Runoff and Erosion Risks Indicators on the Main Soils of the Mediterranean Mountains of Occidental Rif Area (Morocco)

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Abstract: In Mediterranean mountains of Morocco, erosion problems are varied and dangerous: sheet erosion (1 to 5 t/(ha • year), rill erosion (10 to 100 t/(ha • year), gully erosion (100 to 300 t/(ha • year), mass movements (up to 10000 t/(ha • year), and tillage erosion (1 to 60 t/(ha • year). Linear erosion being more important than sheet erosion on steep slopes, runoff energy is more important on the mountains than rainfall energy. Therefore, a simple irrigator was used to simulate 50-mm rainfalls at 75-90 mm/h on 1-m² microplots, in order to measure prepounding rainfall (Pi) and stable infiltration rate (If) on 64 plots representative of various soils and land uses, on 15 to 40% hillslopes.

Significant correlations (R = 0.70 to 0.95) were observed (i) between stable infiltration (If) and soil properties (topsoil organic matter and stable macro-aggregate contents, cohesion, bulk density), and chiefly (ii) between stable infiltration and soil surface status (% of surface covered by stones, litter and crusts). In contrast, there was no significant relation between infiltration rate, texture (topsoil sand, clay and clay + loam contents), initial soil moisture or resistance to shearing stress (scissometer), probably because the range of variations was too limited.

These data emphasise the possibility to evaluate runoff and erosion risk in mountains areas taking into account land use (forest and Pinus plantations, overgrazed bush land, i.e. matorral, cereals and cannabis), soils (If on sandy clay fersiallitic soils > If on loamy clay brown vertisols > If on sandy lithosols), slopes and indicators like prepounding rainfall, sealing crust, topsoil water-stable macro-aggregate content and compaction.

Keyword: Morocco, mountains, runoff and erosion risks, indicators, land use, soils, rainfall simulation

1 Introduction

In Mediterranean mountains of Morocco, erosion have been studied for more than 50 years. Because of demographic pressure, overgrazing and forest clearing, the vegetation cover is degraded and runoff increases, resulting in gullies, degradation of riverbed embankment, hillslope sliding and accelerated sedimentation in the reservoirs (within 30 years). Erosion processes are numerous and involve several levels : sheet erosion amounts to 1—5 t/(ha • year), rill erosion to 10—100 t/(ha • year), gully erosion to 100—300 t/(ha • year), mass movements up to 10^4 t/(ha • year), and tillage erosion to 1-60 t/(ha • year) (Roose, 1996). On steep hillslopes, linear erosion is much more dangerous than sheet erosion because runoff energy is greater than rainfall energy (Heusch, 1970). Many authors have spent time to study erosion processes and determine factors and parameters allowing a prediction of erosion risks in Mediterranean mountains. Heusch (1970) reported that river embankment degradation was more dangerous than sheet erosion on marl landscapes of the pre-Rif hills. Merzouk (1985) studied soil erodibility. Roose *et al.* (1993) demonstrated in Algeria that it was possible to increase crop production and reduce runoff and erosion risks simultaneously. Al Karkouri *et al.* (2000) found a good relation between runoff beginning, stable infiltration and topsoil stable macro-aggregate content. In Morocco, the Forest Administration worked on an ambitious program to predict soil losses on 14 watersheds, using the RUSLE model (Renard *et al.*, 1997). More than 100 runoff plots were built throughout Morocco to test various climate, vegetation cover, soil and slope conditions. But after 16 years, there was no clear conclusion. The present trend is to find indicators easy to measure and to define the behaviour of the environment in relation to runoff and erosion risks. Many authors have shown that soil structural stability is a relevant indicator, related to soil organic matter (SOM) content, infiltration capacity, and soil erodibility (Tisdall & Oades, 1982 ; Quirk & Murray, 1991 ; Le Bissonnais, 1996 ; Barthès *et al.*, 1999). Others have shown the relation between runoff and surface or topsoil properties such as bulk density, sealing crust, rocks and vegetation cover (Barnett & Rogers, 1966 ; Sabir *et al.*, 1998). The objective of our study was to understand the relationships between erosion processes and soil indicators of runoff and erosion risks easy to measure in the Mediterranean mountains of western Rif. We tried to demonstrate the role of land use, soil organic matter and stable macro-aggregation on soil infiltration capacity and erosion risks.

2 Material and methods

The study area is located between Tetouan and ChefChaouen cities, in the western part of the Rif mountains, in northern Morocco. The climate is Mediterranean sub-humid with 600 to 800-mm annual rainfall, mainly during the cool season. June, July and August are very hot and dry, but exceptional rainstorms may reach 120 mm/day every 20 years. The average R index (Wischmeier & Smith, 1978) is 50. The natural forest *(Quercus suber)* is very degraded and the matorral is generally overgrazed .Wheat is the main extensive crop but cannabis is progressing against the forest on acid rocks. Various *Pinus radiata, P. alepensis* or Eucalyptus are planted by foresters on steep slopes (15 up to 60%). The most frequent soils are lithosols. Farmers distinguish between five soil types in relation to land use: “Ferrich” are eroded lithosols, “Ahmer” are red sandy clay fersiallitic soils, “Toiresse” are young clay vertisols, ”Rmel” are brown sandy fersiallitic soils, and “Adouka” are clay marl lithosols.

The study comprised two stages: first a quick inquiry was conducted with farmers, in order to define the farming systems and the erosion problems at the village territory scale; second, rainfall simulations were carried out on each soil type and main land uses.

A simple rainfall simulator was developed, producing 50-mm irrigation at a 75- to 90-mm/hr intensity on a 1-m² microplot (Roose, 1996b); such rainstorm occurs once every 20 years. The simulations were carried out on various land uses (quercus natural forest, 40-year old *Pinus radiata* plantation, overgrazed matorral, agroforestry systems, traditional ploughed wheat crop, and *Cannabis esculenta* with mineral and organic manure). The following parameters were measured or observed: bulk density (da in g/cm^3), resistance to penetration (PEN in kg/cm²), resistance to shearing stress (SS in kg/cm²), soil organic matter (SOM in %), texture (clay, silt, sand, in %), water-stable macro-aggregates > 0.2 mm (MA in %; Kemper & Rosenau, 1986), soil surface features such as covering by litter, weeds and stones (SC in %), on one hand, or compacted, sealing or sedimentation crusts (SF in %), on the other hand, topsoil moisture content before and after rainfall simulation (Hp in %)(Roose, 1996).

3 Results

The data are summarised on Tables 1 to 6. They indicate that land use had a strong influence on topsoil organic matter and water-stable macro-aggregate contents, on proportion of soil surface covered by crust, on prepounding rainfall (Pi) and on final infiltration capacity (If). Natural forests, pine plantations and agroforestry systems had greater topsoil SOM, aggregate stability and infiltration rate than ploughed cereal and cannabis crops. Bulk density and resistance to penetration were high under overgrazed matorral, due to goats and cows trampling (Sabir *et al.*, 1998). Changes in land use resulted in changes in topsoil physical status, hence in hydrological behaviours: prepounding rainfall, infiltration capacity, and thus resistance to erosion, were greater under forest than under overgrazed matorral and tilled fields. After deforestation, successive cultural practices reduced structural stability and amounts of suspended sediments, and changed hydrological properties: linear erosion increased by increasing runoff energy.

Table 1 Effects of land use on the properties of a young eroded lithosol “Ferrich”

Land use	SOM %	s	MA %	s	SO %	s	CV %	s	PEN	s	If	s	Pi mm	s
Forest	5c	0.6			81.3a	21.9	83.3a	8.3	1.3a	0.2	66.4d	5.9	4.8c	0.7
Matorral	3.5b	0.6			37.3b	21.7	45.3cb	8.3	1.6b	0.2	25.1a	5.9	3.1a	0.7
Agroforestry	1.3a	0.7	15.6a	2.2	75.5a	26.8	62.0ba	9.2	1.1a	0.2	56.2c	7.3	3.1a	0.9
Cereals	1.2a	0.5	46.7b	3.1	56.0ab	18.9	59.8ba	7.2	1.2a	0.1	38.1b	5.1	3.9b	0.6
Cannabis	1.8a	0.6			32.3b	11.3	32.3c	8.3	1.6b	0.1	14.7a	5.9	3.9b	0.6

Table 2 Effects of land use on the properties of a young fersiallitic soil “Ahmer”

Land use	SOM %	s	MA %	s	SO %	s	CV %	s	PEN	s	If	s	Pi mm	s
Matorral	2.7a	0.4	35.4a	1.4	63.6a	16.9	73.2a	5.2	1.7a	0.1	41.3a	3.4	3.4a	0.6
Agroforestry	0.9b	0.9	21.0b	3.1	32.0b	17.9	-	-	1.1b	0.3	56.5a	4	4a	1.2
Cereals	1.9b	0.5	21.0b	1.3	60.1a	15.5	50.2b	4.7	1.4b	0.1	41.6A	1.8	1.8b	0.5
Cannabis	1.4b	0.6	27.7c	1.8	37.2b	11.9	28.0c	6.6	1.7a	0.2	20.4b	3	3ab	0.7
Reafforestation	3.9a	0.6	48.5d	1.8	79.3a	21.9	81.0a	6.4	1.2b	0.2	61.0c	4.1	4.1a	0.7

Table 3 Effects of land use on the properties of a young vertisol “Toiresse”

Land use	SOM %	s	MA %	s	SO %	s	CV %	s	PEN	s	If	s	Pi mm	s
Agroforestry	3.6a	0.5	42.7a	3.1	79.8a	13.8	68.3a	3.4	1.1a	0.2	51.3a	5.1	4.1a	0.6
Cereals	3.9a	0.5	40.5a	4.3	81.5a	15.6	64.3a	3.5	1.3a	0.2	46.3a	5.4	3.1a	0.8
Cannabis	3.2a	0.6			64.0a	21.9	29.7b	4.0	1.3a	0.2	43.2a	4.9	3.3a	0.7

Table 4 Effects of land use on the properties of a brown vertisol “Toiresse”

Land use	SOM %	s	MA %	s	SO %	s	CV %	s	PEN	s	If	s	Pi mm	s
Forest														
Matorral	3.5a	0.6			27.7a	21.9	36.7b	2.4	1.6a	0.2	18.3a	5.9	1a	0.5
Agroforestry	3.4a	0.6			72.0b	21.9	64.0a	3.4	1.3a	0.2	58.1c	5.7	5.1b	0.6
Cereals	3.0a	0.5			63.0b	19.2	56.3a	2.9	1.4a	0.2	45.4b	4.6	5b	0.7
Cannabis	1.7b	0.6			65.0b	25.4	16.7c	2.2	1.4a	0.2	47.0b	6.3	5b	07

Table 5 Effects of land use on the properties of a brown fersiallitic soil “Rmel”

Land use	SOM %	s	MA %		SO %	s	CV %	s	PEN	s	If	s	Pi mm	s
Forest	4.4b	0.6			88.0b	14	82.3a	7.4	1.1a	0.2	61.1a	5.9	4.0ab	0.7
Matorral	2.0a	0.7	41.3a	2.2	37.4a	12	83.0a	9.1	3.8c	0.2	33.5a	7.3	2.2a	0.9
Agroforestry	4.6b	0.6			75.3b	16	70.3ab	7.4	1.1a	0.2	49.2ab	5.9	4.7b	0.7
Cereals	2.0a	0.4	11.2b	1.8	61.2c	11	60.2b	5.2	1.5b	0.1	38.8a	4.2	3.3ab	0.5
Cannabis	2.3a	0.6			66.7c	18	57.0b	7.3	1.3ab	0.2	38.1a	5.9	2.5ab	0.7
Reafforestation	4.8b	0.5			80.7b	25	76.7ab	7.5	1.1a	0.2	52.0ab	5.5	4.5b	0.7

Table 6 Effects of land use on surface features and topsoils properties in the Mediterranean mountains of the occidental Rif, Morocco

Land use	SOM %	s	MA %	s	SO %	s	CV %	s	PEN	s	If	s	Pi mm	s
Forest	4.7d	0.5			84.7a	17.9	82.8a	7.1	1.2ab	0.1	63.7c	4.8	4.3bc	0.6
Matorral	2.9ab	0.3	37.1bc	3.6	32.7c	12.2	59.8	9.6	2.0c	0.4	31.1a	3.3	2.4a	0.4
Agroforestry	3.2bc	0.3	23.7a	4.8	72.7a	12.4	66.3ab	5.8	1.1a	0.1	53.5c	3.3	4.3c	0.4
Cereals	2.3a	0.4	22.7a	2.9	63.7ab	9.1	57.7b	7.5	1.4ab	0.4	41.6b	2.5	3.2ab	0.3
Cannabis	2.1a	0.3	27.7ab	5.5	53.0b	11.3	32.7c	9.3	1.5b	0.2	32.7a	3.0	3.8bc	0.4
Re-afforestation	4.4cd	0.5	48.5c	5.5	80.0a	17.3	78.8a	5.7	1.2ab	0.1	56.5c	4.8	4.3bc	0.6

4 Discussion

Regressions between soil hydrologic properties (final infiltration capacity, prepounding rainfall) and topsoil properties (SOM content, water-stable aggregation, bulk density, resistance to penetration, soil moisture) or surface features (sealed or covered surfaces) indicated that soil hydrologic behaviour was determined by surface features (Table 7). Stable infiltration capacity was strongly correlated with SOM content and surface features but not significantly with texture, initial moisture nor resistance to shearing stress, probably because the range of variations was too limited. Prepounding rainfall was well correlated with compaction, sealing crust and topsoil organic matter content, which was correlated to macro-aggregate stability.

Table 7 Relationships between soil hydrodynamic properties and soil surface features

Lithosol “Ferrich”		Young fersiallitic “Ahmer”	
If = - 8.47 + 0.86 SO	R = 0.97	If = -0.83 + 0.73 SO	R = 0.77
If = -16.61 + 0.98 CV	R = 0.95	If = 177.17 – 102.68 da	R = -0.92
If = 144.78 – 78.10 da	R = -0.73	If = 90.49 – 32.50 PEN	R = -0.75
If = 124.40 – 62.90 PEN	R =-0.84	MA = 17.26 + 5.87 SOM	R = 0.77
Young vertisol “Toiresse”		Brown fersiallitic “Rmel”	
If = -1.23 + 0.76 SO	R = 0.96	If = 57.22 – 8.01 PEN	R = - 0.66
If = 179.27 – 97.21 PEN	R = -0.96	If = 30.58 + 4.51 SOM	R = 0.69
Pi = -1.27 + 0.08 SO	R = 0.85	Pi = 1.72 + 0.57 SOM	R = 0.69
Pi = 16.74 – 9.62 PEN	R = -0.82	MA = 8.13 + 12.52 SOM	R = 0.72
Pi = -1.39 + 1.35 SOM	R = 0.81		

For the whole topsoil tested, the final infiltration capacity is trongly correlated to the open surface without crust (SO), the surface covered by litter and stones and by bulk density (see figure 1). Generally, the stable macroaggregate was well correlated to topsoil organic matter (Fig 2)

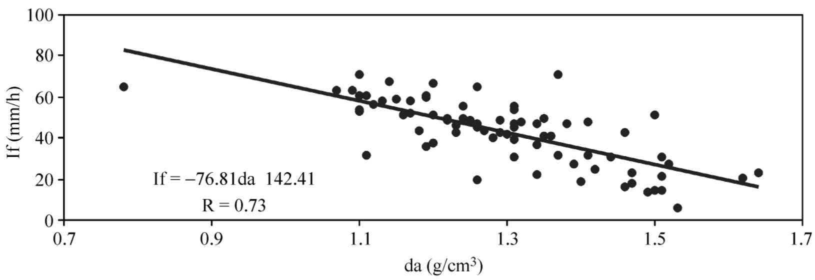

Fig. 1 Relationship between final infiltration rate (If) and bulk density of the top 10 cm

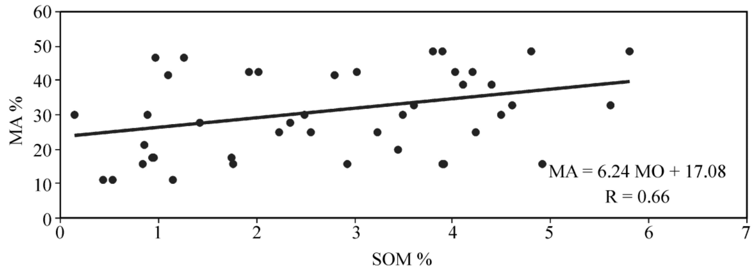

Fig. 2 Relation ship between structural stability (MA) and organic matter content (SOM) of topsoil

5 Conclusions

In the monitions, because of steep slopes, erosion risk is mainly depending on runoff energy. We thus studied the hydraulic properties of five representative soil types of the western Rif under several land uses (forest, matorral, cereals), using a simple irrigator simulating 50-mm rainfalls at high intensity (about 80 mm/hr). Our results indicated that deforestation, overgrazing and successive tillages reduced drastically SOM and water-stable macro-aggregate contents, as well as the infiltration capacity. In the same way, these degradations had significant effects on surface or topsoil features such as proportion of covered surface, sealing crust, compaction, and bulk density. Bulk density, prepounding rainfall, topsoil SOM and stable macro-aggregate contents may be considered as relevant indicators of infiltration capacities (runoff risk) and soil erodibility (erosion risk).

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