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ORIGINAL PAPER

Effects of land use and cover type on the risks of runoff and water erosion: infiltration tests in the Ourika watershed (High Atlas, Morocco)

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Abstract
The upstream section of the Ourika watershed is located in the northwest slopes of the High Atlas Mountains of Morocco. It is characterized by rugged topography and sparse vegetation, and is under increasing human-induced pressures, exacerbated by climate variability and change. Its vulnerability to water erosion is high and, thus, wadi flows with significant solid loads are a constant risk. Infiltration measures through rain simulations, using a simple irrigator ramp, were carried out as part of an investigation to highlight the role of vegetation cover in mitigating soil erosion in the watershed. The methodology assessed the effect of land use and cover type on the soil surface state and properties on 1-m^2 plots. Seventeen experimental sites were considered with reference to both land use and plant cover, with three test plots per site, making it a total of 51 test plots for the rainfall simulations. Soil samples were collected at different depths from each site to determine soil properties. Results obtained show that dense forests protect the soil, produce organic matter improving soil aggregation, and hence ensuring adequate infiltration. In woodlands, bare soil is susceptible to crusting, runoff, and water erosion. In overgrazed scrublands, soil compaction due to animal trampling, induces significant runoff. Croplands are poor in organic matter and are consequently very susceptible to crusting, losing infiltration capability. Infiltration was positively correlated with initial abstraction ($R = 0.71$), covered and non-crusted soil surfaces ($R = 0.84$ and $R = 0.83$, respectively), organic matter content ($R = 0.62$) and aggregate soil stability ($R = 0.69$). By contrast, it was negatively correlated with soil detachability ($R = -0.65$), penetration resistance ($R = -0.81$), and shear strength ($R = -0.64$). However, a weak correlation between infiltration and either of bulk density, total porosity, or texture was observed. Findings showed that total infiltration was not correlated with the physical parameters of the soil but rather with the surface state of soils. Covered surface greatly decreased runoff and soil erosion by increasing the surface roughness and decreasing the runoff velocity in the study zone.

Keywords Land use · Vegetation cover · Soil surface state and properties · Water erosion · Rainfall simulations · Ourika watershed · Morocco

Introduction

Land degradation has been gaining momentum, globally, on more than 20% of cultivated lands, 30% of forested areas, and 10% of meadows (Bai et al. 2008). The main culprit has been water erosion, with over 56% of the degradation directly linked to it (Pimentel et al. 1995; Nanna 1996; Flanagan 2002). Water erosion exacerbates the loss of land productivity (Elirehema 2001), thus negatively affecting both agricultural and forest productivity, water quality, and infrastructure (Vrieling 2006). Several studies have highlighted the effects of plant cover in mitigating soil erosion, showing that it is the most important factor in reducing soil erosion (Alejandro and Kenji 2007). Additionally, they have shown

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that soil erosion is more influenced by land use than other environmental features at both plot and watershed scales (Valentin et al. 2008). In the Mediterranean regions, soil remains a fragile component of ecosystems and, if exposed to high and intense rainfall, becomes susceptible to erosion, which is aggravated by hilly or mountainous topography associated with low plant cover (Albergel et al. 2010).

In Morocco, soil erosion has been increasing annually. Indeed, in recent decades, the countryside has undergone considerable changes, with specific degradation varying from region to region and ranging from 5 to 20 t/ha/year (Ghanam 2003). In addition, water reservoirs such as dams have been associated with the accumulation of sediments, which results in an annual loss of storage capacity equivalent to 75 million m^3. This corresponds to an irrigation potential of around 5–6000 ha/year (Sabir et al. 2007).

Rainfall simulations have being used since the 1930s to study soil erosion and soil hydrology (Martínez-Murillo et al. 2013). Indeed, they have been successful in hydrology and many other disciplines. During the course of the last 80 years, more than 100 rainfall simulators with plot areas of less than 5 m^2 have been developed (Iserloh et al. 2010). Rainfall simulation contributes to the knowledge of water erosion processes under different environmental situations (Torri et al. 2012). It allows for the exploration of processes which are difficult to detect in natural context during rainfall events (Yair et al. 2013).

The Ourika watershed, located northwest of the High Atlas, is characterized by rugged topography, friable substrates, harsh and brutal climate, sparse vegetation, and an increase in human activity, which render it particularly vulnerable to soil erosion (Meliho et al. 2016a, b, c). A loss of forest cover or density, and any changes in land uses may induce modifications in the quality and quantity of soil organic matter (Riezebos and Loerts 1998; Kocyigit and Demirci 2012). Other soil properties are equally altered (Wang et al. 2011; Tesfahunegn 2013). Indeed, land-use change influences water infiltration (Lal 1988).

Land use, particularly the surface state of the soil (covered soil surface, non-crusted soil surface, penetration resistance, shear strength, and surface roughness) is a significant factor affecting soil erosion by water effect. Thus, variations in soil physical properties (bulk density, total porosity, humidity, and texture) and chemical properties (organic matter content, structural stability of aggregates) may be responsible for the risks of runoff and soil erosion in the upstream section of the Ourika watershed.

This study deals with the effects of different land uses on soil infiltration capacity depending on both physical and chemical parameters, and their interactions in order to identify the main factor of runoff and water erosion risks in the Ourika watershed. To assess erosion risk indicators, rainfall simulations offer an interesting alternative and involve the application of infiltration tests on 1 m^2 plots with the help of a simple irrigator ramp (Roose and Smolikowski 1997).

Materials and methods

Study area

The upstream section of the Ourika watershed, covering an area of 576 km^2 and located in the High Atlas region of Marrakech, is a sub-watershed of the larger Tensift basin (Fig. 1). The average altitude of the watershed is 2500 m with a predominance of altitudes (75%) ranging from 1600 and 3200 m. Its slopes are generally steep, intensifying runoff and erosion (Meliho et al. 2016a, b, c). Geologically, two types of facies characterize the watershed: a hard bedrock (igneous or metamorphic rock) located upstream and a soft to moderately soft substrate of Permo-Triassic and Quaternary deposits located at lower altitudes. Its climate is characterized by high spatial and temporal variability. Annual rainfall averages 500 mm, increasing with altitude, with about 400 mm/year in the foothills while exceeding 700 mm/year in the highest peaks. Ourika watershed shelters a remarkable diversity of forest and pre-forest ecosystems characterized mainly by the holm oak, cedar, juniper, as well as oleo-mastic species.

Experimental design

Land-use types in the Ourika watershed were grouped into six classes (croplands, woodlands, moderately dense forests, dense forests, scrubland, and bare non-forest lands). The choice of the experimental sites was solely based on Ourika watershed's substrates and land uses, as there are no pedological maps available for the region. Superposition of the watershed land use (Meliho et al. 2016b) and substrate maps was used to identify homogeneous units (experimental sites) from which the experiment tests were carried out.

Seventeen stations were chosen based on both land use and the nature of the underlying substrate (Fig. 2). For each station, three replicates were performed, giving 51 rain simulation tests. Indeed, 15 repetitions were carried out in croplands (cereals, fallow, arboriculture), nine in woodlands, nine in moderately dense forests, six in dense forests, nine in scrublands, and three in bare non-forest lands (thorny xerophytes).

Consolidation of land use into six classes, irrespective of substrate and slope, was a result of substrate and slope not significantly influencing infiltration, initial abstraction or runoff coefficient at the chosen 5% significance level. However, substrate had a significant effect on soil detachability.

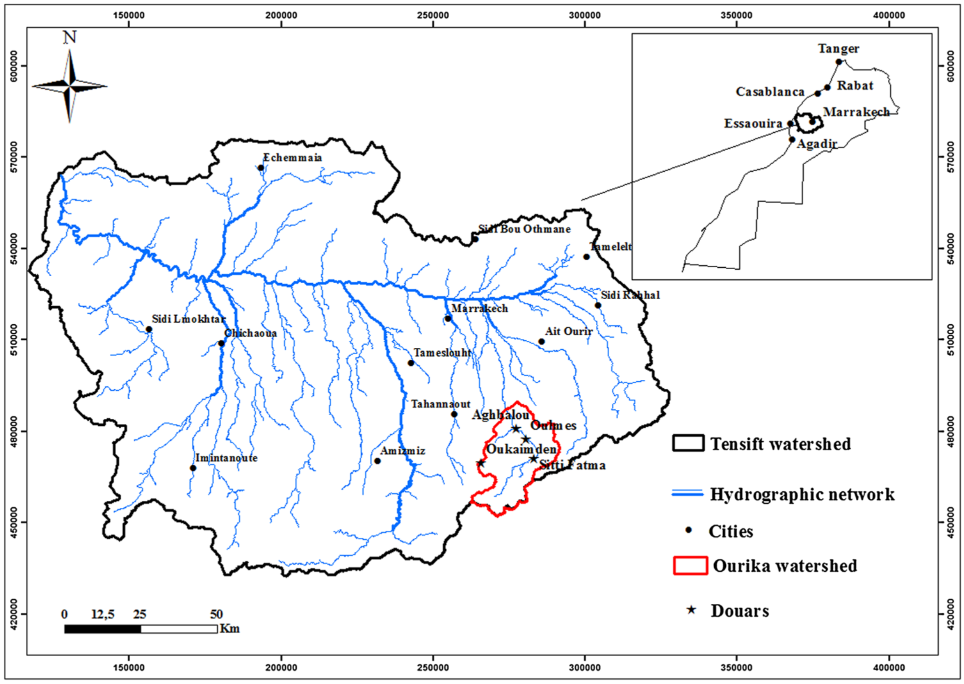

Fig. 1 Location of the Ourika watershed

Description of soil surface state

Measurement of soil surface state was effected using the quadrat method (Roose 1996). Covered soil surface (SC%) included litter, vegetation, and pebbles not integrated into the soil mass whereas non-crusted soil surface (SO%) were largely made up of cracks and clods forming traps that facilitate infiltration. After setting up the diagonals of each plot, a pencil was allowed to descend systematically, without aiming, at regular intervals every 2 cm along the line. At the point of contact with the ground, the surface state observed was noted. It is from these readings that the proportion of each surface state was calculated. The formulae are as follows:

- % of bare soil surface = (number of points with bare land)/(total number of points along the two diagonals),
- % of covered soil surface = 100% − % of bare soil surface,
- % of non-crusted soil surface = (number of points where the soil is not crusted)/(total number of points observed along the two diagonals),
- % of crusted soil surface = 100% − % non-crusted soil surface.

Penetration resistance (PEN) and shear strength (SS) were measured using a pocket penetrometer and a scissometer, respectively. Ten measurements were realized for each plot. Penetration resistance (kg/cm^2) provides information on soil compaction while shear strength (kg/cm^2) gives an idea of the force used by water to detach aggregates from the soil.

Employing the chain method (Roose 1996), soil surface roughness index (*R* %) was determined. It corresponds to the difference between the expanded chain length and the plot width, divided by the plot width. Three repetitions were done for this parameter.

Rainfall simulations

Rainfall simulation is one of several methods used to study soil hydrodynamics (Roose and Smolikowski 1997; Roose 1996). Installation of the rainfall simulator consisted of placing two 1.66-m-long metallic rods in the direction of the slope (Fig. 3). A parallel orientation of the two side rods of the equipment's frame, with a width of 0.6 m separating them, was maintained. These rods were driven 5 cm below the ground using a hammer to prevent lateral losses of water. A triangular metal platform was then placed downstream to ensure that the dripping water together with the sediments would be directed towards the receptacle.

The equipment was installed on a 50-cm-wide watering ramp connected by a hose to a tank filled with water holding up to 60 l. This was located a few meters above the upstream section of the plot (Fig. 3). The intensity of the simulated rain was maintained at an average of about 80 mm/h by a valve located at the tank's outlet.

Using the rainfall simulator, a simple manual irrigator, allowed drops with relatively low energy to be projected onto a surface of 1 m^2 (Roose 1996). Watering commenced at an average height of 50 cm above the surface with a regular distribution all over the plot. The moment in which runoff is observed is noted, since it allows for the determination

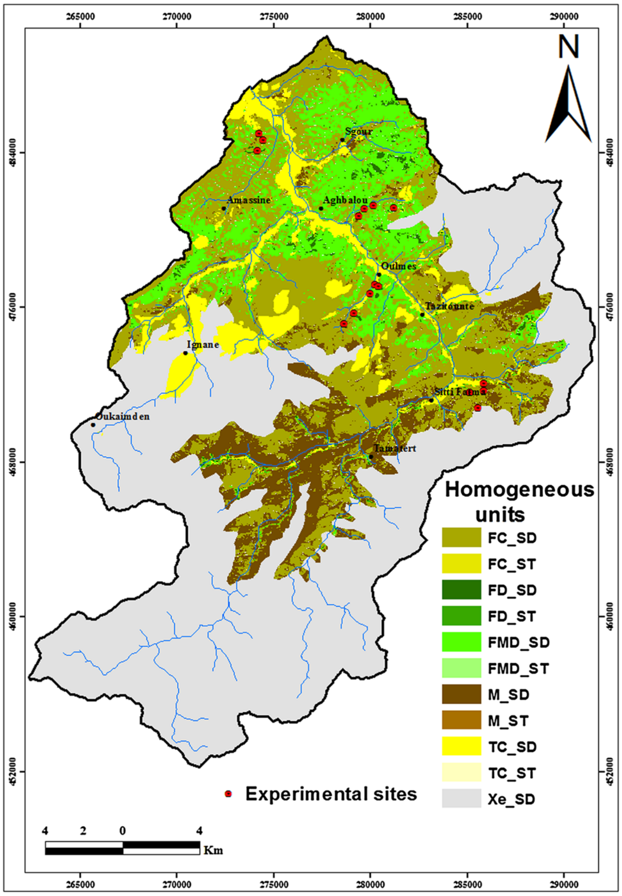

Fig. 2 Homogeneous units and experimental sites in Ourika basin. *FC* woodland, *FD* dense forest, *FMD* moderately dense forest, *M* scrubland, *TC* cropland field, *Xe* thorny xerophytes or bare non-forest land, *SD* hard substrate (pink granite, andesite, migmatite), *ST* soft substrate (red sandstone, red marl, flysch shale, and sandstone)

of initial abstraction (Pi in mm), which simply translates to the height of water infiltrated before the occurrence of runoff.

The quantity of water from runoff, measured every 5 min at the lower end of the plot, allowed for measurement of both runoff and infiltration. Moreover, its collection enabled the determination of overall solid load in grams per liter for the period of the experiment.

Soil sampling

Soil samples from each site were used for the determination of structural stability, particle size distribution, and organic matter content. Others were taken at various depths (0–10, 10–20, and 20–30 cm), using a 10-cm-long cylinder with a diameter of 4 cm, to determine bulk density (BD), total porosity (*P* %), humidity (*H* %), and soil detachability (*D*). Measures were taken to protect the samples from external heat before transporting them to the laboratory for analysis. Particle size distribution was determined using Meriaux's densimeter (Meriaux 1954), aggregate stability by Le Bissonnais and Le Souder method (Le Bissonnais and Le Souder 1995) whereas organic matter content was estimated by employing the Walkley–Black method (Walkley and Black 1934).

Statistical tests

One-way analysis of variance was used to determine the differences in effects of land use on soil physical parameters, soil-surface state parameters, and soil hydrological parameters. The soil-surface state parameters examined were both covered and non-crusted soil surfaces, penetration resistance, shear strength, and surface roughness. The hydrological parameters considered were total infiltration, initial abstraction, run-off coefficient, and soil detachability. The relationships between the different soil parameters were determined through Pearson correlation test. All the tests were carried out using SPSS software.

Results

The results of soil particle distribution, obtained by Meriaux's densimetric method, are presented in Table 1. They show that the soil texture was loamy and sandy loam under cropland, sandy loam under woodland, loam and sandy loam under moderately dense forest, loamy fine sand under dense forest, sandy loam in scrubland, and fine sand under bare non-forest land.

Effects of land use on soil physical parameters

Under all land uses, bulk density increased with depth as total porosity decreased (Tables 2 and 3). Compaction, regardless of depth, was pronounced under bare non-forest land, scrubland and woodland, moderate under cropland and low in moderately dense and dense forests.

Values obtained for both bulk density and porosity at 10 cm of depth (Tables 2 and 3) varied significantly at the 5% significance level between dense forests and bare non-forest lands. At 20 cm, there were significant variations in bulk density between croplands and bare non-forest lands. A similar trend was observed for low-density forests and bare non-forest lands. Additionally, in the bare non-forest lands, the parent rock is encountered at 30-cm depth. As for total porosity, there was a significant variation observed between dense and moderately dense forests, and scrubland.

Soil samples were collected in March 2016. This was during spring, a period characterized by relatively humid soil, and thus could explain the relatively high moisture content values. Indeed, moisture content values generally

Fig. 3 Rainfall simulator

Table 1 Soil texture according to USDA classification for the study sites

Land use	Stations	Clay (%)	Silt (%)	Sand (%)	Texture
Cropland	S1	5	76	19	Silt loam
	S2	12	40	48	Loam
	S3	10	28	62	Sandy loam
	S4	12	29	59	Sandy loam
	S5	7	12	81	Loamy fine sand
Woodland	S6	10	32	58	Sandy loam
	S7	15	0	85	Sandy loam
	S8	14	13	73	Sandy loam
Moderately dense forest	S9	18	33	49	Loam
	S10	11	21	68	Sandy loam
	S11	22	16	62	Sandy clay loam
Dense forest	S12	7	10	83	Loamy fine sand
	S13	9	6	85	Loamy fine sand
Scrubland	S14	13	34	53	Sandy loam
	S15	15	14	70	Sandy loam
	S16	14	5	81	Sandy loam
Bare non-forest land	S17	5	7	89	Fine sand

are a function of the sampling period. They are high in both winter and spring, when rain is at its most abundant, in the Ourika watershed.

For this period, during which the samples were collected, moisture increased with depth in all land uses (Table 4). At a depth of 10 cm, there was a significant difference in moisture, at the 5% significance level, between dense forest and bare non-forest land. However, no significant differences were observed at 20 cm, while at 30 cm a significant difference was noted between dense forest and scrubland. Additionally, no significant difference in soil moisture was observed between moderately dense forest, woodland, cropland, and scrubland. The zero value of humidity obtained at 0–10 cm was not normal because the residual soil water content is about 5% for sandy soil. This abnormal value may be explained by the stoniness of the sample or/and a problem in the preservation of the sample in the plastic bag.

Table 2 Effect of land use on bulk density as a function of soil depth in the Ourika watershed

Land use	BD_{10} (g/cm^3)		BD_{20} (g/cm^3)		BD_{30} (g/cm^3)	
	m	SD	*m*	SD	*m*	SD
Cropland	1.44a	0.17	1.47ac	0.13	1.60a	0.21
Woodland	1.47a	0.10	1.52a	0.09	1.55a	0.17
Moderately dense forest	1.35a	0.26	1.36ac	0.17	1.36ab	0.19
Dense forest	1.26ab	0.44	1.30ac	0.40	138ab	0.33
Scrubland	1.53a	0.21	1.65abc	0.21	1.78ac	0.16
Bare non-forest land	1.78ac	0.26	1.96ab	0.01	–	–

Means followed by the same letter do not significantly differ from each other ($P < 0.05$)

BD10 bulk density between 0 and 10 cm, *BD20* bulk density between 10 and 20 cm, BD30 bulk density between 20 and 30 cm, *m* mean, *SD* standard deviation

Table 3 Effect of land use on porosity as a function of soil depth in the Ourika watershed

Land use	P_{10} (%)		P_{20} (%)		P_{30} (%)	
	m	SD	*m*	SD	*m*	SD
Cropland	45.76a	6.42	44.65ac	4.98	39.59a	7.81
Woodland	44.64a	3.70	42.64a	3.26	41.61a	6.49
Moderately dense forest	49.21a	9.74	48.65ac	6.39	48.64ab	7.24
Dense forest	52.39ab	16.48	50.89ac	15.18	47.87ab	12.49
Scrubland	42.15a	7.91	37.59abc	7.88	32.81ac	6.10
Bare non-forest land	32.89ac	9.83	26.43ab	0.54	–	–

Means followed by the same letter do not significantly differ from each other ($P < 0.05$)

P_{10} porosity at 0–10 cm, P_{20} porosity between 10 and 20 cm, P_{30} porosity between 20 and 30 cm, *m* mean, *SD* standard deviation

Table 4 Effect of land use on moisture as a function of soil depth in the Ourika watershed

Land use	H_{10} (%)		H_{20} (%)		H_{30} (%)	
	m	SD	*m*	SD	*m*	SD
Cropland	22.33a	13.44	29.67a	12.09	37.53a	15.01
Woodland	16.78ab	8.67	28.44a	10.55	34.22a	8.06
Moderately dense forest	20.78ab	7.61	29.22a	4.99	36.78a	5.91
Dense forest	30.83a	8.21	38.67a	13.63	49.00ab	15.58
Scrubland	16.22ab	13.53	28.00a	14.81	29.75ac	13.80
Bare non-forest land	0.00b	0.00	11.50a	0.71	–	–

Means followed by the same letter do not significantly differ from each other ($P < 0.05$)

H_{10} humidity at 0–10 cm, H_{20} humidity at 10–20 cm, H_{30} humidity at 20–30 cm, *m* mean, *SD* standard deviation

Effects of land use on soil surface state

Surface state relates to covered soil surface (SC%), non-crusted soil surface (SO%), penetration resistance (PEN%), shear strength (SS%), and the surface roughness index (*R*%).

The highest proportions of covered soil surface were observed in both dense and moderately dense forests (78.33 and 96%, respectively). In both cropland and scrubland, surface cover was moderate (59 and 52.22%, respectively) whereas both bare non-forest land and woodland registered low values (38.33 and 44.44%, respectively) (Table 5). Plant cover in both dense and moderately dense forests was significantly higher than in scrubland, cropland, woodland, and bare non-forest land, at the chosen 5% significance level.

Non-crusted surface proportions were generally low under most of the land uses characterizing the watershed. The highest values were observed under dense forests (41.67%) and cropland (20.60%) while lower proportions were observed in moderately dense forest (13.44%), bare non-forest land (3.67%), scrubland (2.89%) and woodland (2%). Moreover, the non-crusted soil surface proportion observed under dense forest, at a 5% significance level,

Table 5 Effect of land use on the covered and non-crusted soil surfaces in the Ourika watershed

Land use	SC%		SO%	
	m	SD	*m*	SD
Cropland	59.00a	18.15	20.60a	9.13
Woodland	44.44bc	7.07	2.00bc	1.12
Moderately dense forest	78.33bd	7.07	13.44ab	1.94
Dense forest	96.00bd	1.55	41.67bd	6.83
Scrubland	52.22abc	7.55	2.89bc	1.76
Bare non-forest land	38.33abc	2.89	3.67b	1.53

Means followed by the same letter do not significantly differ from each other ($P < 0.05$)

SC% covered soil surface, *SO%* non-crusted soil surface, *m* mean, *SD* standard deviation

was significantly higher than the rates observed at other land uses. The values observed under cropland, at a 5% significance level, were higher than those observed under other land uses. They were equally higher than values observed under moderately dense forests, however, not statistically significant.

Both penetration resistance and shear strength were greater under scrubland (3.04 and 1.77 kg/cm^2, respectively) than at other land uses (Table 6). The values observed for the former under scrubland were higher than those observed under other land uses, with the exception of woodland, at a 5% significance level. As for shear strength, the observed values under scrubland were similarly greater than those observed under other land uses, but with the exception of both woodland and cropland. The highest values for surface roughness were observed under both forests (4.86% in dense forest, 3.97 in moderately dense forest) and cropland (3.42%). Additionally, there was a significant difference in surface roughness between dense forest and the other land uses, with the exception of moderately dense forest and cropland.

Effect of land uses on hydrological parameters

The hydrological properties considered were final infiltration If (mm/h), initial abstraction Pi (mm), runoff coefficient Kr (%), and soil detachability D (g/m^2/h). Data for final infiltration, measured by rainfall simulation, showed three distinct homogeneous groups. Final infiltration was very high in dense forest (all simulated rain was infiltrated, 80 mm/h), high in both moderately dense forest and cropland (64.14 and 63.73 mm/h, respectively), and low in bare non-forest land, scrubland and woodland (50.62, 44.69, and 36.17 mm/h, respectively) (Table 7 and Fig. 4).

There was a significant difference in infiltration between dense forest and all other land uses. Indeed, infiltration was highest in the forest, increasing with the density of the canopy. The runoff coefficient, on the other hand, was null under dense forest (Table 7), low in moderately dense forest (10.99%), and high in other land uses (50.16% in woodlands).

Initial abstraction (Table 7) was very high in dense forest (80.00 mm). In dense forest, the absence of runoff implied it being equal to the height of the simulated rain. Indeed, the entire volume of water from the simulation was infiltrated during the experiment.

Detachability was absent in dense forest, owing to the absence of runoff. However, it was low in moderately dense forest (5.73 g/m^2/h), high in cropland (19.12 g/m^2/h), woodland (30.25 g/m^2/h), and scrubland (42.55 g/m^2/h), and very high in bare non-forest land (61.93 g/m^2/h).

Effect of land use on the organic matter content, soil structural stability, and the relationship between them

Organic matter content was high in the forest (11.81%) compared to other land uses (lower than 6%). Indeed, the forest floor was covered by a surface litter, rich in organic matter and had stable macro-aggregates [mean weight diameter (MWD = 2.3 mm)] compared to scrubland

Table 6 Effect of land use on soil surface parameters in the Ourika watershed

Land use	PEN (kg/cm^2)		SS (kg/cm^2)		*R%*	
	m	SD	*m*	SD	*m*	SD
Cropland	1.29a	0.46	1.20abc	0.31	3.42ab	1.42
Woodland	2.62b	0.64	1.50ab	0.40	2.80a	0.80
Moderately dense forest	1.23a	0.81	0.94ac	0.42	3.97ab	1.07
Dense forest	0.21a	0.14	0.35acd	0.11	4.86b	1.18
Scrubland	3.04b	1.93	1.77ab	1.17	2.96a	0.81
Bare non-forest land	0.85a	0.05	0.23ac	0.03	2.36a	0.14

Means followed by the same letter do not significantly differ from each other ($P < 0.05$)

PEN penetration resistance of the soil surface (kg/cm^2), *SS* shear strength of the soil surface (kg/cm^2), *R%* surface roughness, *m* mean, *SD* standard deviation

Table 7 Effect of land use on soil hydrological parameters in the Ourika watershed

Land use	If (mm/h)		Pi (mm)		Kr (%)		D ($g/m^2/h$)	
	m	SD	*m*	SD	*m*	SD	*m*	SD
Cropland	63.73a	7.70	6.03a	2.62	16.20a	9.86	19.12a	15.61
Woodland	36.17bc	8.27	1.98bc	0.67	50.16bce	11.56	40.55b	28.88
Moderately dense forest	64.14a	8.06	4.76ab	2.03	10.99abd	9.05	5.73ac	4.97
Dense forest	80.00bd	0.00	80.00cd	0.00	0.00bd	0.00	0.00ac	0.00
Scrubland	44.69bc	8.30	2.75b	1.87	40.97bc	9.54	30.25ab	16.60
Bare non-forest land	50.62abc	1.07	3.78abc	1.26	30.55abc	1.04	61.93b	10.49

Means followed by the same letter do not significantly differ from each other ($P < 0.05$)

If (mm/h) final infiltration, *Pi (mm)* initial abstraction, *Kr* runoff coefficient (%), *D* ($g/m^2/h$) detachability, *m* mean, *SD* standard deviation

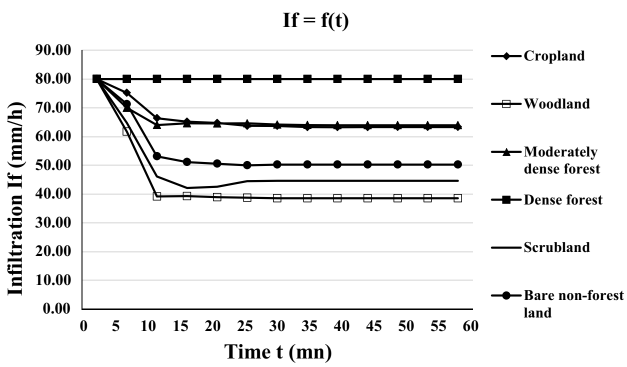

Fig. 4 Evolution of infiltration measured by rain simulation (80 mm/h) based on different land uses in the Ourika watershed

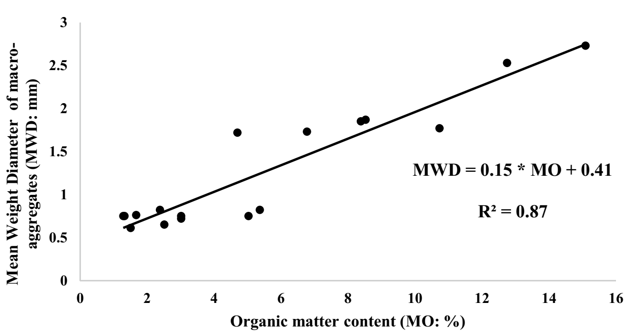

Fig. 5 Relationship between organic matter content and structural stability of soil aggregates

(MWD = 1.06 mm) and cropland (MWD = 1.13 mm). Structural stability of macro-aggregates varied similarly to organic matter in the different land uses and was closely correlated with soil organic matter content ($R^2 = 0.87$) (Fig. 5).

Relationship between hydrology, physical, chemical, and soil surface state parameters

The study of the relationships between hydrological (If, Pi, Kr, *D*) and physical (BD_{10}, BD_{20}, BD_{30}, P_{10}, P_{20}, P_{30}, H_{10}, H_{20}, H_{30}, MWD and texture), surface state (SC, SO, PEN, SS, *R*), chemical (MO) parameters was done by the Pearson correlation test. Our findings are presented in Table 8.

Infiltration was positively correlated with both initial abstraction ($R = 0.71$), covered and non-crusted soil surfaces ($R = 0.84$ and $R = 0.83$, respectively), organic matter content ($R = 0.62$), aggregate stability ($R = 0.69$), surface roughness ($R = 0.53$), humidity at 20 and 30 cm depth ($R = 0.63$ and 0.69, respectively). By contrast, it was negatively correlated with the runoff coefficient ($R = -0.99$), soil detachability ($R = -0.71$), penetration resistance ($R = -0.81$), and shear strength ($R = -0.64$).

As for initial abstraction, it was positively correlated with infiltration ($R = 0.71$), covered and non-crusted soil surfaces ($R = 0.62$ and 0.78, respectively), humidity at 20 and 30 cm depth ($R = 0.57$ and 0.56, respectively), and negatively correlated with runoff coefficient ($R = -0.65$).

The runoff coefficient, on the other hand, was positively correlated with detachability ($R = 0.68$), penetration resistance ($R = 0.81$) and shear strength ($R = 0.64$), and negatively correlated with infiltration ($R = -0.99$), covered and non-crusted soil surfaces ($R = -0.84$ and $R = -0.78$, respectively), surface roughness ($R = -0.55$), humidity at 20 and 30 cm depth ($R = -0.57$ and -0.67, respectively).

Detachability was positively correlated with the runoff coefficient ($R = 0.68$) and negatively correlated with infiltration ($R = -0.65$), covered soil surface ($R = -0.81$) and humidity at 30 cm depth ($R = -0.56$).

These findings clearly showed that surface state was the determinant factor with respect to the soil's hydrological behavior in the Ourika watershed (Table 8). Among soil physical properties, only soil humidity below the depth of 10 cm was correlated with the hydrological properties of the soil. This could be explained by the increase in soil humidity in highly covered surfaces. Total infiltration was also correlated with the aggregate stability.

Table 8 Pearson correlation coefficients between the soil hydrological properties and other soil properties

	Soil parameters	If (mm/h)	Pi (mm)	Kr (%)	D (g/m^2/h)
Hydrological parameters	If	1			
	Pi	0.71**	1		
	Kr	− 0.99**	− 0.65*	1	
	D	− 0.65**	− 0.19	0.68**	1
Surface state parameters	SC	0.84**	0.62**	− 0.84**	− 0.81**
	SO	0.83**	0.78**	− 0.78**	− 0.47
	PEN	− 0.81**	− 0.46	0.81**	0.37
	SS	− 0.64**	− 0.46	0.64**	0.11
	R	0.53*	0.44	− 0.55*	− 0.60*
Chemical parameters	MO	0.62**	− 0.31	0.28	0.36
Physical parameters	MWD	0.69**	− 0.35	0.42	0.48
	BD_{10}	− 0.42	− 0.32	0.45	0.30
	BD_{20}	0.28	0.31	− 0.28	− 0.36
	BD_{30}	0.42	0.35	− 0.41	− 0.47
	P_{10}	0.42	0.31	− 0.44	− 0.29
	P_{20}	0.30	0.38	− 0.26	− 0.36
	P_{30}	0.14	0.37	− 0.10	− 0.22
	H_{10}	0.21	0.42	− 0.20	− 0.14
	H_{20}	0.63**	0.57*	− 0.57*	− 0.40
	H_{30}	0.69**	0.56*	− 0.67**	− 0.56*
	A	− 0.38	− 0.35	0.34	0.06
	L	0.19	− 0.25	− 0.23	− 0.21
	S	− 0.10	0.34	0.15	0.19

If infiltration (mm/h), *Pi* initial abstraction (mm), *Kr* runoff coefficient (%), *D* detachability (g/m^2/h), *SC* covered soil surface (%), *SO* non-crusted soil surface (%), *PEN* penetration resistance (kg/cm^2), *SS* shear strength (kg/cm^2), *R* surface roughness (%), *MO* organic matter (%), *MWD* mean weight diameter of soil aggregates (mm), BD_{10} bulk density between 0 and 10 cm (g/cm^3), BD_{20} bulk density between 10 and 20 cm (g/cm^3), BD_{30} bulk density between 20 and 30 cm (g/cm^3), P_{10} porosity at 0–10 cm (%), P_{20} porosity between 10 and 20 cm (%), P_{30} porosity between 20 and 30 cm (%), H_{10} humidity at 0–10 cm (%), H_{20} humidity at 10–20 cm (%), H_{30} humidity at 20–30 cm (%), *A* clay (%), *L* silt (%), *S* sand (%)

*Indicates significant relationship $P < 0.05$

**Indicates significant relationship $P < 0.01$

Discussion

Vegetation improves both physical and surface properties of the soil by creating cavities in it, as it does soil structure through the incorporation of organic material, thus decreasing bulk density, penetration resistance, and shear strength. It equally increases porosity and surface roughness. Tillage, on the other hand, results in rapid loss of organic matter either by mineralization, erosion, or through the destruction of aggregates (Sabir et al. 2007). In our study, the dominance of sandy soil, coupled with low vegetation cover, in bare non-forest lands could explain the high bulk density and low porosity values observed (Tables 2 and 3). In scrubland, soil compaction was probably a result of animal trampling. Under dense and moderately dense forests, the soil was, for the most part, loose on the surface and less dense with increasing depth compared to other land uses. Moreover, the highest macrospore presence was observed in the top 10 cm under dense forests, which could be explained by the abundance of plant cover and consequently litter in the surface horizon (Table 3). As for porosity, it plays a very important role in the proportion and circulation of water and air in the soil for plants. Forest soil is rich in litter and consequently better aerated due to root systems and soil animal dynamics. Despite the tillage in croplands, porosity remained lower than in forests. The absence of moisture at the 10 cm depth in the bare non-forest lands (Table 4) could be attributed to both the sandy texture of the soil and the low plant cover. By contrast, the high moisture content in forests confirmed the importance of vegetation, which limits the drying effect of sunlight to the soil. This was not the case for either croplands or scrubland whose soil is generally subjected to the direct effects of solar radiation.

Field observations showed that the high surface cover in forests was a direct result of dense vegetation and, consequently, litter accumulation. In croplands, residues of previous crops were responsible for most of the cover. In scrubland, herbaceous, and to some extent scrub vegetation, provided soil cover, while pebbles were, for the most part, responsible for the observed cover in both bare non-forested lands and woodlands.

Despite a general environmental degradation, surface cover rate was high under all soil types. Indeed, even when vegetation was scarce, pebbles were present and, to a lesser extent, played a role in protecting the soil surface. Non-crusted surfaces did not account for significant portions of the watershed, with the highest rates being observed under forest and croplands. This could be attributed to the presence of cracks created by root systems and soil animal activity in the forest, and by clods because of plowing in croplands.

Under forests and bare non-forest lands, very low values of both penetration resistance and shear strength were observed (Table 6). This could be attributed to the high litter and, thus, organic matter content in the forest, which attenuate the prevalence of these parameters. By contrast, the low values obtained in bare non-forest lands were most likely the result of the sandy texture of the soil. Under scrubland, woodlands, and croplands, these soil properties become more notable. This could be the result of animal trampling in scrubland, the presence of crusts in woodlands, and tillage in cropland, which result in loss of soil cohesion as well as crusting. Surface roughness was significant in both forests and croplands, and was mainly attributed to litter originating from abundant vegetation in forests and plough tracks in croplands. To a lesser extent, it could also have been a result of the presence of both herbaceous plants and tiny pebbles, which enable its presence in scrubland, woodlands, and bare non-forest lands.

Vegetation cover, upon improving the physical properties and surface state of the soil, facilitates water infiltration into the soil, thus reducing the risk of runoff and erosion. Several authors have shown that it is the most significant factor with respect to improving soil water infiltration and, consequently, mitigating runoff risks (Roose 1996; Karkouri et al. 2000; Sabir et al. 2004, 2007; She et al. 2014; Liu et al. 2014).

As for total infiltration, it was negatively correlated with both the runoff coefficient ($R = -0.99$) and penetration resistance ($R = -0.81$). By contrast, it was positively correlated with both covered and non-crusted ($R = 0.84$ and $R = 0.83$, respectively) soil surfaces, thus confirming the importance of plant cover with respect to mitigating runoff and consequently water erosion. Indeed, infiltration in the Ourika watershed is a function of soil surface states. Some authors (Sabir et al. 2007, 2004; Karkouri et al. 2000) have observed similar results in various regions of Morocco. They found final infiltration to be closely related to surface states, and particularly surfaces covered with crusts as well as those characterized by compacted areas. Additionally, they showed that it was equally correlated with aggregate stability, which itself is a function of organic matter content in the topsoil. The runoff coefficient values observed in this study ranged from 0 (dense forest) to 50.16% (woodland). These are fairly similar to values obtained in the western Mediterranean regions (4.7–47.4%) (Martínez-Murillo et al. 2013). High runoff coefficient values varying from 25.35 (straw covered soil) to 65.15% (bare soil) were observed by other authors in Mediterranean vineyards (Prosdocimi et al. 2016).

Detachability, on the other hand, was negatively correlated with the covered soil surface ($R = -0.81$), with bare soils being the most susceptible to runoff and erosion. Our findings are in tandem with those obtained by another author (Cheggour 2008) in the Rheraya basin, wherein an exponential relationship between turbidity and bare soil was observed. Factors such as the covered soil surface (vegetation, litter, rocks) probably masked the effect of texture on soil detachability. In our study, soil detachability values ranged from 0 to 61.93 $g/m^2/h$. These values are lower than those obtained in the western Mediterranean badlands environments (14.1–1045.1 $g/m^2/h$) (Martínez-Murillo et al. 2013).

Interestingly, significant correlations between infiltration and soil physical parameters were not observed. This could probably have been due to low variations in these parameters within the studied plots. These results point in the same direction as those obtained by other authors (Sabir et al. 2007, 2004; Karkouri et al. 2000) who performed similar infiltration tests, but on more developed soils of the central Rif in Morocco. Their findings showed that total infiltration was not correlated with the physical parameters of the soil but rather with the surface state of soils.

Soil hydrodynamic parameters and physical properties were weakly correlated (Table 8). Infiltration was weakly correlated with bulk density ($R = -0.42$, $R = -0.28$ and $R = -0.42$ at depths of 10, 20, and 30, respectively), total porosity ($R = 0.42$, $R = 0.30$ and $R = 0.14$ at depths of 10, 20, and 30, respectively). In the same manner, there was no strong correlation between infiltration and the proportions of clay ($R = -0.38$), silt ($R = 0.19$) or sand ($R = -0.10$). Similar weak correlation relationships were observed for initial abstraction (Table 8). These findings could be explained by the fact that the effect of soil physical properties on hydrodynamic parameters seemed to be masked by that of surface state, which was the determining factor. However, in the high non-crusted soils (forest dense and moderately dense, cropland), the correlation between Infiltration and soil physical properties such as bulk density and total porosity in the first 10 cm of the soil significantly increased ($R = -0.56$ and $R = 0.56$, respectively). Infiltration was also significantly correlated with clay proportion in the soil ($R = -0.76$). This points to the fact that in non-crusted soils, soil physical properties improved soil hydrodynamic properties.

Conclusions

Results of this study show that infiltration tests make it possible to identify the factors responsible for runoff and therefore water erosion. Despite the simplicity of the experimental device used, results obtained are useful for understanding runoff and erosion risks in semi-arid mountainous areas. It provides important information concerning runoff and erosion risks, as a product of land-use patterns.

In this regard, dense to moderately dense forests, characterized by high organic matter, provide adequate cover for soils and improve their aggregation, thus, resulting in excellent infiltration. In woodland areas, bare soil is exposed to runoff risks and crusting whereas scrublands, associated with overgrazing, cover much less soil and experience significant runoff, but with reduced solid loads. Croplands, on the other hand, are generally associated with reduced plant cover. This coupled with low organic matter content results in them being highly susceptible to crusting, and results in them losing the ability for infiltration.

Infiltration is a function of hydrological parameters (initial abstraction, runoff coefficient, and detachability) and surface state parameters (covered soil surface, non-crusted soil surface, penetration resistance, and shear strength). It is equally dependent on soil structural stability determined by the content on organic matter. On the other hand, no relationship between iniltration and soil physical properties such as bulk density, total porosity and texture was observed in the study area. Infiltration was negatively correlated with soil detachability ($R = -0.71$), which, in similar fashion, was negatively correlated with covered soil surface ($R = -0.81$). Thus, the degradation of the vegetation, leading to a diminished cover, results in an increase in soil detachability and consequently runoff. The increase in both runoff and detachability resulted in increased risk of erosion and, as such, showed that infiltration could be used as an applicable indicator of runoff and erosion risks.

Finally, the highlighted relationships allow for a preliminary analysis of dominant processes of water erosion in both the Ourika watershed and the Marrakech High Atlas region as a whole. Indeed, they would be useful for the calibration of water erosion hydrological models as well as serve as a database for future perspectives of spatial erosion risk of the Ourika watershed.

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Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there are no conflicts of interest to declare.

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