got the same soil moisture variation, from 30 to 50% following the dry or wet season and (3) the two pineapple treatments with a high soil moisture, around 50-65% probably due to a weak water need of pineapples. Not much difference is generally distinguished between the two dry and wet seasons because of irrigation in crop systems during the dry period (Khamsouk, 2001). In Ecuador where the volcanic mountain climate is more dry, the soil moisture values are smaller than 20%—25 % (De Noni *et al*., 1996—2001).

3.3 Runoff and erosion parameters

The following table 2 presents runoff and erosion data:

For all tested treatments, mean runoff parameters are defined for all the period of measurements (Table 2). According to the runoff coefficients, the treatment plots which frequently flow (high Cram values) combine the highest runoff under the most aggressive rainfall (highest Crmax values). Therefore, the treatments like “bare soil” in the two countries, “furrowed pineapple” in Martinique and traditional cereals crops in Ecuador are the most sensitive to erosive rainfalls while the treatments with mulch or soil conservation measures have got a great resistance to runoff. Moreover, according to runoff results on “bare soil” treatment specially, it seems that runoff decreases when the slope rises (Table 2).

According to the mean erosion results, the treatments have got specific behaviours to soil loss (Table 2). Indeed, the highest soil losses have occurred on the “bare soil”, on the “classical furrowed pineapples” and on the traditional crop at Tumbaco while the weakest erosions are found on the mulched treatments or on soil conservation measures. Besides, according to the five “bare soil” plots, soil loss considerably increases with the slope.

Regarding the strong macro-aggregates contents determined in these eroded situations, the water erosion would be a non-selective process: so, runoff strength could carry a lot of coarse sediments out of runoff plots. In Ecuador, there are not macro-aggregates data but the comparison of particle size distribution between particles soils “in situ” and eroded sediments don’t show difference, which would be indicate that erosion process is non selective action like in Martinique (De Noni *et al*., 2001 ; Khamsouk, 2001).

Table 2 Mean runoff and erosion parameters and a few mean macro-aggregates obtained from plots in Ecuador and in Martinique.

	Runoff Plots	Slope %	Runoff parameters Crma %	Crmax %	Erosion parameters E t/ha/yr	MA content%
ECUADOR						
Bare Soils	Tw	20	18.6	63	87.2	X
	Mw	40	8.8	34	131.6	X
Traditional cereals	Tt	20	6.1	34	19.3	X
Crops	Mt	40	0.6	6.2	0.8	X
Soil conservation	Te	20	2.1	5.8	4.4	X
Crops measures	Me	40	0.1	2.4	0.4	X
MARTINIQUE						
Bare soils	Bs11	11	7	45	86	84
	Bs25	25	5	32	127.5	75
	Bs40	40	4	28	147.5	79
Mulched sugarcane	Sc11	11	0.5	6	0.1	X
	Sc25	25	0.5	8	0.1	X
	Sc40	40	0.5	26	0.2	X
Lasting banana	Ba9	9	3	26	0.4	X
Plantation	Ba11	11	2.5	24	0.5	X
Classical furrowed Pineapple	Pa7	7	11.5	51	17	78
Superficial tillage + Mulched strips pineapple	Pa9	9	0.5	7	0.1	X

"X" : not determined

4 Discussion

The results observed in the two volcanic countries are interesting because the comparison of their variable crops systems behaviours under runoff and erosion show good relationships. The main points in common are as follows:

- the slope effect on the runoff. The runoff decrease is found in the two countries such as the runoff plots studies on Africa soils (Roose, 1980 et 1994 ; Heusch, 1971 ; Roose, 1980) or in hortonian runoff processes (Poesen, 1984). Besides, Heusch (1971) suggests that in a homogeneous situation, runoff decrease on steep slope would be induced by a faster underground water infiltration under gravity attraction, which would lead to a faster soil wiping before soil porosity saturation. More recently, Govers (1990) proposes to explain the runoff decrease with slope growth by a differential superficial soil cracking on steep slopes. It is understood that on steep slopes, soil infiltration seems more active than on weak slopes and its would induce runoff decrease as noted on all the runoff plots ;

- the slope effect on the erosion. In contrast to the runoff decrease, the slope effect produces erosion increase. Indeed, when slope grows, the runoff energy increase despite of its water depth decrease and it could produce soil erosion. Despite of the great resistance maybe due to remarkable soil properties (high clay content, volcanic constituents), observed erosion is very strong and it increases with slope, on bare soils particularly. Therefore, when slope increases from 10 to 40%, erosion processes would change from sheet and rill erosion to rill and creep erosion (De Noni *et al.*, 1990, 2001). Some authors have established an exponential relationship between slope and soil loss (Roose, 1994 ; Lal, 1976). In the case of Ecuador, a linear relationship is found between these variables (De Noni *et al*., 2001) ;

- the no selective erosion process. The measured erosion is often characterised by a lot of coarse loss sediments (more than 75% of soil loss are due to macro-aggregates) and a no selective particle size distribution between soil "in situ" and eroded sediments. The weak suspended losses show that volcanic soil seems very resistant to aggregate breakdown and sealing processes under rainfall aggressiveness as expected their weak erodibility K index. This resistance is already noted through other studies such as the absence of sealing on soil surface (Roose *et al*., 1999) or the great water stable aggregate content under a structural stability test (Khamsouk *et al*., 1999). But erosion can be strong and no selective because runoff is able to take off aggregated topsoil as a whole and soil loss occurs by small aggregate flows ;

- the feasibility of soil conservation measures. The sheltering surface is a good and easy way for soil loss reduction in crop systems. Through the mulched treatments such as "lasting banana plantation", "mulched sugarcane" or "mulched pineapple", results show that runoff and erosion are weak. On the mulched sugarcane and pineapple treatments, the great sheltering surface content due to whole mulch and low leaf assures negligible runoff and erosion. Anyway, these treatments were only under erosion events when great and sudden hurricanes occurred. This behaviour looks like to the crop systems with whole sheltered grass's one (Roose, 1980—1994). For any crop system, the mulch organisation looks like to the great interest for the soil protection and in the same way, the chemical loss by runoff and erosion. (Lal, 1976 ; Roose, 1994 ; Rishirumuhirwa, 1997 ; Khamsouk, 2001).

The sheltering surface by mulched strips or low protected crop leafs can considerably reduce soil loss, especially when mulched strips can reduce runoff velocity and energy even on steep slope. Above 20% slope, it's seems necessary in the two countries to use contour lines strips to fight better against runoff energy and soil losses. The data obtained in Ecuador show that simple conservation system like contour ridging combined with grass strips or low earth walls, can reduce noticeably erosion (De Noni *et al*., 1996—2001).

5 Conclusion

In conclusion, new data obtained on cropped andosols in Martinique and Ecuador steeplands show that the effect of erosion can be strong on these soils. Generally, andosols are considered as well aggregated and very resistant to water erosion but when they are denuded by cropping, compacted by farming and desiccated by sun, erosion appears and the erosive risks become very important with the slope increase.

Our studies show that is possible to crop andosols steeplands if simple anti-erosive measures are used by farmers. First, to increase infiltration rate, soils must be covered by intensive cropping system including crop residues mulching. Secondly, to reduce runoff velocity and energy, grass strips and low dry stone walls can be managed each 10 to 20 meters depending of slope steepness and soil erodibility. These strips must be productive of forage, fire wood and poles for building to be acceptable for poor farmers. Using such simple measures suited to traditional conditions and accepted by the local farmers and despite of natural limitations of tropical mountains, this kind of approach should lead to conservation of soil properties, to increase soil fertility and to improve farmer's living standards.

References

Colmet-Daage F., Lagache P., 1965 – Caractéristiques de quelques groupes de sols dérivés de roches volcaniques aux Antilles françaises. Cah. ORSTOM sér. Pédol., **3**, 91-121.

De Noni, G., Viennot, M., & Trujillo, G., 1990 - Mesures de l'érosion dans les Andes de l'Equateur. Cah. ORSTOM, sér. Pédol., 25, 1-2 :183-196.

De Noni G. Et Viennot M., 1996 - Mutations récentes de l'agriculture équatorienne, conséquences sur la " durabilité " des agrosystèmes andins, Cah. ORSTOM, sér. Pédol. 23, 2 : 277-288.

De Noni G., Asseline J., Viennot M., 2000 - Erosion des sols volcaniques de la cordillère des Andes, en Equateur. Revue de Géographie Alpine (Revue internationale de l'arc alpin), 88 (2) : 13-26

De Noni G., Viennot M., Asseline J., Trujillo G., 2001. Terres d'altitude, terres de risque. La lutte contre l'érosion dans les Andes équatoriennes. IRD Editions, Paris, Collection Latitude 23, 224 p. (36 photos NB, 16 cartes).

Govers G., 1990 - A field study on topographical and topsoil effects on runoff generation. In : Geomorphology-Hydrology-Soils, Catena supplement, **18**, 91-111.

Heusch B., 1971 – Estimation et contrôle de l'érosion hydrique. Société des Sciences Naturelles et Physiques du Maroc, **37**, 41-54.

Hudson N.W., 1996 – Mesures de terrain de l'érosion et d'écoulement des eaux de surface. Bulletin pédologique de la FAO, Rome.

Khamsouk B., Roose E., DOREL M., BLANCHART E., 1999 - Effets des systèmes de culture bananière sur la stabilité structurale et l'érosion d'un sol brun rouille à halloysite en Martinique. Bulletin Réseau Erosion **19**, 206-215.

Khamsouk B., 2001 – Impact de la culture bananière sur l'environnement. Influence des systèmes de cultures bananières sur l'érosion, le bilan hydrique et les pertes en nutriments sur un sol volcanique en Martinique (cas du sol brun rouille à halloysite). Thèse Ecole Nationale Supérieure d'Agronomie de Montpellier, Montpellier.

Lal R., 1976 - Soil erosion problems on an alfisol in Western Nigeria. Effects of slope, crop rotation and residue management. Geoderma,**16**, 363-375.

Poesen J., 1984 - The influence of slope angle on infiltration rate and Hortonian overland flow volume. Zeitschriftfür Geomorphologie, **49**, 117-131.

Rishir Umuhirwa T., 1997 – Rôle du bananier dans le fonctionnement des exploitations agricoles dans les hauts plateaux de l'Afrique orientale (Application au cas de la région Kirimiro-Burundi). Thèse n° 1636 Ecole Polytechnique Fédérale de Lausanne, Lausanne..

Roose E., 1980 – Dynamique actuelle des sols ferrallitiques et ferrugineux tropicaux d'Afrique occidentale. Travaux et Documents ORSTOM 130, Paris.

Roose E., Arabi M., Brahamia K., Chebbani R., Mazour M., Morsli B., 1993 – Erosion en nappe et ruissellement en montagne méditerranéenne algérienne. Réduction des risques érosifs et infiltration de la production agricole pour la GCES. Synthèse des campagnes 1984-1995 sur un réseau de 50 parcelles d'érosion., Cah. ORSTOM sér. Pédol., **28**, 289-308.

Roose E., 1994 – Introduction à la Gestion Conservatoire de l'Eau, de la biomasse et de la fertilité des Sols (GCES). Bulletin Pédologique de la FAO n°70, Rome.

Roose E., Khamsouk B., Lassoudiere A., Dorel M., 1999 – Origine du ruissellement et de l'érosion sur sols bruns à halloysite de Martinique. Premières observations sous bananiers. Bulletin Réseau Erosion, **19**, 139-147.

Wischmeier W.H., Smith D.D., 1978 – Predicting rainfall erosion losses – A guide to conservation planning. United States Department of Agriculture. Agriculture Handbook, n°282.

Proceedings

12th International Soil Conservation

Organization Conference

May 26 – 31, 2002 Beijing, China

Sustainable Utilization of Global Soil and Water Resources

Process of Soil Erosion and Its Environment Effect

Volume II

Tsinghua University Press