Plant Archives Vol. 19 No. 2, 2019 pp. 2701-2707 **e-ISSN:2581-6063 (online), ISSN:0972-5210**

EFFECT OF SOIL SURFACES ON HYDRODYNAMIC PARAMETERS IN THE BEN AHMED WATERSHED-CENTRAL MOROCCO

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Abstract

Erosion is a major process of land degradation; that affects the surface layer of soils. The methodology assessed the effect of states surfaces on the hydrodynamic parameters on 1m^2 plots. Four experimental sites were considered with reference to bare, tilled and covered soils, with three test plots per site. Making it a total of 12 test plots for the rainfall simulations. Soil samples were collected at 0-20 cm depths from each site to determine soil properties (aggregate stability, bulk density, humidity). Showed that surface state was the determinant factor with respect to the soil's hydrological behavior in the Ben Ahmed watershed. Infiltration was positively correlated with initial abstraction (R = 0.78), bare and tilled soil surfaces (R = 0.64 and R = 0.99, respectively), aggregate stability (R = 0.55). By contrast, it was negatively correlated with the runoff coefficient (R = -0.99), humidity (R = -0.99), soil detachability (R = -0.87), and covered soil surface (R = -0.60). However, a weak correlation between infiltration and either of bulk density. Covered surface greatly decreased runoff and soil erosion by increasing the surface roughness and decreasing the runoff velocity in the study zone.

Key words: central Morocco, hydrodynamic parameters, rainfall simulation, state surface, watershed

Introduction

Water erosion is a dynamic process of detaching, transporting and depositing soil particles under the effect of the kinetic energy of water. Soil loss causes adverse influences of widespread with different intensities depending on the environment biophysical characteristics and threats human sustainability (Lal, 1998). The soil erosion rates are accelerated by tillage and low vegetation cover (Cerdà *et al.,* 2009 and 2010).

Land use and soil cover are considered the most important factors affecting the intensity and frequency of overland flow and surface wash erosion (Mitchell, 1990; Kosmas *et al.,* 1997; García-Ruiz, 2010). Many authors have demonstrated that in a wide range of environments both runoff and sediment loss decrease exponentially as the percentage of vegetation cover increases (Elwell & Stocking, 1976; Francis & Thornes, 1990). The main causes of soil erosion are inappropriate agricultural practices, deforestation, overgrazing, land abandonment, forest fires and construction activities (Grimm *et al.,* 2002). Amongst these factors, agricultural land uses generate the highest erosion yield (García-Ruiz, 2010; Nunes, Coelho, Almeida, & Figueiredo, 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

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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 been 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.

This study deals with the effects of states surfaces on hydrodynamic parameters (infiltration, runoff, detachability) depending on soil parameters (aggregate stability, bulk density, humidity) and their interactions in order to identify the main factor of runoff and water erosion risks in the Ben Ahmed watershed. To assess erosion risk indicators, rainfall simulations offer an interesting alternative and involve the application of rainfall simulation tests on 1 m^2 plots with the help of a rain simulator.

Materials and Methods

Study area

The Ben Ahmed watershed is located in the region of Casa-Settat (Settat province), 70 km southeast of Casablanca, on the road between Berrechid and Khouribga. It is spread over an area of 545ha. The study area receives an annual average rainfall of 400 mm and exhibits a semi-arid climatic condition with a mean minimum and maximum temperature of 9°C and 26°C, respectively. Almost 74.5% of the area is occupied by agriculture land.

Rainfall Simulation

Rainfall simulation is one of several methods used to study soil hydrodynamics (Roose, 1996; Roose and Smolikowski, 1997). A rainfall simulator was used in all the erosion experiments. In order to better assess soil behavior on the release of runoff and erosion and to facilitate the comparison of results, we used the method of rainfall simulation. The approach is based on the introduction of micro-plots on which the erosive dynamics and different surface state situations were analyzed. The study area is mainly occupied by rendzinas and alluvial soils are objective study. The rainfall simulator used is the type ORSTOM.

The study consists to measure on four micro-plots of 1 m^2 the streamed volumes and sediments under the influence of rainfall generated by a rainfall simulator. The simulator was covered with a wind protector to prevent the wind from affecting the experiments. The study plot is limited by a metal frame of 1 m^2 down into the earth to a depth of 10 cm. A water collection system, made up of a collecting gutter, limits the plot at its base and receives water and runoff sediment. For each of the micro-plots, rain erosive sequence of 60 mm/h was simulated for 30 minutes. For each simulated event, runoff was sampled at 1min intervals. The sediments were collected during each test and every 5 min, runoff water was collected through a gutter system installed at the micro-plots to determine sediment loads associated with runoff flow. The erosion rate was calculated as the total quantity of

Fig. 1. Rainfall simulation

soil lost divided by the duration of the test.

The rainfall simulation tests were realized on 4 sites of two types of soil, each site has a surface state. The objective is to test the influence of the surface states on the variability of runoff and erosion. The states of soils studied are:

- Alluvial soil (bare soil, fallow)
- Alluvial soil with mulch
- Rendzinas (tilled soil)
- Rendzinas (bare soil)

Soil samples from each site were used for the determination of structural stability, others were taken, using a 20-cm-long cylinder with a diameter of 4 cm, to determine bulk density (BD) and humidity (%). Aggregate stability by Le Bissonnais and Le Souder method (Le Bissonnais and Le Souder 1995).

Statistical tests

One-way analysis of variance was used to determine the differences physical parameters, soil-surface state parameters, and soil hydrological parameters. The soil-surface state parameters examined were bare soil, soil covered and tilled soil. 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.

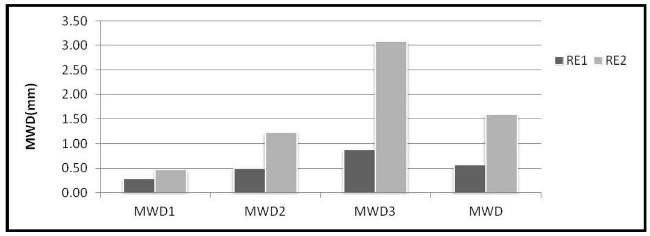
Results

Soil parameters

The results of the structural stability are presented in terms of mean weighted diameter (MWD), for fast wetting (MWD_1), slow wetting (MWD_2) and mechanical disintegration (MWD_3). Tests for fast wetting, MWD values are low for the four sites (< 0.4mm). These results show that soils are unstable with a significant risk of erosion. For the slow re-wetting test, soils have MWD values ranged between 0.8 and 1.33 mm, except for rendzinas (RE1), which have a MWD value below this range, because of their lowly cloddy structure. Similarly, concerning the ethanol test, aggregates are stable. We can conclude that the studied soils are more resistant to slow wetting and mechanical disaggregation. The rapid wetting is the most destructive treatment for all soils (Fig. 1). With reference to the standards established by (Le Bissonnais et Le Souder, 1995), the studied soils are considered highly unstable when subject to rapid wetting with a risk of substantial and permanent erosion and runoff. Values obtained for aggregate stability (Table 1) varied significantly at the 5% significance level between alluvial soils bare and covered; a significant difference was noted between rendzinas tilled and bare soil. However, no significant differences were observed between alluvial soils covered rendzinas tilled.

Bulk density and humidity

Values obtained for bulk density at 20cm of depth (Table 1) varied between 1.14 and 1.153 $g.cm^{-3}$. In the majority of the values recorded, the surface horizons have a BD higher than 1$g.cm^{-3}$. The results show a significant difference ($P<0.05$) between alluvial soil bare and covered, there were significant variations in bulk density between rendzinas tilled and bare soil. Soil samples were collected in October. This was during winter, a period characterized by relatively humid soil, and thus could explain the relatively high moisture content values. There was a significant difference in moisture, at the 5% significance level, between alluvial (bare and covered), and between rendzinas (tilled and bare).



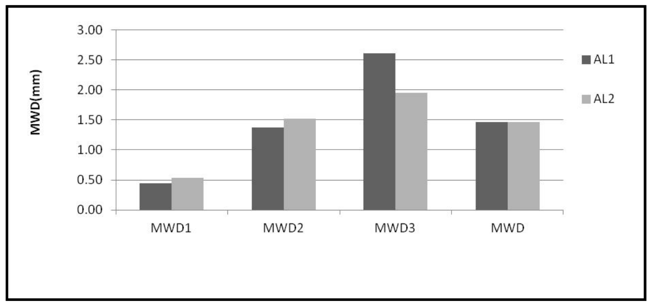


Fig. 2. Mean weighted diameter

Runoff and soil loss

The average sediment losses rate from test plots had the same trend as runoff, *i.e.*, the amount of soil loss Fig. 2. This may depict as sediment losses and surface runoff from test plots relate directly. During the experiment, 12 erosive rainfall events were recorded. Fig. 3 shows scatter plot graphs for the relationship between runoff and soil loss. The best regression equation was selected based on determination coefficients of the line of best fit. Sediment losses increase linearly as a function of cumulative runoff. This is consistent with the results of Boardman *et al.,* (2003) obtained by rain simulations on semi-arid rangelands.

Table 1: Soil hydrological parameters in the Ben Ahmed watershed.

soils	MWD		BD_{20}(g/cm^3)		H_{20}(%)	
	m	SD	m	SD	M	SD
Alluvial soil (bare soil)	0.57a	0.01	1.14a	0,01	33a	1
Alluvial soil (covered with mulch)	1.46b	0.01	1.53d	0,02	38.3c	0.57
Rendzinas (tilled soil)	1.48b	0.01	1.3c	0,01	31b	0.16
Rendzinas (bare soil)	1.59c	0.01	1.22b	0,01	44.5d	0.5

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

H_20 humidity at 0–20 cm, m mean, SD standard deviation, MWD mean weight diameter, BD bulk density

The relationship between runoff and soil loss varies across runoff intensity in a systematic way (Fig. 2). In fact, increased runoff also increases its runoff speed, so its ability to detach and transport the sediments, and therefore its concentration. Correlation is very important for Alluvial bare and covered soils ($R^2 = 0.79$ $R^2 = 0.93$ respectively). It is low for rendzinas tilled soil ($R^2 = 0.44$), this weak relationship observed between detachability and runoff is explained by the response time between liquid-solid flow points which is important enough to decrease the relationship.

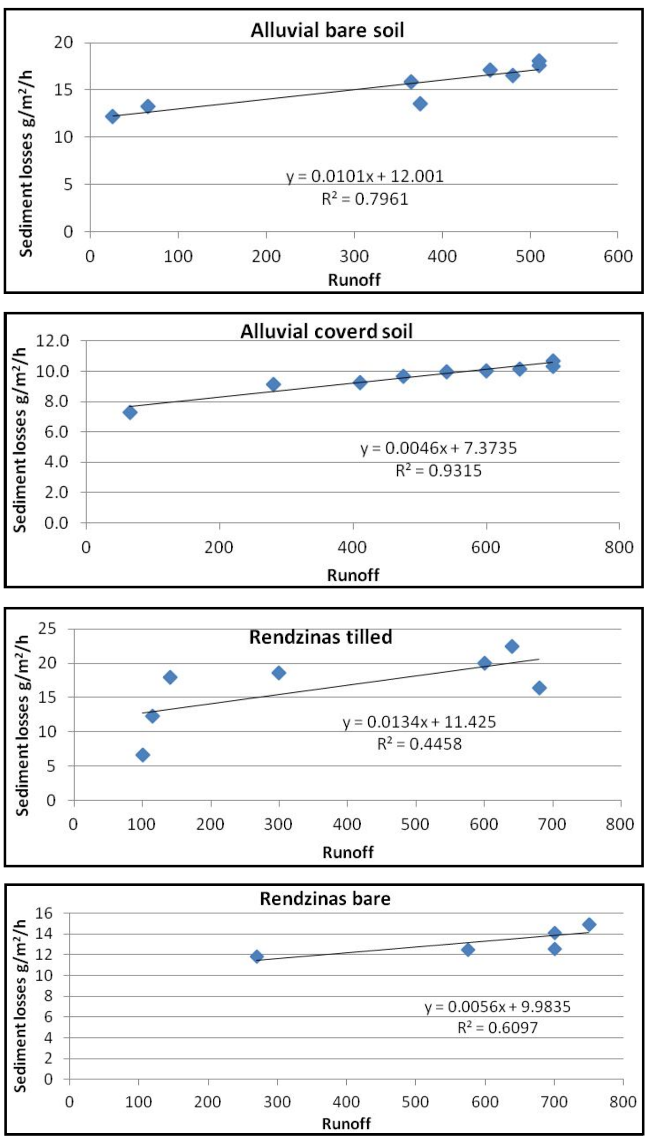


Fig. 2. Relationship between runoff and sediment losses

Hydrological and erosive response

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 infiltration was very high in Alluvial soil covered with mulch, high in rendzinas tilled and alluvial bare soils (24 and 33 mm/h, respectively) and low in bare rendzinas soil (15mm/h) (Table 2). There was a significant difference in infiltration between alluvial and rendzinas soil. Indeed, infiltration was highest in the alluvial covered soil. The runoff coefficient, on the other hand, was, very high in rendzinas bare soil (72%), high in rendzinas tilled and alluvial bare soils (60 and 45% respectively) and low in alluvial covered soil (37%). Initial abstraction (Table 2) was very high in alluvial soil covered with mulch (24 mm). Detachability was low in alluvial covered soil (4.66 g/m^2/h), owing to the low of runoff. However, it was high in alluvial bare soil (7.71 g/m^2/h) and rendzinas bare soil (11.18g/m^2/h) and very high in rendzinas tilled soil (28.84g/m^2/h).

Relationship between hydrology, physical, and soil surface state parameters

The study of the relationships between hydrological (If, Pi, Kr, *D*), physical (BD20, H_20, MWD) and surface state (SC, SB, ST). Our findings are presented in table 3.

Infiltration was positively correlated with initial abstraction ($R = 0.78$), bare and tilled soil surfaces ($R = 0.64$ and $R = 0.99$, respectively), aggregate stability ($R = 0.55$). By contrast, it was negatively correlated with the runoff coefficient ($R = -0.99$), soil detachability ($R = -0.87$), humidity ($R = -0.99$) and covered soil surface ($R = -0.60$).

As for initial abstraction, it was positively correlated with infiltration ($R = 0.78$), bare soil surface ($R = 0.89$) and, negatively correlated with runoff coefficient ($R= -0.80$), soil detachability ($R = -0.60$), humidity ($R = -0.54$),

Table 2: Soil hydrological parameters in the Ben Ahmed watershed.

Sols	Inf (mm/h)		Pi(mm)		Ke(%)		D(g/m²/h)	
	m	SD	m	SD	M	SD	m	SD
Alluvial soil (bare soil)	33c	1	16.9b	0.15	45b	0.55	7.71b	0.72
Alluvial soil (covered with mulch)	37d	1	15.9C	0.9	60c	0.55	4.66d	1.00
Rendzinas (tilled soil)	24b	1	24c	0.25	37a	0.26	28.84a	0.81
Rendzinas (bare soil)	15a	1	15.6a	0.35	72d	0.55	11.18c	1.00

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/m²/h)* detachability, *m:* mean, *SD:* standard deviation

covered and tilled soil surfaces (R = -0.99 and R = -0.98, respectively).

On the other hand, the runoff coefficient was positively correlated with detachability (R = 0.90), humidity (R = 0.99), tilled soil surface (R = 0.88), aggregate stability (R = 0.52) and negatively correlated with covered and tilled soil surfaces (R = -1 and R = -0.88, respectively).

Detachability was positively correlated with the runoff coefficient (R = 0.90), covered and bare soil surfaces (R = 0.55 and R = 0.71, respectively) and negatively correlated with infiltration (R = -0.87), tilled soil surface (R = -0.99) and initial abstraction (R = -0.60).

These findings clearly showed that surface state was the determinant factor with respect to the soil's hydrological behavior in the Ben Ahmed watershed (Table 3). Among soil physical properties, only soil humidity was correlated with the hydrological properties of the soil. Total infiltration and runoff coefficient were also correlated with the aggregate stability.

Table 3: Pearson correlation coefficients between the soil hydrological properties and other soil properties.

	Paramètres de sol	If (mm/h)	Pi (mm)	Kr(%)	D (g/m²/h)
	If	1			
Hydrological	Pi	0.78**	1		
parameters	Kr	-0.99**	-0.80**	1	
	D	-0.87**	-0.60*	0.90**	1
Soil parameters	H_{20}	-0.99* *	-0.54*	0.99*	-0.63*
	Da	-0.34	-0.10	0.37	0.31
Surfaces state	DMP	0.55*	0.35	0.52*	-0.36
	SB	0.64**	0.89*	-0.66**	0.71*
	SC	-0.60*	-0.99**	-1**	0.55*
	ST	0.99**	-0.98**	0.88**	-0.99**

If: infiltration (mm/h), *Pi:* initial abstraction (mm), *Kr:* runoff coefficient (%), *D:* detachability (g/m²/h), *SC:* covered soil surface (%),SB: bare soil, ST: tilled soil *MWD:* mean weight diameter of soil aggregates (mm), BD_{20}: bulk density between 0 and 20 cm (g/cm³), H_{20}: humidity at 0–20 cm (%),
*Indicates significant relationship $P < 0.05$
**Indicates significant relationship $P < 0.01$

Discussion

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; Sabir *et al.,* 2004, 2007; She *et al.,* 2014; Liu *et al.,* 2014).

Infiltration was positively correlated with initial abstraction (R = 0.78), bare and tilled soil surfaces (R = 0.64 and R = 0.99, respectively), aggregate stability (R = 0.55). By contrast, it was negatively correlated with the runoff coefficient (R = -0.99), soil detachability (R = -0.87) and covered soil surface (R = -0.60), humidity (R = -0.99), thus confirming the importance of plant cover with respect to mitigating runoff and consequently water erosion. Indeed, infiltration in the Ben Ahmed watershed is a function of soil surface states. Some authors (Al Karkouri *et al.,* 2000, Sabir *et al.,* 2004, 2007) have observed similar results in various regions of Morocco. They found final infiltration to be closely related to surface states.

The runoff coefficient values observed in this study ranged from 37 (covered soil) to 72% (bare soil). These are fairly similar to values obtained in Mediterranean vineyards. High runoff coefficient values varying from 25.35 (straw covered soil) to 65.15% (bare soil) were observed by (Prosdocimi *et al.,* 2016). Several studies have highlighted the spatial variability of runoff as a function of surface conditions (Le Bissonnais, 2000, Esteves & Lapetite, 2003, Merz *et al.,* 2006, Moreno-de las Heras *et al.,* 2010).

Detachability, on the other hand, was positively correlated with the covered soil surface (R = 0.55), 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. In our study, soil detachability values ranged from 4.66 to 28.84 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), and in the Ourika watershed High Atlas, Morocco (0-61.33 g/m^2/h) (Meliho *et al.,* 2017).

Soil hydrodynamic parameters and bulk density were weakly correlated (Table 3). Infiltration was weakly correlated with bulk density (R = -0.34). In the same manner, there was no strong correlation between initial abstraction, runoff coefficient and bulk density (R = -0.10, R = 0.37, respectively) (Table 3).

Conclusion

Rainfall simulation tests make it possible to identify the factors responsible for runoff and there -fore water erosion. Despite the complexity of the experimental device used, results obtained are useful for understanding runoff and erosion risks in Ben Ahmed watershed areas.

Non-vegetated plots were recorded the highest runoff coefficients and highest values of detachability, contributed to that covered. Bare soil is exposed to runoff risks and crusting whereas scrublands.

Infiltration is a function of hydrological parameters (initial abstraction, runoff coefficient, and detachability) and surface state parameters (covered soil surface, bare and tilled soils). It is equally dependent on soil structural stability and humidity. It was negatively correlated with the runoff coefficient (R = -0.99), soil detachability (R = -0.87), and covered soil surface (R = -0.60). 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.

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