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Agricultural Practices for Hillslope Erosion Mitigation: A Case Study in Morocco

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Abstract: In the last decades, the Rif area in Morocco has been frequently affected by soil erosion due to intense rainfall events. In order to help farmers improve their lives and avoid damages caused by this phenomenon, a management project (the MCA Project) aiming to grow fruit trees has been realized. The objective of this study was to evaluate, in three provinces of Morocco, the effect on the hydrological response of selected erosion control management techniques combined with olive tree plantations. The investigated variables were the final infiltration (If), the imbibition of rainwater (Pi), the runoff coefficient (Kr), and the soil detachment (D). In particular, for each investigated soil utilization, three replications of a rain simulation test (80 mm/h) and soil sampling were conducted. Results for surface conditions demonstrate that under vegetation in matorral and fallow, the surface is covered at more than 75% with a high content of organic matter (OM) at 4.5% and 2.6%, respectively. Despite the compaction observed in those land uses, the surface area opened exceeded 90% in the study area. Regarding the soils physical properties, they were rich in silt at more than 40%; the rate of porosity is high where bulk density is low. At the Taounate site, low porosity was at 62% in fallow and at 55% in plowing, with high densities of 1.01 g/cm^2 and 1.2 g/cm^2, respectively. Tests also demonstrate that vegetation has an important role in moisture conservation in the depths of 0 to 10 cm at all sites with macroagregate stability (MA%) compared to plowing sites. In terms of soil hydrology, vegetation reduces the runoff because, under matorral (it was at 0%), it avoids soil erosion.

Keywords: erosion control management; hydrological parameters; runoff risk; Rif; agro-sylvo-pastoral systems; olive trees; agroforestry; soil erosion management; Mediterranean

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1. Introduction

In the Mediterranean basin, soil erosion due to intense rainfall events, i.e., water erosion, is one of the major processes of land degradation, hence constituting a great source of desertification [1]. Moreover, there is an increasing trend of aridity that accelerates such a process [2]. According to FAO studies [3], water erosion affects 50% of the soil in Turkey, 40% in Morocco, and 35% in Greece.

The factors favoring water erosion in this area are generally the fragility of the soil, the irregularity of intense rainfall events, the soil slope, the high air temperatures, which accelerate the mineralization of organic matter, and the vegetation cover reduction caused by climate and man [4]. The most visible form of erosive action is represented by the gullies, which cause the formation of "badlands", which have no agricultural interest, and mudslides, which clog reservoirs and cause a reduction in their storage capacity. Given the problems caused by water erosion, it is necessary to take adequate measures to slow down this phenomenon and ensure sustainable management of water and soil resources [5].

In this regard, many countries of the southern Mediterranean have started, in the last decades, a proactive policy of land development and conservation. Several anti-erosion techniques have been introduced and popularized on sloping land [6–10]. Some countries adopted traditional practices or improved them; others took inspiration from technologies developed in Europe or the United States [11].

In Morocco, there are many national intervention plans dealing with water erosion. Many Soil Defense and Restoration (DRS) intervention actions use fruit trees (such as olive trees, almond trees, and vines) to conserve soil and water, improve the incomes of farmers, and create jobs in the areas of intervention [12].

In the western Rif, Heusch [13] showed that water erosion causes each year more than 3000 t/km^2 of soil to be poured into the sea, and 60% of the eroded soils in Morocco come from this area, which covers only 6% of the national territory. The causes of this degradation are deforestation due to land cultivation and other natural causes such as climate and the nature of the substrate.

Under these constraints, a considerable effort has been provided by the population of the western Rif, thanks to the developed agro-forestry-pastoral farming systems. Various fruit tree species have been planted on the terraces, on the boundaries of plots and properties, and in the gullies [14]. The growing fruit is of capital interest to the population, not only for economic aspects but also for the fruit trees' capacity against water erosion [15].

However, knowledge of the variation of the soil hydrological parameters (e.g., infiltration and runoff) associated with the soil's physical properties (e.g., apparent density, roughness, and porosity) is very important to define the susceptibility of soils to water erosion [16,17]. Equally important is to develop experimental studies for the analysis of erosion phenomena at the basin scale [18]. For instance, the infiltration capacity of surface horizons essentially depends on the state of the soil surface, which is affected by its roughness, biological activity, plant cover [19,20], humidity, cracking, stoniness, aggregation, and water repellency [21].

In the western Rif region (Larache) and in the pre-Rif regions (Taounate and Taza) studies evaluating the impact of fruit tree DRS on the hydrological soil characteristics are rare. Most of such studies have shown only that the production of runoff from the soil is strongly linked to its physical characteristics, surface condition, and vegetation cover [22,23]. In 2015, Simonneaux et al. [24] provided an interesting study on soil erosion in Morocco, where the "soil loss" was estimated by indirect measures.

Due to the limited availability of peer-reviewed experimental studies on erosion in the Moroccan Rif area, the present work represents a novel contribution, especially considering that the majority of experiments on soil conservation based on experimental plots are located in China and the USA, with very limited availability in the South Mediterranean [25]. Most of the recent contributions focus on modeling applications [26] or trackers [27]. At the same time, the Rif is one of the most critical areas for environmental development and is a hotspot for erosion [28].

The study was carried out as a part of the Millennium Challenge Account (MCA)—Morocco Project for the fruit tree component in the Moroccan Rif. The component aims to stimulate the growth of the agricultural sector in this area through the transition from annual extensive crops, and in particular cereals, to multi-annual fruit tree crops that are market-oriented (e.g., olives, almonds, and figs).

Specifically, we first aim at determining the effects of the development on hydrodynamics, surface condition, and other soil characteristics; and second, we study the relationships between hydrological parameters and selected soil characteristics that can serve as indicators of runoff and soil erosion.

2. Materials and Methods

2.1. The Study Area

The study area was included in the MCA—Morocco Project and is part of the Rif in northern Morocco. It extends over the western, central, and eastern Rif.

The three provinces of Larache, Taounate, and Taza were selected as investigation areas. In each of these provinces, some of the perimeters developed in the Fruit Arboriculture Project (FAP-MCA) have been selected as our experimental sites. Table 1 summarizes the investigated study perimeters, and their location is represented in Figure 1.

Table 1. FAP-MCA perimeters retained in each province of our study area.

Project Area	**Zone 1**	**Zone 2**	**Zone 3**
Provinces	**Larache**	**Taounate**	**Taza**
Study Perimeters	Ain Maabad Dar Lkhil	El Gara	Ahl Zaouia
	Ain Hadid	Faytora	Lkassibat
	Sidi Ait Atmane		Ait Maalla

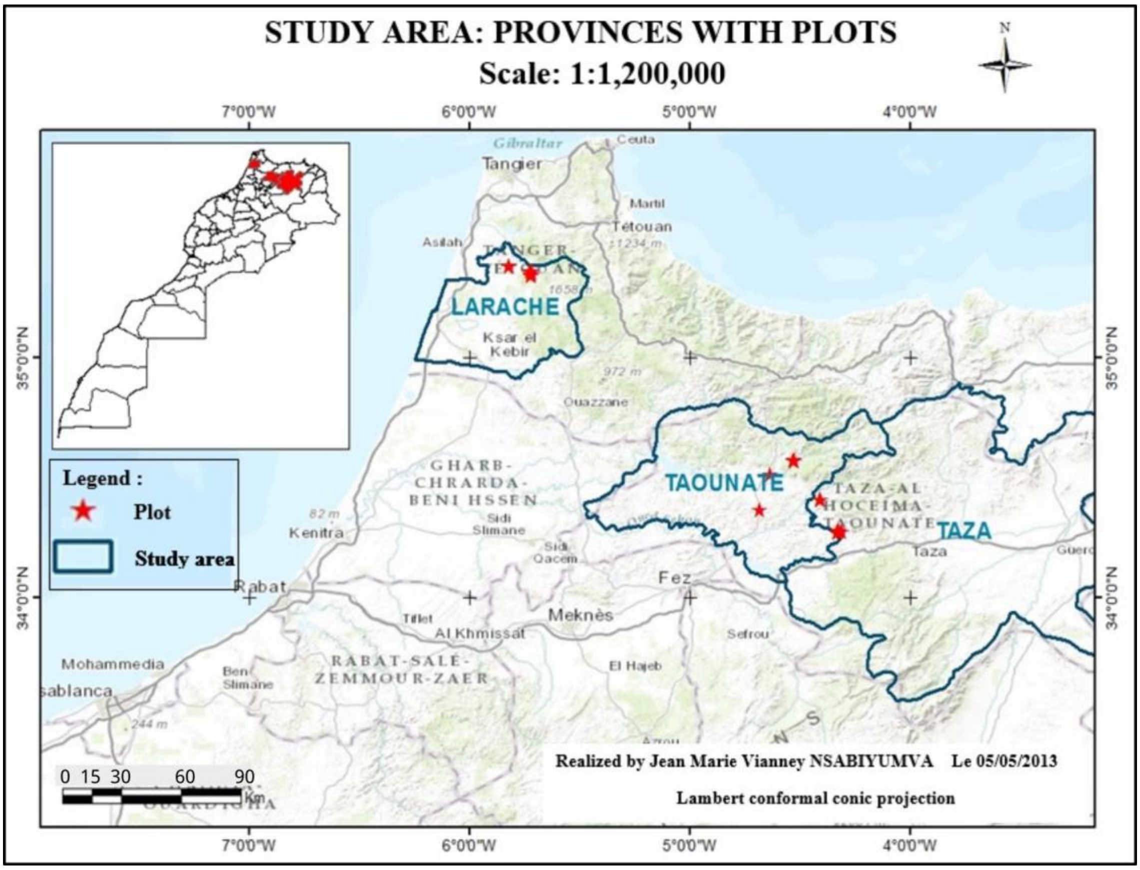

Figure 1. Location of study areas in the provinces of Larache, Taounate, and Taza.

Additionally, for comparative studies, other study perimeters have been added in the first two provinces despite not being developed under the FAP. In Larache, we chose a matorral and a perimeter plowed at Ain Maabid Dar Lkhil; and in Taounate, we chose a third Kifah perimeter developed as part of the "Economic and rural development of the western Rif Project" known in Morocco as the DERRO Project.

2.1.1. Description of the Study Area's Physical Environment

The geological and pedological situation of the study area is reported in Table 2 [29].

Table 2. Comparison among three study sites on geological and pedological conditions.

Sites	Geology	Soils
Larache	marly material of the Cretaceous; schistose scales and quartzite debris	little evolved soils of erosion; calcimagnesic soils with vertic caracter and vertic soils
Taounate	clayey marls	vertic soils eroded
Taza	Soft bedrock or hard geological bedrock and marly material	mineral soils, little evolved soils, calcimagnesic soils, isohumic soils, and soils with iron sesquioxides

About the bioclimate, the province of Larache has a subhumid bioclimate with a warm winter, an average yearly rainfall of 689 mm, an average maximum temperature of the hottest month equal to 33 °C, an average minimum temperature of the coldest month of 7 °C, and a rainfall quotient of 91.9 mm. The province of Taounate has a subhumid bioclimate with a temperate winter; the yearly rainfall is 505 mm; the mean maximum temperature of the hottest month is 36 °C; the average minimum temperature of the coldest month is 5 °C; and the rainfall is 56.4 mm. The province of Taza has a semi-arid to temperate winter; the average cumulative yearly rainfall is 557 mm; the mean maximum temperature of the hottest month is 45 °C; the average minimum temperature of the coldest month is 4 °C; and the rainfall quotient is 45.7 mm. Moreover, the plots studied in those three provinces had slopes ranging from 13% to 40%. In particular, at Larache, the slope of the plots varies between 16% and 37%; in Taounate, the slope is between 16% and 24%. Finally, in Taza, the plots studied were located on a slope of between 13% and 40%.

2.1.2. Land Uses

Regarding land use, forest trees are almost absent except for a few reforested Eucalyptus and pine trees in Taounate, but in the fallow land there were a few trees (juniper) scattered around. *Chamærops humilis* (doum) was present in these perimeters because they were traditionally areas of large crops. Oleander was along the banks of the wadis.

Since the investigated project areas are non-irrigated agricultural areas that were adapted to the olive tree species, the farming system is dominated by cereals and extensive farming to take advantage of pasture stubble and straw during the lean season to feed livestock. This cereal usually grows from medium to steep slopes; hence, it accentuates soil erosion and degradation. According to the beneficiaries of the studied perimeters, farmers in the area tend to abandon extensive breeding (cattle, sheep, and goats) for fruit growing, especially olive trees. This fruit arboriculture project encourages the association of olive trees and cereals in these regions, which will make it possible to conserve water and soil in addition to maintaining livestock farming. Moreover, the discussions with farmers in the field revealed that there are also vegetables, market gardening, and fallow land.

2.1.3. Choice of Experimental Perimeters

The objects of experiments were chosen according to the empirical method according to the knowledge of the field, and the objectives were fixed within the framework of this research. These perimeters are part of those planted by the FAP; it was deemed appropriate to take two types per perimeter, namely plowing and fallowing, to conduct comparative studies to better understand the impact of the cultivation techniques used at each cultivated site on soil erosion. Thus, fallow and plowing were considered when simulating rainfall in these three provinces for each zone. Therefore, in Larache, Taounate, and Taza, there were, respectively, 6, 4, and 6 sites for the simulation of rainfall. However, all the perimeters added for the comparison were not concerned by rainfall, except the Larache matorral, which showed no runoff. In total, the rainfall simulation concerned 17 sites in 3 repetitions, therefore 51 simulation plots.

2.2. Methods

2.2.1. Rainfall Simulation Tests

Before conducting the rainfall simulation, the choice of the location of the experimental plot was made according to the following criteria: the representativeness and homogeneity of the soil surface, and the degree and direction of the slope. In each selected plot, there was the installation of the simulation plot, which has an area of 1.66 m × 0.6 m (1 m^2). Two 1.66-m metal angles were inserted into the ground for about 5 cm to avoid lateral water losses (leaks). Downstream of these two angles, a triangular metal platform was installed to direct runoff water and sediment into a container. Afterward, the ground surface condition was described by the quadrat point method [30] using the diagonals and a stake every 2 cm. Thus, the surfaces covered at ground level (SC, %) include all that is litter (L, %), vegetation (Veg, %), and pebbles not integrated into the soil mass (CNI, %). The open surfaces (SO, %) mainly concern the cracks (Fiss, %), the galleries, and the clods (Mt, %), while the closed surfaces (SF, %) correspond to the areas closed off by a film (Pel, %) or to the visible pebbles embedded in the ground (CI, %). In addition, the total soil organic matter (OM, %) was obtained after the determination of the carbon content (C, %) since the ratio of organic matter to carbon is almost constant and equal to OM/C = 1.72 [31]. In addition, other parameters such as the soil penetration resistance (PEN, kg/cm^2) and the shear strength to the force used by the water in detaching the aggregates (SS, kg/cm^2) related to the surface condition were measured, respectively, by a pocket penetrometer and a scissometer in nine measurements (3 repetitions × 3 for each simulation plot). The simulation plot (Figure 2) was divided into three parts along the angles delimiting the plot. Finally, the roughness index (Ir, %) was measured by the chain method [30], which consists of using a metal chain laid in a straight line. The roughness index is determined by Ir = $(L_d - l)/l$) where L_d (m) is the length of the extended chain and l (m) is the width of the plot over the width of the plot. Three repetitions were carried out to also measure the roughness index.

Figure 2. Images related to the construction of the experimental plots.

After the evaluation of the surface condition, the preparation of the rainfall simulation device has been carried out. This consisted of a watering ramp 50 cm wide, less than that of the plot, and connected by a flexible pipe to a tank that was filled with 60 L of water and that was located a few meters higher than the plot. Subsequently, the adjustment of the simulated rainfall intensity (on average 80 mm/h) was carried out after several tests using a valve at the outlet of the tank. A graduated cylinder and a stopwatch were used. The measurement of the simulated rainfall intensity was carried out at the beginning and end of the simulation.

After obtaining the desired rainfall intensity, the rainfall simulator was used. The rainfall simulator can be considered a simple manual irrigator [30], which allows drops with relatively little energy to be projected onto a surface of 1 m^2. Watering was performed at an average height of 50 cm above the soil surface. It was a question of distributing the water and avoiding watering outside the plot. The watering was carried out simultaneously with the timing: at the beginning, the elapsed time (reaction time: Tr, min) was recorded for the triggering of the runoff to quantify the height of the imbibition rain (Pi, mm).

Then, the recording of the amount of runoff water every 5 min was performed until the stabilization of the runoff; otherwise, until the time reached one hour. The collected runoff water has been put in a container and then stored in a transparent jerrycan with a capacity of 10 L to later measure the quantities of sediments in the laboratory.

On a previously prepared simulation sheet, the various measurements were noted: location of the site and coordinates, degree of slope, date, surface condition, runoff trigger time, runoff volumes, and so on. A simulation test required, on average, 3 h of work for a team of 3 people. Through these simulation tests, we managed to determine the final infiltration (If, mm/h), which corresponds to the average of the last two permanent infiltration values, and the imbibition rain (*Pi*, mm), which is the height of water infiltrated before the start of runoff. *Pi* is calculated from the soil reaction time (*Tr*, min) and the simulation rainfall intensity (*i*, mm/h). It was given by the following formula:

$$Pi = (i \times Tr)/60.$$

2.2.2. Soil Sampling

Two soil samples (1 kg each) were taken next to the rainfall simulation plot at a depth ranging from 0 to 5 cm to determine the soil structural stability (rate of water-stable macroaggregates) and to carry out other soil analyses (particle size and organic matter) in the laboratory.

The undermining facilitated their removal. At three points around the rainfall simulation plot, a soil sample is taken in depth increments of 0–5, 5–10, and 10–15 cm to assess the soil bulk density using a 10 cm long cylinder and 4 cm in diameter. All the samples were kept away from heat and transported to the laboratory for the following analysis.

2.2.3. Physical Analyses of Samples

The physical analyses of the samples concerned the following parameters: bulk density, total porosity, soil moisture, structural stability measured by macroaggregate stability, and detachability. The analyses were conducted in the laboratories of the National Forestry School of Engineers and the Agronomic and Veterinary Institute (IAV) Hassan II. In particular:

- Bulk density (Da, g/cm^3):

After having placed the soil samples taken at different depths in boxes for drying, the samples have been weighed fresh and dried after 24 h in an oven at 105 °C. According to Blake [32], the formula for calculating the bulk density is:

$$Da = ma/V$$

With *ma* = anhydrous mass of soil (g); *V* = volume of sampling cylinder (cm^3).

- Total porosity (*P*, %) is deduced by the following formula [32]:

$$P = 100 - [(Da/Dr) \times 100]$$

With Dr = actual soil density, which is a constant = 2.65 g/cm^3

- Soil moisture (H, %)

The collected samples were weighed to determine their fresh weight (Pf, g). In the laboratory, these samples were dried in an oven at 105 °C for 24 h and weighed again to find their dry weight (Ps, g). The difference between the fresh weight (Pf) and the dry weight (Ps), which gives the weight of water (Pwater, g) and the soil moisture (H, %), was obtained by this formula [33]:

$$\text{H} = \text{Pwater}/\text{Ps} \times 100$$

- Rate of water-stable macroaggregates (MA, %)

For this study, the structural stability is estimated by a stability test that is based on disaggregation combining wetting and sieving. This method [34] is used to estimate the rate of water-stable macroaggregates with a diameter greater than 1 mm but between 1 and 2 mm. Aggregates of 1 to 2 mm in diameter are shaken vigorously in the test tube, and stable aggregates of more than 0.25 mm in diameter are measured. Each study perimeter has been considered to have a homogeneous stratum, and it has been subjected to three repetitions.

- Detachability of soils (D, g/m^2/h)

After agitation to mix the runoff collected in the simulation plot, quantification was performed after water removal by pipette. Then, the drying of the deposited sediments was carried out in the oven for 24 h. Finally, the weighing made it possible to give the quantity of sediments from which the detachability of the soils (D) is obtained by the following formula [35]:

$$D = \textit{Sediment weight}\ (\text{g}) \times [60/\textit{simulation time}\ (\text{min})]$$

2.3. Statistical Data Processing

To be able to compare the effects of land uses on the hydrological behavior of soils and to find the correlations that may exist between the different parameters and the investigated variables, statistical processing was carried out on the observed data. The treatment consisted of analyses of variance (ANOVA) and simple and multiple comparisons of the means according to the method of the least significant difference (P.P.D.S.).

Since the soil samples collected in Larache have different numbers depending on the land use, the Scheffé test was used [36]. For the other regions (Taounate and Taza), there are only two situations to compare (plowed land and fallow). For this, the recommended test is a T-Student for independent samples. The probability threshold considered for all the tests is 5%. Through a simple linear regression, the Pearson correlation coefficient R was obtained, and regression equations were determined to better understand the soil parameter that most influences the hydrological parameters (If, Pi, Kr, and D).

3. Results and Discussions

3.1. Results

3.1.1. Effects of Land Uses on the Surface Conditions

After the application of the statistical tests and the comparison of the average values obtained for each property of the soil in the different land uses between the three provinces (Table 3), it was noticed that the higher contents of organic matter (OM) are observed under matorral and fallow (4.50% and 2.60%, respectively). For plowed sites, we obtained values ranging between 2.03% and 3.56%. In addition, it was found that the studied surface parameters are statistically significantly different between plowing and fallow.

Table 3. Effects of land uses on the surface conditions of the FAP-MCA perimeters in Larache, Taounate, and Taza provinces in Morocco.

Provinces	**Larache**			**Taounate**		**Taza**	
Land Uses	**Matorral**	**Fallow**	**Plowing**	**Fallow**	**Plowing**	**Fallow**	**Plowing**
	Organic matter						
OM (%)	4.43	3.56	2.8	3.46	3.1	2.56	2.03
	Surface conditions						
SN (%)	1.08 a	9.00 a	83.69 b	22.83 a	75.67 b	18.25 a	90.83 b
SC (%)	99.25 b	91.00 b	16.31 a	77.17 a	24.50 b	81.75 b	9.17 a
SO (%)	99.90 b	90.78 a,b	78.67 a	96.67 a	90.17 b	92.33 b	82.50 a
SF (%)	0.10 a	9.22 a,b	19.67 b	3.34 a	9.83 b	7.58 a	17.50 a
PEN (kg/cm^2)	0.71 a	0.68 a	0.59 a	0.37 a	0.25 a	1.30 a	1.50 a
SS (kg/cm^2)	2.49 b	2.37 a,b	1.69 a	3.22 a	2.06 b	2.80 a	2.63 a
Ir (%)	3.16 a	16.94 a,b	22.17 b	21.21 a	44.33 b	16.12 a	31.26 a

Note: OM—rate of organic matter; SN—percentage of the bare surface; SC—rate of the cover surface; SO—rate of the open surface; SF—rate of the closed area; PEN—force of penetration resistance; SS—force of shear resistance; Ir—rate of roughness. The means of the same row followed by the same letter are not statistically different ($p < 0.05$).

However, the results obtained show that the soils under fallow were covered (SC) and open (SO) to more than 75%, and the soils of the plowed plots had bare and open surfaces greater than 75%. In terms of fallow land, we have covered areas of 91% in Larache, 82% in Taza, and a lower rate in Taounate (77%). The open surfaces exceed 90% for the three regions.

Moreover, the soils under fallow are more compacted and more resistant in Larache and Taounate. At Taza, the trends are reversed only for penetration (PEN) and shear strength (SS). Although the penetrometer values are not statistically different, the value is more pronounced in Taza in both fallow (PEN = 1.3 kg/cm^2) and plowing (PEN = 1.5 kg/cm^2) compared to the other two regions. This situation in Taza could be due to the presence of crusts formed on the surface during previous rains on the plowed and sun-dried land under which our experiments were carried out.

3.1.2. Effects of Land Uses on Soil Physical Properties

Among the physical properties of the soils in the three provinces is the soil's texture. Then, the soils analyzed are generally rich in silt, at more than 40%, despite the presence of a high rate of clay and a few sandy particles.

Moreover, according to the results obtained, the soils of Larache have a sandy clay texture with 40.11% clay, 43.96% silt, and 15.22% sand. Those of Taounate have a silty clay texture composed of 39.24% clay, 40.46% silt, and 20.29% sand. In Taza, the soils analyzed had 37.61% clay, 42.83% silt, and 19.58% sand, and they had a texture of fine clay silt (Table 4).

Table 4. Texture of soils analyzed of the FAP-MCA perimeters in Larache, Taounate, and Taza provinces at Morocco.

Provinces	**SF (%)**	**SG (%)**	**Arg (%)**	**LG (%)**	**LF (%)**	**Texture**
Larache	7.60	7.62	40.81	29.15	14.81	Sandy clay
Taounate	16.92	3.37	39.24	25.86	14.60	Silty-clayey
Taza	6.92	12.66	37.61	19.46	23.37	Fine clay silt

Note: SF (%): Fine sand rate; SG (%): Coarse sand; Arg (%): Clay rate; LG (%): Coarse silt rate; LF (%): Fine silt rate.

Regarding the physical properties of the soils in the three provinces (Table 5), it can be noticed that the soils are generally loosely packed because the bulk density (Da) varies from 0.79 to 1.20 g/cm^3 at the soil surface (0–10 cm). At sites covered by litter or vegetation (matorral and fallow), the density values do not show significant statistical differences and have low surface values (0.80 to 1.00 g/cm^3). The highest values (1.01 and 1.20 g/cm^3) are observed in Taounate for fallow and plowing, respectively. These density values increase from surface to depth.

Table 5. Effects of land uses on the physical properties of soils in the FAP-MCA perimeters in Larache, Taounate, and Taza provinces in Morocco.

Provinces	Larache				Taounate		Taza	
Land Uses	**Matorral**	**VPO**	**Fallow**	**Plowing**	**Fallow**	**Plowing**	**Fallow**	**Plowing**
Soil Physical Properties								
Da10 (g/cm^3)	0.79 a	0.82 a	0.90 a	0.88 a	1.01 a	1.20 b	0.90 a	1.00 a
Da20 (g/cm^3)	0.87 a	0.93 a	0.99 a	0.88 a	1.11 a	1.31 a	1.00 a	1.14 b
Da30 (g/cm^3)	1.09 a	0.94 a	1.00 a	0.92 a	1.31 a	1.27 a	1.03 a	1.13 a
P10 (%)	70.22 a	69.14 a	65.99 a	66.65 a	61.97 b	54.64 a	66.10 a	62.25 a
P20 (%)	67.00 a	65.01 a	62.70 a	66.86 a	58.75 a	50.54 a	62.26 b	56.72 a
P30 (%)	58.71 a	64.42 a	62.10 a	65.19 a	58.30 a	52.04 a	61.03 a	57.18 a
H10 (%)	34.59 b	29.87 a,b	29.79 a,b	24.49 a	42.10 b	18.04 a	19.28 a	16.93 a
H20 (%)	32.31 b	31.70 a,b	28.51 a	28.23 a	40.54 b	17.57 a	22.03 a	20.02 a
H30 (%)	29.04 a	46.01 a	25.29 a	28.13 a	44.67 b	20.84 a	22.03 a	22.10 a
MA (%)	34.02 a,b	58.37 b	19.82 a	17.46 a	54.51 b	40.94 a	59.00 a	43.46 a

Note: Da "n": Bulk density at "n" (cm) soil depth; P "n": Rate of porosity at "n" (cm) soil depth; H "n": Soil moisture at "n" (cm) soil depth; the means of the same row followed by the same letter are not statistically different ($p < 0.05$).

For the porosity (P) at the level of these three provinces, an expected opposite trend to that of the evolution of bulk density was observed, with the lowest values in Taounate (respectively 62% and 55% on the surface for fallow and plowing) where densities were high. The porosity increased from surface to depth. However, the porosity values in the plots covered by vegetation (matorral and fallow) are not statistically different except in Taounate.

The soil moisture content (H) at the level of the provinces of study increased with depth. These values presented significant differences in covered and non-plowed plots, even if these values cannot be directly linked to erosion control.

However, on the surface and at depth (0–10 cm), this rate remains high at the level of fallow land compared to plowing. Thus, the fallow land in Taounate had 42.10% soil moisture, followed by that of Larache with a soil moisture rate of 29.79%, and finally that of Taza with a soil moisture rate of 19.28%. The lowest soil moisture levels exist at the plowing level and vary from 16% to 25% for these three regions.

As for the stable macroaggregate rate (MA), there are no significant statistical differences in terms of plowing in the three provinces. However, these values are statistically significantly different in plots covered by vegetation or litter. They are high in all fallows in the three provinces compared to plowing.

3.1.3. Effects of Land Uses on Soils Hydrological Properties

From the point of view of hydrological properties (Table 6), the values of the final infiltration (If) do not show a statistically significant difference at the level of fallows despite the existence of runoff. The final infiltration remains higher in the plowings than in the fallows at the level of the three provinces. Indeed, the plowing being freshly stirred is very loose and very open, as demonstrated by P (%) values. This state favored infiltration in all the plowing perimeters in the three regions after one hour of simulation. The furrows along contour lines have created a roughness favorable to infiltration, especially in Taounate and Taza, where the runoff coefficient is zero and without detachability.

In Larache, since the plowing was carried out on the steepest slope, this situation favors runoff (15%) and soil detachability (29 g/m^2/h).

Table 6. Effects of land uses on the hydrological properties of soil of the FAP-MCA perimeters in Larache, Taounate, and Taza provinces in Morocco.

Provinces	Larache		Taounate			Taza	
Land Uses	Fallow	Plowing	Matorral	Fallow	Plowing	Fallow	Plowing
Soil Hydrological Properties							
If (mm/h)	39.68 a	64.70 ab	74.4 b	55.52 a	73.43 a	69.36 a	71.53 a
Pi (mm/h)	4.74 a	24.03 a	74.4 b	36.57 a	73.43 a	46.12 a	71.53 a
Kr (%)	46.61 b	14.63 a	0.00 a	13.18 a	0.00 a	2.23 b	0.00 a
D ($g/m^2/h$)	2.28 a	29.21 a	0.00 a	1.07 a	0.00 a	0.20 a	0.00 a

Note: If—final infiltration; Pi—imbibition of rainwater; Kr—rate of runoff coefficient; D—detachability. The means of the same row followed by the same letter are not statistically different ($p < 0.05$).

For the fallow sites, we found a higher runoff coefficient but fewer eroded particles in the direction of the slopes than in cultivated soils.

In Larache province, the vegetation under matorral seems to promote infiltration as much as possible (If = 74.4 mm/h) and reduce runoff and detachability as much as possible (D = 0 $g/m^2/h$).

3.1.4. Influences of Soil Parameters on Their Hydrological Properties in Larache, Taounate, and Taza Provinces of Morocco

The highlighting of the influence of soil parameters on their hydrological properties was conducted by studying the correlation between the hydrological properties and the explanatory variables (Table 7).

Table 7. Relationship between hydrological properties (If, Pi, Kr, and D) and physical parameters and soil surface condition in Larache province.

Explanatory Variables	Regression Equations	R^2
	Final infiltration: If (mm/h)	
SO	If = −50.352 + 1.289 × SO	0.785
PEN	If = 85.263 − 49.559 × PEN	0.696
SS	If = 127.589 − 33.978 × SS	0.653
P20	If = −254.402 + 4.771 × P20	0.428
	imbibition rainwater: Pi (mm/h)	
SO	Pi = −107.779 + 1.616 × SO	0.619
PEN	Pi = 62.387 − 62.319 × PEN	0.550
P10	Pi = −499.655 + 7.865 × P10	0.446
	Runoff coefficient: Kr (%)	
SO	Kr = 134.580 − 1.326 × SO	0.696
PEN	Kr = −7.292 + 55.027 × PEN	0.564
SS	Kr = − 47.579 + 34.514 × SS	0.717
	Detachability: D ($g/m^2/h$)	
	<60%	

Note: If—final infiltration; Pi—imbibition rainwater; Kr—runoff coefficient; D—detachability; SO—open surface; PEN—resistance to penetrometry; SS—resistance to shear strength; P "n"—porosity at "n" cm of soil depth; R^2—correlation coefficient.

Thus, the variables considered more explanatory of hydrological properties (final infiltration (If), imbibition of rainwater (Pi), runoff coefficient (Kr), and detachability (D)) are those whose coefficient of determination (R^2) is greater than 60%. The variables that influenced them were different in the investigated provinces. The final infiltration was positively correlated with soil cohesion parameters (open surface and porosity) and negatively correlated with settlement ones. The open surface explained its variation at 79%, and resistance to penetration (PEN) explained it at 70%. In the province of Taounate, the final infiltration is positively correlated with the roughness index (Ir), which explains it at 93%, and negatively correlated with the shear strength (SS), which explains it at 86%. For Taza, the final infiltration is mainly explained by the roughness index (Ir) and the surface porosity at a soil depth of 0 to 10 cm (P10).

Concerning the imbibition of rainwater (Pi), the open surface with a positive correlation is the only variable that explains it to more than 60% in Larache. In the province of Taounate, its variation is explained by three parameters at more than 74%. Thus, two of these parameters were negatively correlated with Pi, such as the shear strength (SS) and the resistance to penetrometry (PEN). They explained its variation, respectively, at 94% and 87%. However, the correlation with the roughness index (Ir) was positive and explained Pi at 75%. For Taza province, the open surface (SO), the roughness index (Ir), and the porosity at a soil depth of 0 to 10 cm (P10) exerted their influence with respective rates of 87%, 84%, and 73% with a positive correlation.

For the runoff coefficient (Kr), in Larache province, it is positively correlated to shear strength (SS) and negatively correlated to the open area (SO) that influenced it, respectively, at 72% and 70%. In Taounate, the roughness index (Ir), with its negative correlation to Kr, and the shear strength (SS), with a positive correlation, explained their influence on Kr, respectively, at 85% and 79%. For Taza province, the highest correlations for Kr were obtained with the open surface (SO) and the roughness index (Ir), at 88% and 79%, respectively.

In these three provinces, the three hydrological parameters (If, Pi, and Kr) were explained by the parameters of soil cohesion (SO, Ir, and P10), which allow water to infiltrate. In addition, they are also explained by the settlement parameters (SS and PEN), which promote runoff by reducing the infiltration time.

For detachability, all variables explained it to less than 60% in Larache (see Figure 3 and Table 7). However, in Taounate (see Figure 4 and Table 8), it is more positively correlated with shear strength (SS), surface of 0–10 cm (H10) soil moisture, and resistance to penetrometry (PEN). The latter explain it respectively at 99%, 85%, and 84%. In addition, detachability is negatively correlated with the roughness index (Ir), which explains its 82% variation. Finally, in Taza (see Figure 5 and Table 9), the correlations for detachability were negative for all three explanatory parameters. However, it is explained by the open area (SO) at 89%, the roughness index (Ir) at 79%, and the surface porosity at a soil depth of 0 to 10 cm (P10) at 66%. Apart from surface soil moisture (H10), which is the only new explanatory parameter of detachability, the others related to cohesion (SO, Ir, and P10) and compaction (SS and PN) had already explained If and Pi in these three provinces. Thus, they are those related to soil compaction that positively influence detachability.

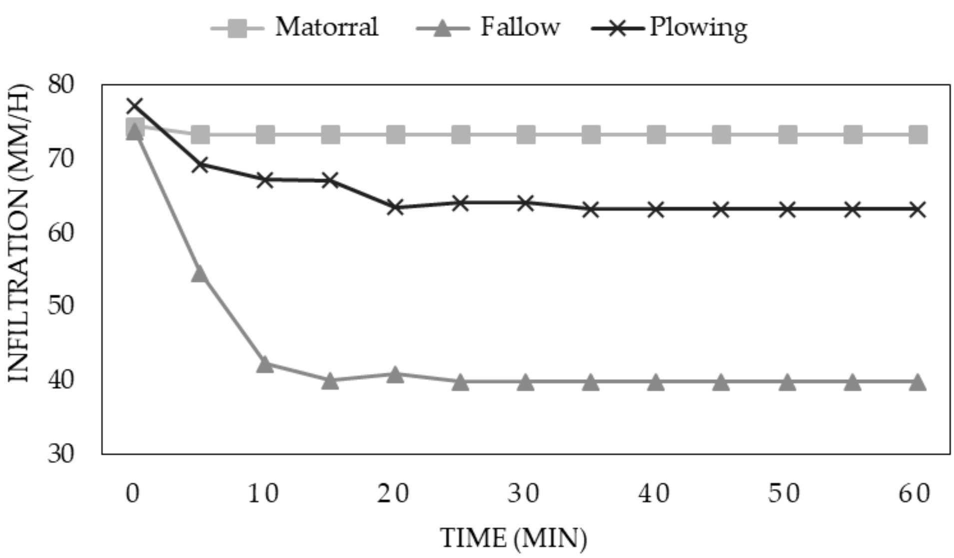

Figure 3. Effect of land use (fallow, plowing, and matorral) on the infiltration capacity [I (mm/h)] of soils in the perimeters studied in Larache province.

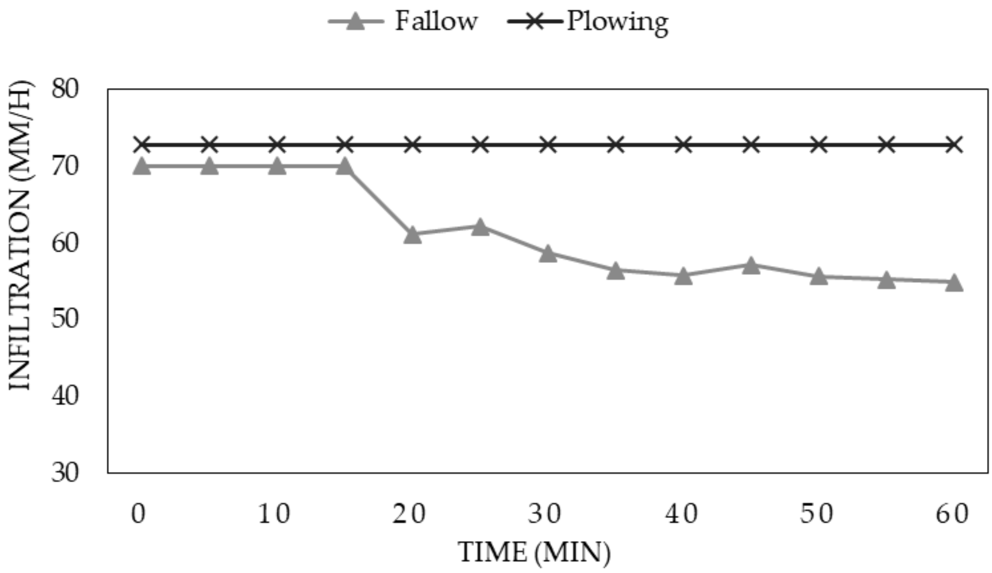

Figure 4. Effect of land use (fallow and plowing) on the infiltration capacity (I (mm/h)) of soils in the perimeters examined in Taounate province.

Table 8. Relationship between hydrological properties (If, Pi, Kr, and D) and physical parameters and soil surface condition in Taounate province.

Explanatory Variables	Regression Equations	R^2
	Final infiltration: If (mm/h)	
PEN	If = 89.09 − 80.699 × PEN	0.464
SS	If = 75.374 − 9.629 × SS	0.858
Ir	If = 0.572 + 2.729 × Ir	0.930
	Imbibition rainwater: Pi (mm/h)	
PEN	Pi = 112.150 − 187.376 × PEN	0.873
SS	Pi = 74.298 − 17.052 × SS	0.938
Ir	Pi = −42.142 + 4.148 × Ir	0.749
	Runoff coefficient: Kr (%)	
PEN	Kr = −12.165 + 61.487 × PEN	0.400
SS	Kr = −1.993 + 7.583 × SS	0.790
Ir	Kr = 56.813 − 2.145 × Ir	0.853
H10	Kr = −8.877 + 0.402 × H10	0.517
	Detachability: D ($g/m^2/h$)	
PEN	D = −1.133 + 5.463 × PEN	0.835
SS	D = −0.056 + 0.521 × SS	0.986
Ir	D = 3.561 − 0.129 × Ir	0.819
H10	D = −0.685 + 0.032 × H10	0.849

Note: If—final infiltration; Pi—imbibition rainwater; Kr—runoff coefficient; D—detachability; PEN—resistance to penetrometry; SS—resistance to shear strength; Ir—roughness index; H10—soil moisture at 10 cm depth; R^2—correlation coefficient.

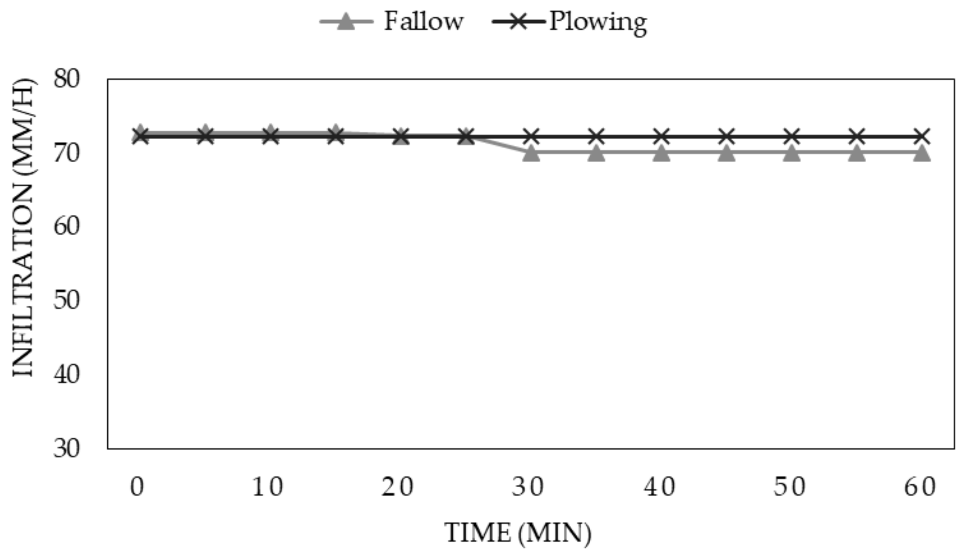

Figure 5. Effect of land use (fallow and plowing) on the infiltration capacity [I (mm/h)] of soils in the perimeters examined in Taza province.

Table 9. Relationship between hydrological properties (If, Pi, Kr, and D) and physical parameters and soil surface condition in Taza province.

Explanatory Variables	Regression Equations	R^2
	Final infiltration: If (mm/h)	
SO	If = 30.777 + 0.429 × S0	0.603
PEN	If = 77.428 − 4.427 × PEN	0.534
Ir	If = 53.539 + 0.853 × Ir	0.824
P10	If = 40.453 + 0.451 × P10	0.819
	Imbibition rainwater: Pi (mm/h)	
SO	Pi = -214.019 + 2.950 × SO	0.874
Ir	Pi = −38.642 + 4.916 × Ir	0.839
P10	Pi = −102.471 + 2.426 × P10	0.726
	Runoff coefficient: Kr (%)	
SO	Kr = 23.542 − 0.242 × SO	0.879
Ir	Kr = 8.865 − 0.391 × Ir	0.788
	Detachability: D ($g/m^2/h$)	
SO	D = 2.107 − 0.022 × SO	0.879
Ir	D = 0.793 − 0.035 × Ir	0.788
P10	D = 1.230 − 0.017 × P10	0.662

Note: If—final infiltration; Pi—imbibition rainwater; Kr—runoff coefficient; D—detachability; SO—open surface; PEN—resistance to penetrometry; Ir—roughness index; P10—porosity at 10 cm soil depth; R^2—correlation coefficient.

3.2. Discussion

3.2.1. Effects of Land Uses on Surface Conditions

In those three provinces, the results obtained on organic matter, which are superior to 2% in plowed sites and superior to 2.60% under matorral or fallow, can be justified considering the prevention of organic matter mineralization during soil aeration following tillage, confirming the previous literature [36].

In this situation, the open surfaces exceed 90% in all three regions. This situation could be explained by the plant cover of the herbaceous carpet and the litter observed, as well as the cracks and galleries created under the effect of the very intense pedofaunal activity at the level of these fallows. In addition, as vertisols are the dominant soils there, cracks due to roots explain these high values.

Indeed, many researchers [37–39] showed that in vertisols with plants, there are much smaller cracks in the rows of these plants. This pattern has been attributed to the proliferation of roots holding the soil together. In addition, vertisols are known to have open cracks at the surface or at depth during some years. These cracks can be at least 1 cm wide and up to 50 cm deep. Those cracks are absent if these soils are irrigated [40]. These high proportions of open and covered surfaces obtained at the fallow level are consistent with these studies, which have shown that fallow land allows organic restitution and stimulates the activity of soil fauna and microflora [41–43] in Africa south of the Sahara, in the Central African Republic [44], and in the Ivory Coast [45].

The highest rate of bare surfaces is observed in the Taza region at 90.83%, and that of open surfaces is obtained in the Taounate region at 90.17%. This could be explained by the fact that the plowed soils were freshly disturbed and that the clods, cracks, and embedded stones would have contributed to the increase in the opening in these regions. These results agree with those of the authors, who specified that the clods crack but that they experience significant variability in the state of cracking and their size after plowing in the compacted treatment [46]. In addition, these cracks and clods are also related to swelling clays found in vertisols [40].

The high observed penetrometer values would be signs of compaction due to trampling by livestock, which has been confirmed by other studies [47–49]. Concerning the results in Taza, previous works show that, in plowed sites, precipitation-led erosion with detaching and displacement of soil particles can lead to the clogging of the interstices of the soil surface, forming a slacking crust a few millimeters deep in thickness [50,51]. The roughness (Ir, %) was much more pronounced at the level of the plowing than the fallows in all three provinces, which is explained by the fact that the clods at the level of the plowing in this study area created microreliefs consisting of random irregularities or oriented by the tillage [52].

3.2.2. Effects of Land Uses on Soil Physical Properties

This situation on the bulk density could be explained by the compaction under the effect of the trampling of animals in matorral and fallow land as well as the effect of the plow pan at field level. In some research work, it has been shown that the passage of agricultural machinery aggravates compaction because the mechanical strength of the aggregates decreases [53,54]. Agricultural tools, in particular the plow, can induce the formation of the slaking crust down to a depth of 20 to 30 cm [55].

For porosity (P), the situation observed is in line with the research of Richard et al. [56], which attests that compaction reduces the pores in the soil. Therefore, compaction increases the bulk density of the soil [57,58] and decreases porosity. Porosity values remained higher in plots under plant cover than in plowed ones. Some studies qualify this porosity as of biological origin because the presence of plant residues on the surface and the absence of mechanical disturbance favor the installation of earthworms, which create cavities or galleries [59–61].

For the soil moisture content (H), vegetation, litter, and surface pebbles hinder evaporation, which would explain the high soil moisture rate in Taounate in fallow land. At the level of plowing, evaporation is relatively higher, which reduces the soil moisture rate. Several authors have found similar results, which testify that under vegetation cover or mulch, there is better conservation of soil moisture compared to plowed and uncovered soils because they prevent water evaporation [62,63]. The values for stable macroaggregate rate (MA) obtained in all fallows remain high in the three provinces compared to plowing. Some authors have shown that working the soil would reduce its structural stability [64].

3.2.3. Effects of Land Uses on Soils Hydrological Properties

Regarding the soil hydrological properties, the final infiltration has been influenced by the surface state. So, at Taounate and Taza, the runoff coefficient was zero. The irregularities created by the clods and the roughness due to the used tools allow the storage of the water volume in their orientation [65]. In addition, Lipiec et al. [60] testify that the macroporosity is more important at the level of the plowing and that the infiltration passes through this structural porosity. From there, these results in Larache are confirmed by Lipiec et al. [60] on the importance of macroporosity and microreliefs in plowing because infiltration reached 85%. These results are in the same direction as those of other authors who specify that, on cultivated soils, the pores are clogged by the fractionated aggregates because of the mechanical disintegration due to the raindrops. There is then the formation of the capping crust, which reduces infiltration [66] because the reduction in roughness leads to a reduction in the stored water volume [67]. The diminished microreliefs will then be exceeded, and there will be runoff oriented in the direction of the roughness [65], and indeed, in Larache, this orientation is according to the slope. This same author also explained the tearing mechanism of the particles during runoff in cultivated soil. It can be diffuse or in a concentrated way, as in the thalwegs, and the soil particles are torn by the force exerted on its bed to form rills or gullies as well as the incisions [65], from where this high detachability of 29 $g/m^2/h$ comes.

These results are similar to those obtained by other researchers who have shown that uncultivated soils are more effective in controlling erosion than runoff [68]. Additionally, uncultivated soils have low microporosity, encountered mainly at the level of plowing [61]. The latter is of biological origin [60]. This high runoff can also be explained by the fact that at depth there is already high soil moisture; hence, it should have been due to the soil, which was close to saturation [69]. In addition, the density that was observed at the level of the fallow soils would have been due to the compaction. Therefore, the decrease in porosity facilitated runoff. The low loss of sediments in these fallows cannot be explained by the fact that the raindrops' kinematic energy is intercepted by the plant cover and the litter [70], and the water reaches the ground with lower energy and is less disruptive of soil structure [71].

In Larache province, results on infiltration and runoff with detachability have been influenced by cracks due to the roots of plants, as well as the biological porosity that is created when the soil is not mechanically disturbed and dry, which favor infiltration more than runoff [60,72,73].

3.2.4. Influences of Soil Parameters on Hydrological Properties in Larache, Taounate, and Taza Provinces of Morocco

In these three provinces of the study area, the three hydrological parameters (If, Pi, and Kr) were explained by the parameters of soil cohesion (SO, Ir, and P10), which allow water to infiltrate. In addition, they are also explained by the settlement parameters (SS and PEN), which promote runoff by reducing the infiltration time. These results agree with those of Lipiec et al. [60], who show that macroporosity and microreliefs facilitate infiltration. As for the settlement parameters, Richard et al. [56] showed that settlement disconnects the pores by decreasing the path taken by the infiltration, and hence the imbibition of rainwater decreases. When the percentage of pores decreases in the soil, Assouline et al. [74] say that the water conductivity goes to saturation, which increases the runoff coefficient (Kr).

About detachability, apart from surface soil moisture (H10), which is the only new explanatory parameter of detachability, the others related to cohesion (SO, Ir, and P10) and compaction (SS and PN) had already explained If and Pi in these three provinces. Thus, they are those related to soil compaction that positively influence detachability. These reduce porosity and facilitate runoff [56], which tears soil particles from plowed soil in the direction of the slope. Additionally, on that plowed soil, the slaking crust forms, clogs the pores, and facilitates runoff, which removes the soil, leaving rills or gullies as well as scratches [65].

4. Conclusions

This research was carried out as part of the Defense and Restoration of Soils (DRS) by fruit trees using the olive tree in the Moroccan Rif.

The results of this study allowed us to highlight the importance of plant cover (herbaceous stratum) in increasing the water balance of the soil. Indeed, final infiltration (If) and imbibition of rainwater (Pi) were high in the matorral of Larache (74.4 mm/h), lower in the plowed olive orchard, and even lower in the level of the fallow planted with olive trees. In addition, the role of vegetation cover in protecting soil against erosion has been elucidated. Although the fallow soils present a higher runoff coefficient (Kr = 46.61%), they were less detachable (2.28 $g/m^2/h$) than the plowed soils (30 $g/m^2/h$).

Regarding the hydrological characteristics (If, Pi, Kr, and D), they were favored positively by a high roughness of the ground in the direction of the contour lines in Taounate and Taza. Moreover, in the three regions, they were positively influenced by the open surface and the porosity. All these soil characteristics can be used for the choice of development and for modeling the risks of runoff and erosion since they are easily measurable for future research in the study area. As a further improvement in terms of soil erosion reduction and land management, considering the role of plant cover, it could be suggested to alternate plowing and fallow in this fruit tree to promote restructuring and enrichment in organic matter and fight against erosion.

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