

Hydrodynamic and Erosive Behavior of Vertisols in the Wadi Sra Catchment (Central Rif, Morocco) – Analysis of the Rainfall Simulation Results

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ABSTRACT

The objective of this work was to analyze the hydrodynamic and erosive behavior of soils in the wadi Sra catchment (Central Rif, Morocco) using a mini ramp rain simulator on micro-plots of 1 m². The plots were selected on vertisols with a slope (between 17 and 33%), considering four types of land use: cannabis cultivation, cereal cultivation, fallow land and abandoned land, with the aim of comparing and determining the effects of the land use types on infiltrability and sediment production. The simulation tests were carried out during each season, due to the variability of cultivation practices, surface conditions and prior soil moisture from one season to another. Before each simulation, the surface condition of the concerned plots was checked; it is a question of raising the rate of closed or open surfaces and covered or bare surfaces according to the quadrat points method. Laboratory tests allowed identifying the physico-chemical properties of the soil, the initial humidity, the bulk density and the porosity. The results obtained show that the final infiltration is characterized by a significant variation, between (8.32 mm/h and 70.40 mm/h). Low values concern abandoned and fallow land and very high values are recorded on plowed land (cannabis and cereal cultivation). In addition, solid transport recorded significant spatio-temporal variations, between (5.15 and 157 g/l); the maximum average values are recorded in the cannabis cultivation plots, followed by abandoned land, then fallow land and cereal cultivation land.

Keywords: Central Rif, hydric erosion, infiltration, runoff, rain simulation, soil surface condition.

INTRODUCTION

Hydric erosion presents many environmental and socio-economic problems in the Rif mountains the soil and water potential of which are seriously threatened. Studies on erosion, carried out in this region through different methods (experimental plots, spatial modelling, etc.) show that land losses remain the highest on a national scale. They vary from 36 t·ha⁻¹·yr⁻¹ up to t·ha⁻¹·yr⁻¹ [Heusch, 1970; Marzouk et al., 1996; El Garouani, et al., 2008; El Garouani et al., 2009; Sadiki, 2005; Tribak et al., 2015; Tribak et al., 2021; Naimi et al., 2005; Abahrour, 2009; Naimi et al., 2001, Tahiri et al., 2017; Amhani, 2022; Arari, 2022].

The wadi Sra catchment, located in the Central Rif mountains (Figure 1), is subject to intense erosive dynamics, due to the vulnerability

of the physical environment and the strong anthropogenic pressure. This dynamic generates harmful impacts on the environment and on water and soil resources; the Bouhouda dam located downstream of the basin suffers from excessive siltation. This paper proposed to study the dynamics of runoff and erosion of vertisols according to their uses and the evolution of their surface conditions over different periods of the agricultural year under simulated rains. The recommended method consists of using a mini-rain simulator with a ramp on micro-plots (1 m²), like the simulation work carried out previously in several regions of Morocco [Sabir, 2008; Abahrour et al., 2015; El-ommal et al., 2021; Amhani, 2022; Arari, 2022; Cheggour, 2008; Bensalah, 2019, El Mazi et al., 2022]. This method enables to obtain, experimentally and in a relatively short

time, numerous measured data on the behavior of water in the ground under artificial rains [Morsli et al., 2012; Meddi et al. 2005] in order to test the surface detachability and to quantify the solid charge [Roose and Smolikowski, 1997].

A FRAGILE ENVIRONMENT SUBJECT TO STRONG ANTHROPOGENIC PRESSURE

The catchment of the Sra wadi, with an area of about 553 km², is located in the Central Rif (Figure 1). It is characterized by a rugged topography, stepped between 255 m and 2456 m (Jbel Tidghin) with steep slopes generally exceeding 25%. The structural context of the basin encompasses part of the outer Rif, in particular the Intra-Rifian zone, which presents the structures of the thrust sheets (Ketama sheet and Tangier sheet), as well as the autochthonous formations of the Mesorif and the Upper Miocene (intra-mountain basins). The upstream of the basin is occupied by the alternation of series that are both marly and marly-schistose, or schistose with beds of quartzitic sandstone from the secondary era [Maurer,

1968]; while the downstream part is dominated by very soft marl formations from the Upper Miocene which occupy the intra-mountainous basins of the lower and middle Ouergha [Michard, 1976]. The soils that characterize this basin belong to the classes of less evolved soils of erosion on steep slopes, fersiallitic soils and vertisols in less rugged and intensely exploited areas.

The climate of the region is marked by strong seasonal contrasts and very clear irregularities in precipitation. The annual averages vary between 495 mm in the downstream part of the basin (Ain Aicha station 1981-2018) to 1570 mm upstream of the basin (Ketama station 1980–2003). Nevertheless, the rains are generally concentrated in a few days of the wet season; maximum daily heights of stormy character and high intensity may exceed the threshold of 180 mm; such was the case on November 29th, 2010 (58% of the monthly module).

On the anthropogenic level, the human settlement in the region is very old. Human densities are high, exceeding the threshold of 200 people/km² in 2014 with a record of 220 people/km² in some municipalities. Anthropogenic pressure on natural

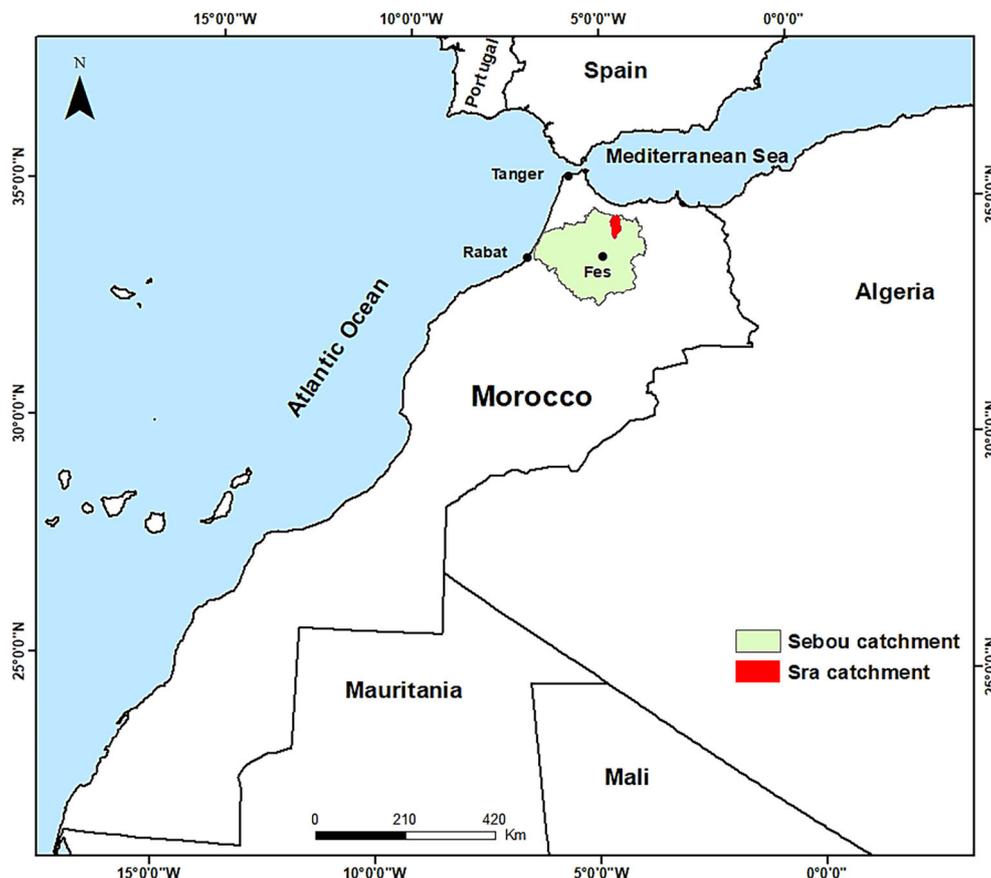


Figure 1. Geographical location of the wadi Sra basin

resources is quite remarkable; it has transformed forest landscapes into cultivated land, intended mainly for cannabis cultivation on steep slopes where the soil is fragile and sensitive to runoff. These pressures lead to frequent changes in land use, as a result of transformations of the entire forest landscape, which is seriously threatened. The areas occupied by forests/reforestation have suffered a significant regression between 1986 and 2018 with (–155%) and a pronounced increase in cultivated (+29.75%) and arboriculture (+33.90%) areas, in order to meet the needs of populations in agricultural land [El-ommal et al., 2021].

MATERIALS AND METHODS

Experimental device

The methodology of this work is essentially based on rain simulation. This technique makes it possible to obtain in the field, numerous measured data on the behavior of water on the surface and in the ground under artificial and controlled rains in an experimental way and in a relatively short time, [Morsli et al., 2012; Meddi et al., 2005, Sabir et al., 2008]; moreover it enables to test the detachability of a soil surface [Roose and Smolikowski, 1997; Morgan et al., 1997]. It also allows a good assessment of the dynamics of runoff and its solid load depending on the plant cover, on the surface states of the soils and on the cultivation techniques [Roose et al., 2012].

The experimental device consists of the use of a mini-rain simulator with ramp (a simple manual irrigator), which allows simulating rainfall on an artificially plot delimited by a rectangular metal frame of one m², sunk in soil to concentrate water and runoff in the concerned plot. This device is equipped at the bottom of the plot with a tank to receive runoff water; it also includes a 50 cm wide watering ramp with a line of 0.5 mm diameter separated by a distance of 1 cm and connected by a conventional ten-liter watering can. The simulated rain intensity is 80 mm/h⁻¹ for 40 to 50 min for each test.

The choice of experimental sites

The plots were selected on vertisols with a slope (between 17 and 33%), considering four types of land use: cannabis cultivation, cereal cultivation, fallow land and abandoned land, with

the aim of comparing and determining the effects of land use on infiltrability and sediment production. The simulation tests were carried out during each season, due to the variability of cultivation practices, surface conditions and prior soil moisture from one season to another.

Rainfall simulation tests

The simulation technique has enabled to obtain results in three phases in an experimentally way and short time:

- rainfall of Imbibition (R_i in mm): which is the height of water infiltrated and necessary to saturate the soil and cause the start of runoff [Lelong et al., 1993];
- the transition phase, representing the duration between the onset of runoff and its stability in relation with the infiltration capacity of a soil, which decreases over time during the test simulation to a constant regime called final infiltration FI (mm/h);
- the detachability of the soil (g/l): consists of the evaluation of the sediments transported by the runoff and kept in a small tank at the end of the rain simulation for each plot. The tanks are kept for a long time so that the sediments are redeposited until the water is clear. The sediments are then dried in an oven for 24 hours at 105 °C.

Measurement of surface conditions

Before each simulation, the states of the surfaces inside each plot (1 m²) were checked and recorded in the field in different seasons using the quadrat point method described by [Roose 1996]. It is a question of determining by two diagonal transects inside the plot at every 10 cm the rate of covered or bare surfaces and closed or open surfaces. Therefore, the sum of covered and bare surfaces equals 100%. Similarly, the sum of closed and open areas equals 100%.

Roughness index (I_r%)

The roughness index (I_r%) was also well measured (three repetitions) by means of a flexible metal chain according to the method of [Roose 1996]. Three replicates are measured before each simulation for all plots without breaking the ground roughness which deeply controls infiltrability and detachability.

Bulk density and porosity

Before each rainfall simulation, two soil samples were taken for all plots and during each season using a cylinder to determine soil moisture, bulk density (Bd, g/cm³) and total soil porosity. These samples were weighed before and after drying in an oven at 105 °C for 24 hours to evaluate the ratio of water weight to dry soil weight using the following relationship Eq. 1:

$$BD \text{ (g/cm}^3\text{)} = \frac{MS}{V} \quad (1)$$

where: *BD* – bulk density;
MS – volume of dried soil;
V – volume of cylinder (269.3 cm³).

Porosity (%) is based on the results of the bulk density established above, according to the following Eq. 2:

$$P\% = 100\% - \left(\frac{BD}{PD}\right) * 100 \quad (2)$$

where: *P* – porosity;
BD – bulk density;
PD – particle density (2.65 g·cm³).

Similarly, a soil sample was taken in the 0-30 horizon, in order to determine the texture: clay, silt and sand according to the Robinson pipette method and the organic matter content MO% according to the Walkley and Blak method [1934].

Statistical data analysis

In order to determine the influence of different factors (surface conditions, roughness, bulk density, previous soil moisture, organic matter and texture) on soil hydrodynamic behavior and soil losses, Statistical analyses were performed including correlation and determination coefficients.

RESULTS AND DISCUSSION

Imbibition rain according to the type of land use in each season

The rain simulations carried out in the field show that the imbibition rain, depending on land use within different seasons, varies between 1.35 and 9.60 mm/h¹, with a rapid onset of runoff in all the plots (Table 1). The highest values are recorded in cannabis cultivation land (9.60 mm/h¹) and cereal cultivation land (8 mm/h¹); however,

the lowest values mainly concern abandoned land (1.53 mm/h¹). This can be explained by different factors, as the roughness of surfaces (Ir%) which presents values between 6 and 26.11% in cannabis cultivation fields and between 10 and 21.13% in cereal cultivation plots. Plowing contributes largely to the increase infiltration and imbibition rain during the first tests of the simulation. It is one of the primary factors that increase soil porosity, because it opens up the soil surface, breaks surface crusts and reinforces roughness [Collinet and Lafforgue, 1979; Roose, 1996; Tribak et al., 2017; Abahrour et al., 2015].

The open surfaces well represented in the plowed lands remain in favor of significant infiltration to the detriment of runoff processes; on the other hand, fallow lands show a low rate of open surfaces, which explains the clear tendency to runoff. However, the abandoned fields present favorable parameters for excessive runoff; the roughness index does not exceed 3.99% in all seasons and the quasi-permanence of bare surfaces, generally exceeding a rate of 85.3% all year round. Thus, they recorded a weak imbibition rain between 1.5 and 4 mm/h, which remains similar to the simulation values obtained in the abandoned lands of the Oriental Prerifan basins [Abahrour, 2009].

It is important to mention that the imbibition rains show a great contrast from one season to another, with much lower quantities in winter which do not exceed 2.88 mm/h in all land uses. These low values, during the winter, remain proportional to the initial humidity of the soil which presents higher values ranging from 12.42 to 20.03%. On the other hand, summer gives very high amounts of imbibition rain and low initial soil moisture values, generally less than 2.65% in all types of land use (Table 1). This is confirmed by Morsli et al., [2012] in Algeria which indicates very low runoff values in wet soils (1.6–2.6 mm) and (0.5–1.3 mm) for very wet soils.

Dynamics of infiltrability according to land uses

The various rain simulation tests have shown that the final infiltration is characterized by an apparent fluctuation between (8.32 mm/h¹ and 70.40 mm/h¹). Very high values are recorded on plowed land (cannabis and cereal cultivation) and fallow land, compared to abandoned fields, which recorded low values (Figure 2). Infiltration curves in plowed land, particularly cereal and

Table 1. Soil surface conditions and imbibition rain according to seasonal land use

| Seasons | Plowed land (cannabis cultivation) | | | | | | | |
|----------------------------------|------------------------------------|-------|-----------------------|-------|-------|-------|-------|-------|
| | Hp % | Ir % | BD g/cm ³ | BA % | CA % | CS % | OS % | Ri mm |
| Autumn | 6.44 | 9 | 1.21 | 94.12 | 5.88 | 23.1 | 76.9 | 4.34 |
| Winter | 19.3 | 6 | 1.15 | 91.14 | 8.86 | 65 | 35 | 2 |
| Spring | 8.81 | 26.11 | 1.06 | 94.12 | 5.88 | 11.76 | 89.24 | 8.53 |
| Summer | 1.64 | 15 | 1.05 | 94 | 6 | 8 | 92 | 9.60 |
| Plowed land (cereal cultivation) | | | | | | | | |
| | Hp % | Ir % | BD g/cm ³ | BA % | CA % | CS % | OS % | Ri mm |
| Autumn | 8.05 | 10 | 1.09 | 80.54 | 19.46 | 51.22 | 48.78 | 4.00 |
| Winter | 19.34 | 21.13 | 1.32 | 22.45 | 77.65 | 84.12 | 15.88 | 2.88 |
| Spring | 5.93 | 19.33 | 1.03 | 70.36 | 29.64 | 61.76 | 39.24 | 8.00 |
| Summer | 2.65 | 12.22 | 1.1 | 70.3 | 28.7 | 58.17 | 41.83 | 5.51 |
| Fallow land | | | | | | | | |
| | Hp % | Ir % | BD -g/cm ³ | BA % | CA % | CS % | OS % | Ri mm |
| Autumn | 12.57 | 4.33 | 1.41 | 41.72 | 58.28 | 91.18 | 8.82 | 2.80 |
| Winter | 20.03 | 4 | 1.26 | 8.82 | 91.18 | 76.34 | 22.66 | 2.67 |
| Spring | 8.28 | 6.66 | 1.34 | 8.82 | 91.18 | 88.82 | 11.18 | 5.53 |
| Summer | 2.25 | 3.76 | 1.5 | 12 | 88 | 95.18 | 4.82 | 4.11 |
| Abandoned lands | | | | | | | | |
| | Hp % | Ir % | BD g/cm ³ | BA % | CA % | CS % | OS % | Ri mm |
| Autumn | 3.03 | 2.22 | 1.6 | 92.26 | 7.74 | 14.7 | 85.3 | 3.33 |
| Winter | 12.42 | 3.25 | 1.39 | 97.25 | 2.75 | 52.94 | 47.06 | 1.53 |
| Spring | 8.44 | 3.99 | 1.40 | 85.3 | 14.7 | 73.53 | 26.47 | 1.61 |
| Summer | 1.17 | 2.11 | 1.32 | 94.12 | 5.88 | 11.76 | 89.24 | 4 |

Note: Ri – rain of Imbibition (mm/h), Hp – prior soil humidity (%), Ir – index of roughness, BD – bulk density (g/cm³), BA – bare area (%), CA – covered area (%), CS – closed surface (%), OS – open surface (%).

cannabis cultivation, show that infiltration is generally very high. This remains largely explained by their surface condition which presents favorable parameters for infiltration, linked firstly to plowing which increases the roughness (from 6 to 26.11%) and the dominance of open surfaces which have reached in the cannabis cultivation plots a rate of 89.24%. This remains proportional to some results which found in other regions of the Maghreb in the Eastern Prerif that the infiltration rates remain clearly very high on plowed land (more than 50 mm/h) and greatly exceed the rates recorded on abandoned or fallow land [Amhani, 2022; Arari, 2022]. Moreover, experimental studies in Algeria show that working deep clay soil reduces the runoff coefficient by about 90% [Touaïbia and Gomer, 1992]. In the Boudinar basin in the north of Morocco, [El Abassi, 1999] shows that the runoff coefficient is generally between 2 and 5% on plowed plots. Similarly, in the Guadalentin basin (south-eastern Spain), Cerdà [1997] shows that cultivated soils generate little runoff due to high macroporosity.

On the other hand, the abandoned lands give lower values of the final infiltration which go down to 8.32 mm/h, with a significant decrease after the start of the runoff until the end of the simulation. This remains proportional to the factors marking this type of area in all seasons favoring the low permeability of the soil, namely: the predominance of bare surfaces which exceed 85% in all the plots, the very low roughness, the index of which (Ir%) presents values less than 3.99%, as well as a higher bulk density (1.6 g/cm³). These values reflect a large compaction of the soil and a surface hardening which increase over time and limits the infiltration capacity as much as possible. It remains similar to other results mentioned by some authors in other regions of the Maghreb. In the Eastern Prerifan basins, runoff rates in abandoned land are extremely high (68.60% mm/h) [Abahrour 2009]. In Algeria, the maximum runoff on bare and compacted soil can reach relatively high values: up to 56% in Tlemcen and 80% in Médéa [Morsli et al., 2004].

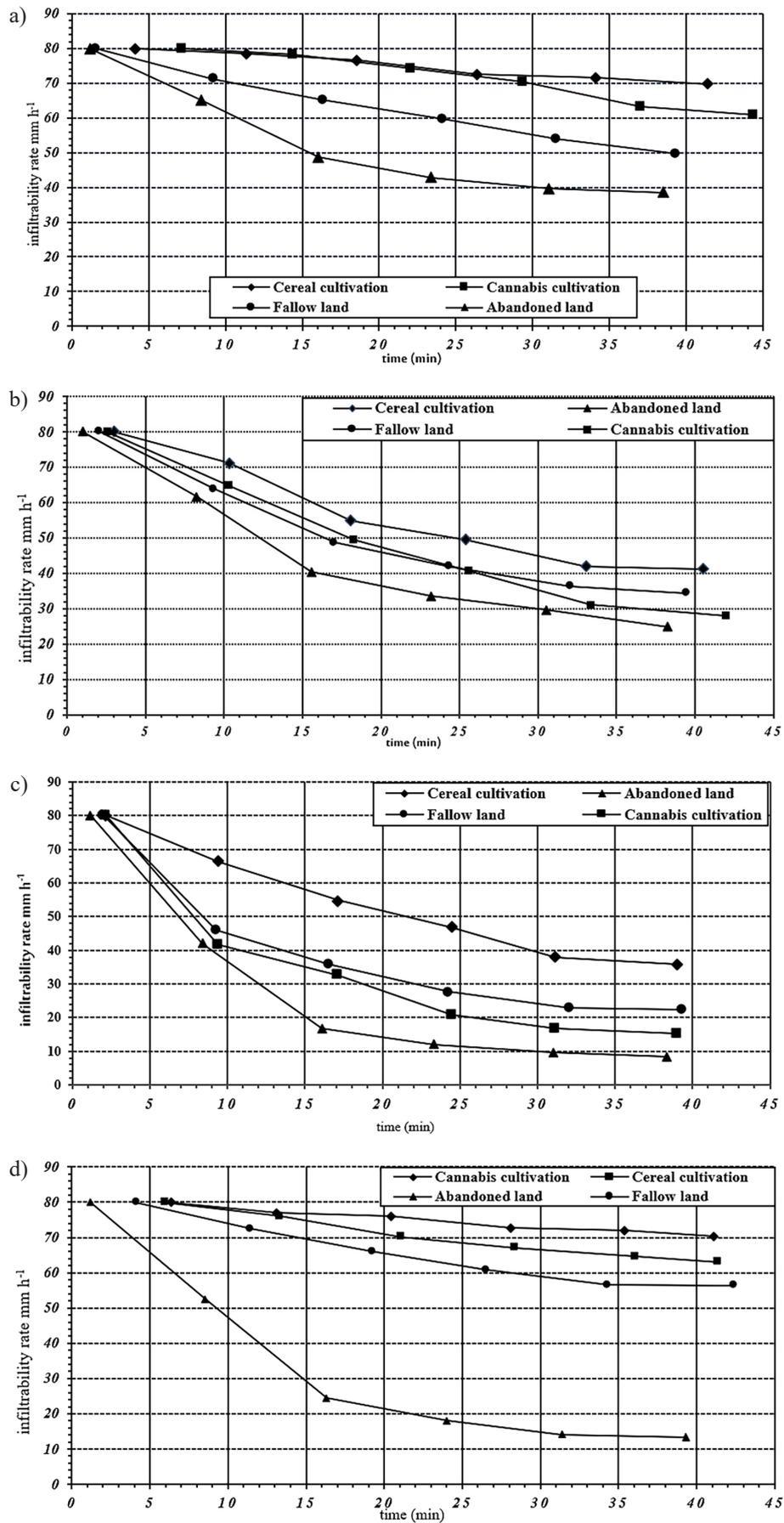


Figure 2. Evolution of the infiltration measured by the rain simulation according to the seasonal soils occupation, (a) summer, (b) autumn, (c) winter, (d) spring

Dynamics of infiltrability according to the seasons

Various rain simulation tests, according to the seasons, have shown that the infiltration capacity has also recorded significant variability. The highest values are recorded in spring and summer; however, low values are recorded in winter and autumn (Figure 2). This largely depends on the initial soil humidity, which remains extremely high in winter and low in summer (Table 1). It is important to point out that the winter and autumn tests were carried out after rainy periods. This increased enormously the rates of humidity and closed surfaces by superficial crusts and consequently, the runoff coefficients which can reach maximum values of 68%. In Algeria, the value of the final infiltration decreases from 35 to 50% from dry to wet soil and from 23 to 45% from wet to very wet soil [Meddi et al., 2005].

Thus, land intended for cannabis cultivation recorded, in the spring, a high final infiltration (FI) value exceeding 70 mm/h⁻¹ (Figure 2d), which remains linked to the high land roughness the index of which (Ir %) has a value of (26.11%), as well as the predominance of open surfaces (89.24%). However, plowing cannabis later in the year, sown in early March through May, increases greatly the soil porosity and allows breaking the superficial crusts. However, the infiltration capacity in the autumn season remains lower, due to the deterioration of roughness and the increase in closed surfaces and bulk density (1.21 g/cm³). This value reflects a compaction of the soil linked to trampling resulting from the frequent passage of farmers during the development of cannabis

plots. This reduces the structural porosity of the soil, limiting largely the infiltration and promoting the runoff (Coulon, 1988). In the Western Moroccan Rif the soil porosity in the cannabis fields does not exceed 53%; however, in the fields of cereal cultivation it can occupy up to 63.7% [Sabir and Roose, 2004].

Detachability of soil particles and solid transport

The sediments transport measured downstream of the plots show clearly the fragility of vertisols with an average of 76.43 g/l. Nevertheless, there is a great seasonal variability, depending on the mode of land use, ranging from 5.15 to 157 g/l (Figure 3). The high solid transport values correspond to cannabis cultivation fields (122.30 g/l), followed by abandoned land (113.66 g/l) then cereal cultivation (55.31 g/l) and finally fallow land (14.46 g/l). These values are in perfect agreement with the results of similar research carried out in other regions of Morocco. In the Eastern Prerif abandoned land in vertisols recorded higher values (255 g/l); however, fallow land recorded lower values (6.61 g/l) [Abahrour et al., 2015]. The low values recorded in fallow land are linked to the high rates of covered areas (82.16%), due to the presence of residual mulch and weeds favoring good surface protection.

Thus, the volume of soil losses remains higher in cannabis cultivation plots compared to other types of occupation; depending on the season, the values remain between 90.66 and 150.54 g/l (Figure 3). These results are proportional to

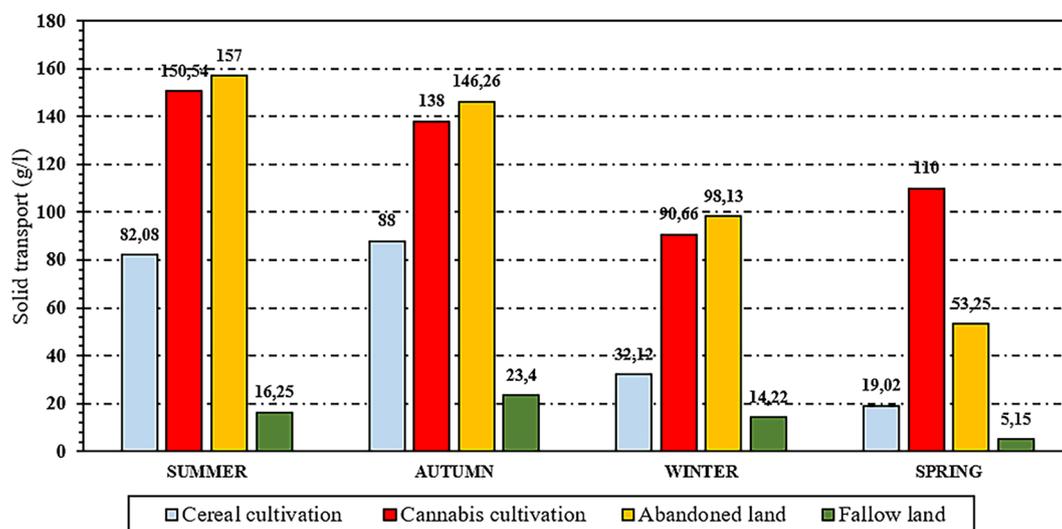


Figure 3. Volume of soil losses according to the seasonal land use

the domination of bare surface in the plots, from sowing to harvest, occupying an average rate of 91.4%. This value depends essentially on the ridging and weeding activities that are carried out during the months of April and May, reducing greatly the roughness of the land. With the considerable extension of cannabis cultivation in recent decades, the frequency of such practices, for a good part of the year, can contribute to increased erosion rates. On the other hand, cereal cultivation presents the values lower than cannabis cultivation, ranging from 19.02 to 82.08 g/l, with an average value of 55.31 g/l. Cereal growing provides significant soil protection during the winter and spring seasons; similarly, after harvesting, it promotes surface conditions that are well protected by crop residues up to 77.65%.

Despite the reduced rates of runoff coefficient in croplands during spring, soil losses remain very high compared to other types of land use. Tillage increases porosity, and temporarily improves infiltration and storage capacity, but it also increases soil detachability [Aserar et al., 2019]. In this sense, several studies in other regions of the Maghreb show that plowed land presents a very degraded state of the soils structures, easily uprooted and transported [Moussadak et al., 2011; Aserar et al., 2019; Amhani, 2022; Arari, 2022]. Similarly, Bufalo and Elleuch [1987] point out that following a continuous and heavy rain, the closed surface state increases by superficial crusts which greatly limit infiltrability while favoring high runoff coefficients. Similarly, experiments have shown that on unstable cultivated soils, clods of less than 1 cm in diameter evolve very quickly in a closed surface due to strong crusting [Roose 1996]. The clods of more than 5-8 cm constitute a sign of compaction; they often behave like stones (low permeability) and are the source of a redistribution of materials which contribute to clogging the pores of the soil surface [Boli, 1996].

The influence of the covered surface state on soil loss is very clear in the fallow plots which recorded lower values, ranging from 5.15 to 23.4 g/l (Figure 6). The low values recorded in spring are comparable to those indicated by Abahrour [2009] in the Eastern Prerif (6.61 g/l) and by [Lelong et al., 1993] in France (2 to 5 g/l). The importance of covered areas in improving soil structure and fertility, and increasing infiltration and decreasing soil loss has been also observed by several researchers [Tribak, 2000; Mouffadal,

2001; Moussadak et al., 2011; Roose et al., 2012; Morsli and Habi 2015]. Thus the soil cover slows the flow of water to the surface, giving it more time to infiltrate effectively reducing soil losses [Aserar et al., 2019]. In this regard, it should be noted that even during the spring season the land devoted to cannabis cultivation presents a high rate of bare surface states (94.12%) marking the start of plowing. This makes this type of land use, widespread in the study area, more sensitive to uprooting (110 g/l); however, fallows do not exceed 5.15 g/l and cereal crops (19.02 g/l).

Determining factors of infiltration and soil loss

The coefficients of determination between the infiltrability and the state of the soil surface presented in Table 2 show clearly a better relationship with the open surfaces and the infiltrability $r = 0.87$; then, the rate of open soil surfaces explains the variability of the final infiltration at 75%. The influence of the opening surfaces on the final infiltrability was well observed in the tests carried out. For example, the plot recently plowed by cannabis in the spring, which has 89.24% of the open surfaces, recorded 70.4 mm/h^{-1} , while the low values of the final infiltration are recorded at the abandoned fields which have low proportions of open surfaces. For comparison, the influence of the opening surfaces on infiltrability, according to the tests carried out in the High Atlas, show a good positive correlation ($R^2 = 0.77\%$) [Cheggour et al., 2008].

On the other hand, the index of roughness shows a fairly significant positive relationship with the infiltrability $r = 0.65$. This factor remains very important in increasing imbibition rain in the first rain simulation waterings due to the presence of clods in recently plowed plots. The initial soil moisture shows, however, a negative relationship with the infiltrability ($r = -0.50$). This is compatible with the results found by [Sabir et al., 2008] which indicate that there is a weak influence of the initial humidity on the infiltration.

The relationships observed between solid transport and surface states indicate a significant positive correlation with the bare surface state ($R^2 = 0.82\%$). The highest solid transport averages are recorded in cannabis fields (122.30 g/l) with the highest percentages of bare surfaces (more than 91.14%). This explains clearly why bare soil surfaces are an important source of sediments in

the basin. In turn, the best relationship is observed between solid transport and the state of covered surface ($R^2 = 0.82\%$). Indeed, the experimental device shows that the low value of solid transport was recorded in spring on the fallow plot (5.15 g/l), which has a high proportion of covered area estimated at 91.18%.

Measurements under simulated rainfall have highlighted the importance of soil surface conditions, in particular covered surfaces, in protecting the soil against the risk of water erosion. This has been observed by several researchers who have used the same simulation device in other regions, between covered areas and soil losses. In the Western Rif) the correlation is significant between detachability and covered surfaces ($r = 0.88$) [Zaher et al., 2021; Cheggour, 2008] in the High Atlas also showed a better positive correlation between the bare surface state parameter and solid transport ($R^2 = 0.71\%$). Similarly [Nadoum K et al., 1995], indicate that increasing the quantity of residues left on the surface is very effective in controlling erosion. According to [Roose, 1996] a mulch covering 80% of the soil can reduce erosion by 90%. Moreover, according to the results obtained by [Moussadek et al., 2011] the presence of residues on the surface reinforces the structural stability of the soils as well as reduces runoff and soil losses by more than 50%. It also represents a strong physical barrier to rain which induces a significant reduction in soil losses compared to bare soils [Aserar et al., 2019].

The relationship between roughness and solid transport is negative ($R = -0.19$); it explains the role of this parameter in reducing the risk of erosion. This parameter remains very low, although the final infiltration exceeds 70 mm/h^{-1} in

plowed land for cannabis cultivation, where the roughness rate is very high in the spring. However, its effect remains limited in the increase of the imbibition rain with the first essay of the simulation. At the end of the test, the roughness deteriorates and makes the surface of the soil homogeneous and crusted, and the runoff water remains the most loaded with sediment, especially in the case of bare surface states which are dominant in cropland.

CONCLUSIONS

This study allowed determining the hydrodynamic and erosive behavior of vertisols in the Wadi Sra basin according to the land uses under simulated rains. The results highlighted the fragility of the soils and the importance of hydric erosion, which constitute an important source of sediments. Moreover, these results confirm the effect of anthropic activities on the hydrodynamic behavior and the detachability of soils, which result in surface states, and variable land use patterns along the year from one field to another. The results obtained confirm that the areas devoted to cannabis cultivation marked the highest value of solid transport. In addition, they confirm that the modes of agricultural activities have an important influence on the states of surfaces which largely control the hydrological behavior and soil erosion.

The field observations as well as the specific measurements, allowed noting that the sheet erosion on the slopes is less important than the gullies which produce the main part of the sediments in the region. Thus, it seems that a rational

Table 2. Impact of soil surface characteristics on infiltrability and erosion risk

| Parameters | <i>R</i> | <i>R</i> ² | Regression equations |
|-----------------------------------|----------|-----------------------|--|
| Final Infiltration (mm/h) | | | |
| % Open surface | +0.87 | 0.75 | IF = 0.023x ² - 0.8122x + 32.35*OS |
| % Prior soil humidity | -0.50 | 0.25 | IF = 0.0014x ² - 0.2722x + 16.727*Hp |
| % Index of roughness | +0.65 | 0.45 | IF = 0.0042x ² - 0.1039x + 5.2483*IR |
| Bulk density (g/cm ³) | -0.60 | 0.36 | IF = -0.0001x ² + 0.0068x + 1.2684*Bd |
| Solid sediment transport (g/l) | | | |
| % Covered area | -0.83 | 0.82 | TS = 0.0046x ² - 1.3331x + 99.084*CA |
| % Bare area | +0.83 | 0.82 | TS = -0.0043x ² + 1.3102x + 1.1551*BA |
| % Index of roughness | -0.19 | 0.10 | TS = -0.0007x ² + 0.0998x + 7.9532*Ir |
| % Clay | +0.82 | 0.68 | TS = 0.6373 - 3.5295*C |
| % Sand | -0.49 | 0.24 | TS = -0.1795 + 42.195*S |
| % Organic matter | -0.40 | 0.16 | TS = -0.0133 + 2.2359*OM |

exploitation, although continuous, of the soil does not present great erosive risks. The low runoff rates on plowed land confirm this statement. Nevertheless, bare, abandoned and overgrazed land suffers serious damage when runoff spills over steep slopes and accumulates in eroding gullies. The structural degradation of fallow or abandoned soils explains the high runoff rates, particularly in the autumn season. These runoff high rates are at the origin of spectacular degradations which evolve into a network of linear incisions often marking the landscape in abandoned lands. Thus, the major sediment exports are mainly related to the exceptional flows that characterize the autumn season when optimal runoff conditions are present. Similarly, the floods of this season, generally very violent and of short duration, are heavily loaded with sediments, seriously threatening infrastructures and urban sites downstream of the Sra basin.

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