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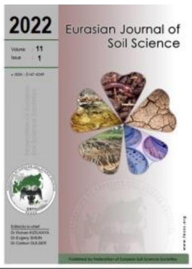

Deforestation effects on soil properties and erosion: a case study in the central Rif, Morocco

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Abstract

In the Central Rif in the north of Morocco, forest ecosystems have suffered a very sharp decline in favor of crops. Deforestation followed by cultivation illustrates the important environmental, economic and social roles of forests. The objective of this work is to assess the impact of deforestation on soil properties and erosion in the southern Central Rif. The loss of fertility of cleared soils was assessed using physico-chemical analyses after 2, 8 and 20 years of cultivation. A manual rainfall simulation was used to assess the impact of cultivation on the hydrodynamic behavior of the soil. The results show that the conversion of forests into agricultural areas has multiple consequences on the natural system. The general trend of soil texture elements after cultivation shows a significant increase in sand content, and a decrease in clay and silt content. Soil erodibility measured by USLE-K factor increased 3.5 times in the cultivated soil for 20 yrs. compared to the forest soil. Subsequent tillage of cultivated land increases bulk density and fragments large aggregates into smaller ones. Cultivation for 8 and 20 yr decreased SOM by 41 and 82% respectively. Total Nitrogen decreased by 45%, acidity increased by 0.8 unit after 20 years of cultivation. Conversion of natural forest to agricultural land significantly increases soil erosion. The erosion rate becomes higher in the cultivated the 8 and 20 yr cultivation, with an average of 219.60 ± 19.3 and 989.17 ± 68.4 g m^{-2} h^{-1} respectively. This degradation hinders agricultural productivity, leading farmers to abandon the land and seek new plots at the expense of forests to meet their agricultural land needs.

Keywords: Land use change, cultivation, rainfall simulation, organic matter, erosion.

Introduction

Land use change characterized by deforestation for expansion of agricultural land increases the effects of climate change on land degradation (Kassa et al., 2017; Eekhout and de Vente, 2022). Erosion and soil fertility decline contribute to about 84% and 7% of soil degradation worldwide respectively (Oldeman, 1994). Soil erosion affects about 1100 Mha of cultivated land worldwide, and results in the transport of 20-25^{109} Mg of sediment to the oceans per year (Brown, 1984). Incompatible local human land use such as deforestation and soil fertility weakness, have led to changes in the physical and biological properties of the soil (Lu et al., 2002; Khormali et al., 2009). Deforestation and subsequent tillage practices increases the soil erosion, which can reduce soil quality and hinder soil productivity. Subsequent tillage of cultivated land can affect soil structural stability, nutrients and cause mineralization of organic carbon (Veldkamp et al., 2020), and therefore affect the amount of different organic nutrient reserves (Parton et al., 1987). For example, deforestation followed by cultivation decreases soil organic carbon (SOC) stocks, increases soil bulk density, and causes significant changes in soil pH (Assefa et al., 2017; Kassa et al., 2017; Veldkamp et al., 2020).

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In Morocco, the rate of deforestation for the extension of living agriculture exceeds 31.000 ha/year (HCEFLC, 2004). This is remarkable in the Rif's mountains chain in northern Morocco. Indeed, the rapid demographic growth associated with the scarcity of land for agricultural purposes has led to strong pressure on forest environments. The expansion of cannabis cultivation has increased rapidly since 1980 (illegal cultivation at that time) and has largely contributed to the fixation of the population in the region (Chouvy, 2020), but also to increase the rate of deforestation over their agricultural needs. The rapidity of clearing operations is directly associated with the depletion of the soil's fertility potential due to the effect of erosion and cannabis cultivation, which consumes a lot of forest space and its humus (Grovel, 1996; Benabid, 2000). At present, more than two thirds of the old clearings are permanently abandoned, and the slopes are completely stripped (El Mazi et al., 2021). Land degradation caused by erosion increases the concentrations of suspended sediments in watercourses, which leads to silting of downstream dam reservoirs and damage to road infrastructure and even houses (Al Karkouri et al, 2000; Tribak, 2020).

The study area has been the subject of several studies on morphogenesis and water erosion over the last decades (Sabir et al., 2004; Tribak, 2020; Zaher et al., 2021; Arrebei et al., 2020; El Mazi et al., 2021). These studies showed that the deforestation and the successive tillage led to profound changes in soil properties affect directly the soil functional processes. Sabir et al. (2004) showed that the cultivation of cork oak forest land in northern Morocco reduces the organic matter content by 47% and greatly increases the risk of runoff and erosion. However, El Mazi et al. (2021) reported that this cultivation of forest soils on siliceous substrate in northern Morocco for 22 years decreased OM by 73% and made the soil instable and more susceptible to the erosion. Zaher et al. (2021) studied the effects of land use change on soil erosion and hydrological behavior in the Tlata watershed in northern Morocco, showed that detachability increased in the cultivated soil by 3 times compared to the forest soil. The objective of this work is, on one hand, to evaluate and quantify the impact of the conversion of forests into agricultural land on the physico-chemical, hydrodynamic properties of the soil in the Central Rif in northern Morocco, and on the other hand, is to determine the impact of cultivation and subsequent works on soil quality, structural stability, runoff and water erosion.

Material and Methods

Study site

The area concerned by this study is located in the Jbel Lerz and Outka forest massif, part of the central Rif in northern Morocco (Figure 1). It extends between longitudes 4°54' and 5°W, and between latitudes 34°40' and 34°54'N. It is characterized by a bioclimatic gradient ranging from subhumid in the valleys to perhumid in the high peaks. The Mediterranean rainfall is abundant with an average of between 800 mm/year and 1500 mm/year. More than 70% of the rainfall is concentrated between October and March. The number of rainy days exceeds 70 days/year. Autumn rainfall is marked by an often very high daily intensity of certain showers, with intensities of more than 150 mm/day, thus opening up runoff phenomena and water erosion. The most dominant substratum is the Ketma unit shale, the sandstone with albo-aptian shale and quartzite sandstones (Maurer, 1968).

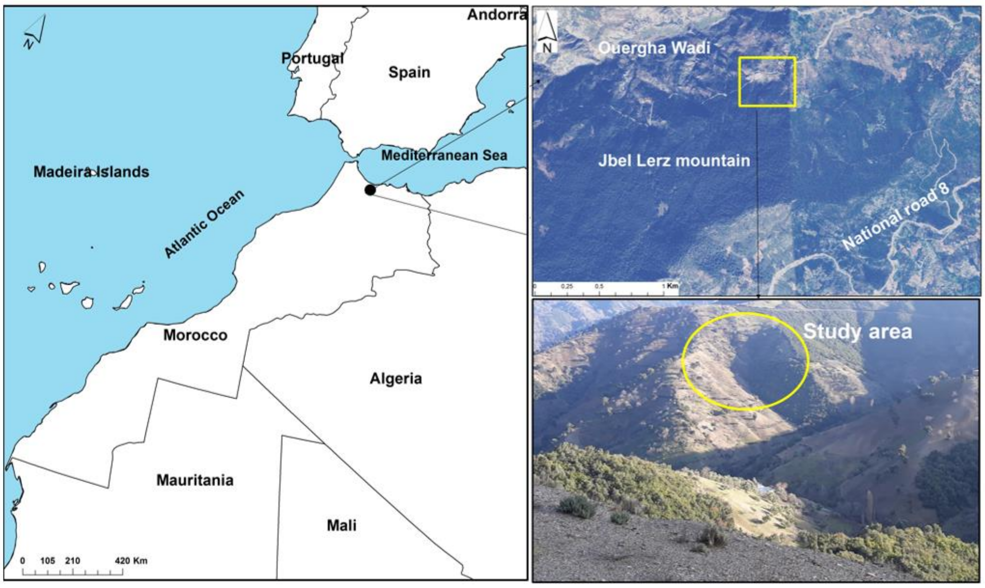

Figure 1. Study area

Characterization of the study plots and cultivation practices

In order to study the impact of the evolution of land use on the degradation of soil resources, 24 plots were selected so as to be as homogeneous as possible in terms of physiography (relief, lithology, soil, climate, etc.). All the sites belong to the burnished soil according to the CPCS classification of its 1967 edition. The sites are located between 1300 and 1400 m altitude, and the slope variations were minimised (<5%). Soil samples were taken from a control plot under the forest, whose soil characteristics are therefore well preserved, and from plots cleared and cultivated for 2, 8 and 20 yr. The forest is composed of *Cedrus atlanticae, Quercus rotundifolia, Arbutus unedo, Genista quadriflora, Daphne gnidium, Cistus laurifolius and Cistus ladaniferus*. The soil under the forest is moderately deep (40-60 cm) and the litter layer is thick (0-5 cm). The recently cultivated plot (2 yr) was under cultivation after a fire. The plots that have been cultivated for 8 and 20 yr were cultivated after traditional land clearing. In these plots the soil is shallow (25-40 cm), with almost no vegetation cover. The conventional tillage system adopted by farmers in the region consists at least two medium-depth soil turnings (10-20 cm) between February and April to prepare the seedbed. The soil is regularly fertilized with chemical fertilizers during the growing season (between April and July). This crop reaches maturity in August before the violent autumn rains of the Mediterranean regime compromise the harvest. The samples for the physico-chemical analyses were taken from the 20 cm depth of the soil, in December after a period of intense natural rainfall between October and November 2019.

Physico-chemical analysis protocols

The samples intended for physico-chemical analyses were air-dried and then sieved to 2 mm by taking 2mm/10 g as the standard measurement of the intended size of each sample for the granulometric analysis. The organic matter was destroyed by hydrogen peroxide. The samples are then dispersed by mechanical agitation after the addition of sodium hexametaphosphate. The suspension is sieved to recover the sands. The silt and clay contents are determined by using the "Robinson pipette" method. The texture is determined using the U.S.D.A. triangle, to assess the clay, silt and sand contents. The measurement of the water pH is done on a soil-water suspension in the ratio 1/2.5 in the laboratory. It was measured by the potentiometer method using a pH meter with electrodes. Organic matter was quantified by the Walkley and Black (1934) method. Exchangeable bases (Ca^{2+}, Mg^{2+}, Na, K) were saturated with a 1 N ammonium acetate solution. The reading and determination of cations were conducted by atomic absorption and flame photometer. Available phosphorus content is determined using Olsen method (Olsen et al., 1954). Total Nitrogen is quantified by the Kjeldahl method (Bremner, 1965).

The structural stability of the soil was evaluated by the procedure proposed by Le Bissonnais (1996), using a combination of three tests simulating the behavior of the soil under different climatic and hydric conditions. The results obtained are presented in mm in the form of mean weight diameter (MWD). The soil erodibility index was measured using the equation proposed by Wischmeier and Smith (1978). The bulk density was measured gravimetrically using a cylinder (0-10 cm), which were then weighed and oven dried (105°C) for 24 h and then reweighed to obtain the soil porosity and bulk density of the sample.

Runoff and erosion

A portable rainfall simulator based on the model produced by Roose and Smolikowski (1997) was used to simulate soil hydrological behaviour and solid transport. The rainfall simulator on a 1 m^2 plot consisted of a device capable of providing a homogeneous rainfall intensity of 75-80 mm h^{-1}. The choice of this intensity is based on the observations of daily rainfall of the hydrological station located 10 km from the study area. The rainfall simulations lasted 40 minutes. The tests were carried out in December after an intense period of natural rainfall. Runoff and sediment transport were collected and laboratory analyses were performed to determine the sediment concentration.

The following parameters could be derived:

- Runoff (LR in mm h^{-1});
- The infiltrated water level (Linf in mm h^{-1}) calculated as follows: (Linf= Rainfall-LR);
- The runoff coefficient (KR in %) with: KR= (LR/rain) × 100;
- The sediment concentration of the runoff water in g l^{-1};
- Soil erosion in g $m^{-2}h^{-1}$ is calculated with erosion= sediment concentration ×LR.

Statistical analysis

The effects of deforestation followed by cultivation on soil hydrological behavior and water erosion were tested using statistical treatments. These treatments consisted of simple regressions, analysis of variance (ANOVA) and comparisons of means using the least significant difference (LSD) method with $P<0.05$. A correlation matrix was calculated, including soil physico-chemical properties and soil erosion. All correlation coefficients were reported at 5% probability. The program used for this analysis is SPSS version 21.

Results and Discussion

Effects of deforestation on soil physical properties

The particle size distribution of the top soil layer (0-20) shows highly significant variations between the forest and the cleared cultivated soils (P < 0.01) (Table 1). In this layer, the forest has lower values for sand and higher values for silt and clay content compared to cultivated soils. The general trend of soil texture elements after cultivation shows a significant increase in sand content, and a decrease in clay and silt content. The clay content decreased from 22.62±1.94 of the soil under forest to 21.84±1.3% after 8 yr and to 17.71±0.7 after 20 yr of cultivation (Table 1). On the other hand, the sand content increased significantly in the cultivated soils, reaching 50.03 ± 36% for the soil cultivated 8 yr and 53.2±3.78% for the soil cultivated 20 yr, compared to 42.52±2.8% for the soil under forest. These changes in the physical properties of the soil observed in cultivated soils compared to forest soils are the result of deforestation and subsequent tillage, which favors the erosion of the finest soil particles. Several studies have shown dramatic changes in particle size distribution after deforestation followed by cultivation (Nunes et al, 2012; Assefa et al., 2020; Gülser et al., 2021).

Table 1. Comparison of average soil physical property between forest and cleared plots under cultivation

Land uses	Forest (control)			Cultivated 2 yr			Cultivated 8 yr			Cultivated 20 yr			ANOVA
Statistics	Mean ± STD			Mean ± STD			Mean ± STD			Mean ± STD			
Sand (%)	42,50	±	2,87	41,07	±	4,01	50,03	±	3,60	53,20	±	3,78	**
Silt (%)	33,28	±	2,37	34,98	±	2,98	29,72	±	2,91	29,11	±	3,80	*
Clay (%)	22,62	±	1,94	23,14	±	0,86	21,84	±	1,36	17,71	±	0,79	***
Bulk density (g cm^{-3})	0,95	±	0,09	1,04	±	0,07	1,24	±	0,07	1,49	±	0,06	***
Porosity (%)	65,06	±	3,20	65,24	±	5,20	53,23	±	2,60	53,04	±	3,80	*
K-USLE	0,11	±	0,02	0,09	±	0,02	0,22	±	0,04	0,35	±	0,07	***
MWD (mm)	2,51	±	0,20	1,96	±	0,09	0,87	±	0,16	0,39	±	0,12	***

Notes: * p < 0.05; ** P < 0.01; *** p < 0.001.

The hydrodynamic behavior of the soil depends on several physical characteristics such as porosity and bulk density which appear to be most strongly and rapidly affected by forest clearing followed by cultivation (Table.1). Bulk density was significantly higher in soils cultivated for 8 (1.24 ± 0.07 g cm^{-3}) and 20 yr (1.49 ± 0.06 g cm^{-3}) than in soils under forest (0.95 ± 0.09 g cm^{-3}). Bulk density did not differ between soils cultivated for 2 yr and forest soils. The table also shows that TP is higher in forest areas than in cultivated soils. Low values were found in soils cultivated for 8 and 20 yr. These changes are related to the decomposition of pre-existing roots and the loss of SOM due to the loss of forest cover to agricultural land (Roose, 1985; Sabir et al. 2004). Furthermore, the low Da value in the forest and cultivated soil for the last 2 yr is probably due to the high SOM content.

The USLE-K factor, used to assess soil erodibility, shows a significant difference between cultivated and forest soils (P < 0.01). USLE-K values were lower in forest soil (0.1 ± 0.02) and higher in soils cultivated for 20 yr (0.35 ± 0.07). There was no significant difference in the K-factor between the forest and the soil cultivated for 2 yr. However, the K-factor increased 2.2 times in the soil cultivated for 8 yr and 3.5 times for the soil cultivated for 20 yr compared to the forest soil. Indeed, land clearing, loss of SOM and increase of fine particles caused by successive tillage have increased soil erodibility (Celik, 2005; Khormali et al., 2009).

The mean weight diameter (MWD), an index of soil structural stability, shows significant differences between clearing stages. MWD was tested significantly higher in forest soils than in cultivated soils. Deforestation resulted in a significant decrease in the MWD of the topsoil (P < 0.01). With reference to the standards established by Le Bissonnais (1996), the structural stability in the soil under the forest tested high (MWD = 2.5 mm), and provides good protection against erosion, even during the devastating late summer and spring storms. However, this stability decreases significantly over time after cultivation. Indeed, the soil of the plots cleared for 2 and 8 yr becomes moderately unstable (Table 1). The soil of the plot cultivated 20 yr is very unstable (MWD = 0.37 mm). This result may be related to cultivation practices, which loss of organic matter and weaken the resistance of soil aggregates to aggressive rainfall (Celik, 2005; Laghrour et al., 2016).

The distribution of soil aggregates after disaggregation shows highly significant differences between forest and cultivated soils (Figure 2). The forest soil had a high percentage of large aggregates (> 2mm), however the cultivated soils had significantly more aggregate mass in the small diameter classes (<1mm) than the forest soil. This increase could be explained by the intensification of successive tillage practices (more than 3 times per year), which fragment large aggregates into smaller ones (Unger, 1997; Materechera and

Mkhabela, 2001). The increase of fine aggregates is an indicator of degradation of cultivated soils (Whalen and Chang, 2002). Smaller aggregates in cultivated land hamper soil productivity, as they reduce the water infiltration capacity, macroporosity and water storage potential of the soil, thus increasing the potential for water erosion (Whalen and Chang, 2002).

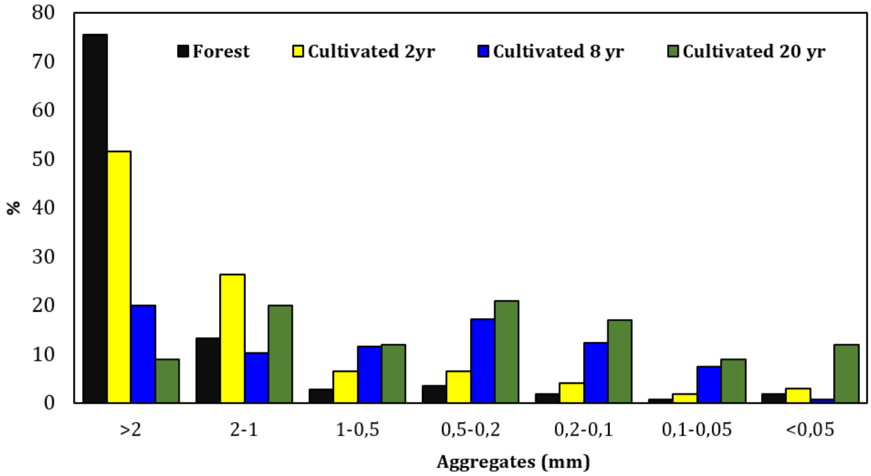

Figure 2. Effects of deforestation and cultivation on the size distribution of soil aggregates

Effects of deforestation on soil chemical properties

The ANOVA test showed that deforestation followed by cultivation resulted in significant changes in soil pH values. ($P<0.001$) (Table 2). There was a decrease in soil acidity in the short term (2 yr), but in the medium and long term there was a significant increase in acidity. Indeed, the pH_w value decreases from 6.2 ± 0.26 for the soil under forest to 5.87 ± 0.12 for the soil cultivated 8 yr, and to 5.42 ± 0.24 for the soil cultivated 20; this indicates that the soil becomes strongly acidic. The pH_{Kcl} has a similar evolution to that of the pH_w. It increased from 5.63 ± 0.21 for the soil under forest to 6.1 ± 0.12 for the soil cultivated for 8 yr and to 5.23 ± 0.16 for the soil cultivated for 20 yr. The weakly acidic soil under forest is probably due to the acidic nature of the lithological substrate, namely shale and sandstone. The increase in pH in the recently cultivated soil (2 yr) compared to the soil under forest is explained by the fact that the plot had suffered a fire and carried a large quantity of large branches that had burnt poorly in the first year and whose complete combustion in the second year provided a greater abundance of ash rich in mineral elements and exchangeable bases, notably Ca^{2+}, which can increase the soil pH (Francos et al., 2019). The decrease in acidity in cultivated soils in the medium and long term can be explained by the leaching of exchangeable bases under the effect of heavy rainfall, which consequently lowers the soil pH (Olorunfemi et al., 2018; Assefa et al., 2020). Thus, tillage mineralizes SOM and continuous application of acidifying ammonium phosphate fertilizers such as ammonia phosphate (Assefa et al., 2017). Serious problems are encountered when the soil pH is below 5.5 (Norton et al., 1999). Indeed, in acidic soils, Al^{3+} and H^+ ions replace Ca^{2+} and Mg^{2+} in the absorbing complex, causing leaching and a reduction in the availability of some exchangeable bases essential for plants (Nunes et al., 2012). These results are similar to others found by other authors. Indeed, Assefa et al. (2020) and Khormali et al. (2009) found that the conversion of forests to agricultural land decreases the soil pH.

Table 2. The effect of deforestation on the chemical properties of the soil

Land uses	Forest (control)	Cultivated 2 yr	Cultivated 8 yr	Cultivated 20 yr	ANOVA
Statistics	Mean ± STD	Mean ± STD	Mean ± STD	Mean ± STD	
Soil pH_w	6.20 ± 0.26	6.61 ± 0.15	5.87 ± 0.12	5.42 ± 0.24	***
Soil pH_{KCl}	5.63 ± 0.21	6.10 ± 0.12	5.11 ± 0.30	5.23 ± 0.16	*
SOM (%)	5. 90 ± 0.67	6.83 ± 0.84	3.24 ± 0.78	1.01 ± 0.21	***
TN (%)	0.11 ± 0.03	0.12 ± 0.04	0.11 ± 0.02	0.08 ± 0.02	**
Available P (mg kg^{-1})	10,90 ± 1.59	53.15 ± 9.40	163.00 ± 37.47	206.30 ± 13.60	***
Available K (mg kg^{-1})	267.67 ± 15.80	511.70 ± 76.90	122.3 ± 10.4	195.00 ± 8.91	***
Ca^{2+} ($mmol_c$ kg^{-1})	7.41 ± 1.17	10.31 ± 3.40	5.90 ± 1.28	5.68 ± 2.46	***
Mg^{2+} ($mmol_c$ kg^{-1})	1.83 ± 0.20	1.77 ± 1.40	0.83 ± 0.71	0.81 ± 0.80	**
Na ($mmol_c$ kg^{-1})	4.50 ± 0.19	0.50 ± 0.02	1.01 ± 0.04	0.51 ± 0.02	**

Notes: * $p < 0.05$; ** $P < 0.01$; *** $p < 0.001$.

Organic matter (SOM) is a significant index of soil fertility and plays an important role in the sustainability of natural systems (Laouina, 2013). Deforestation resulted in a significant decrease in soil SOM ($P\leq0.01$). Cultivation for 8 and 20 yr decreased SOM by 41 and 82% respectively compared to the soil under forest.

The loss of soil SOM may be related soil water erosion and mineralization (Sabir et al., 2004; Gülser et al., 2021). These results are similar to those found by several authors. Indeed, Sabir et al (2004) showed that conversion of cork oak forests to cannabis cultivation has decreased soil OM by 47% in the western Rif in northern Morocco. Furthermore, Gülser et al. (2021) found that cultivation of forest soils in Turkey for 50 years ago decreased OM by 57.14%.

The highest values of total nitrogen content were observed for forest and varied significantly from cultivated soils in the long term. There was no significant difference in total N between the forest and the soil cultivated for 2 yr and 8 yr ($P > 0.05$). However, about 45% of the total N was lost after the 20 yr cultivation. This decrease is completely associated with runoff, hypodermic flow and especially leaching, which is observed the most common loss of nitrogen nitrates (Bonneau and Souchier, 1979). It is also correlated with the acidification of the soil after cultivation. Indeed, some authors have shown that the increase in acidity results in a decrease of nitrogen fixing organisms in the soil (Demolon, 1960). Similarly, if the soil becomes more acidic, certain elements such as nitrogen may be blocked despite the intensive use of chemical fertilizers (FAO, 1989). Concerning available phosphorus content the highest values were found in cultivated soils than in soils under forest. The concentration of this element is higher in the soil cultivated for 8 yr (122 ± 11 mg kg^{-1}) and in the soil cultivated for 20 yr (195 ± 8.91 mg kg^{-1}). The increase in available P in cultivated soils can be explained by the fact that the cultivated plots were amended with a large quantity of complex chemical fertilizers, an amendment that stimulates, especially in acidic soils, the fixation of phosphorus with Al and Fe to form compounds that are not very soluble in the soil (Demolon, 1960). The evolution of available potassium is similar to that of available phosphorus. Higher values of available potassium were found in cultivated soils than in soils under forest. The concentration of this element appears to be very high in the cultivated soil for the last 2 yr with a concentration of 580.33 ± 31.58 mg kg^{-1}. This increase can be attributed to the use of chemical fertilizers by farmers at the time of cultivation to improve the productivity of their fields.

The distribution of calcium (Ca^{2+} in $mmol_c$ kg^{-1}) in the surface layer of the soil also shows significant differences between the forest and cultivated soils. All the plots revealed a very low Ca^{2+} content of less than 11 $mmol_c$ kg^{-1}.The highest levels were found in the soil cultivated for 2 yr (10.31 ± 3.4 $mmol_c$ kg^{-1}), due to the contribution of ash which is a good source of calcium, potassium, phosphorus and magnesium (Giovannini and Lucchesi, 1997). In soils cultivated for 8 and 20 yr the Ca^{2+} content starts to decrease significantly by -18% and -20% respectively compared to the control. Magnesium (Mg^{2+}) content, which is already low at the initial state (< 2 $mmol_c$ kg^{-1}), shows a slight increase in soils cultivated for 2 yr, and then shows a significant decrease in soils cultivated for 8 and 20 yr by about -56% compared with forest. Sodium (Na) losses are higher and exceed those for other exchangeable bases. After clearing, the content of this element starts to fall rapidly during the 2 yr of cultivation (-70.83% of the control), indicates severe degradation and considerable soil poverty. These results are similar to those of Assefa et al. (2020) and Olorunfemi et al. (2018) whose studies showed that deforestation leads to a significant decrease in exchangeable bases in acidic soil due to leaching.

Runoff and soil erosion

The results intended for the runoff coefficient on micro plots (1 m^{-2}) obtained by conducting the rainfall simulation tests with an intensity of 75-80 mm h^{-1}, show that the conversion of forests into agricultural land resulted in a significant increase in runoff rate as a function of time after cultivation (Table 3).

Table 3. The effect of deforestation on the runoff and soil erosion

Land uses	Forest (control)	Cultivated 2 yr	Cultivated 8 yr	Cultivated 20 yr	ANOVA
Statistics	Mean ± STD	Mean ± STD	Mean ± STD	Mean ± STD	
Linf (mm h-1)	78.00 ± 0.80	69.53 ± 1.15	45.20 ± 2.18	27.70 ± 2.70	***
Runoff (mm h-1)	2.00 ± 0.80	10.47 ± 1.15	34.80 ± 2.18	52.32 ± 2.70	***
Runoff coef (%)	2.50 ± 0.90	2.32 ± 1.43	48.50 ± 2.72	65.40 ± 3.37	***
Erosion (g m-2 h-1)	n.a	10.06 ± 3.04	219.60 ± 19.3	989.17 ± 68.40	***

Notes: * $p < 0.05$; ** $P < 0.01$; *** $p < 0.001$.

The highest runoff rate values found in soils cultivated for 8 and 20 yr with an average of 34.8 ± 2.18 mm h^{-1} and 52.32 ± 2.7mm h^{-1} respectively. Soils cultivated 2 yr recorded as the lowest runoff rate values with an average of 10.47±1.15 mm h^{-1}. Figure 3 shows the behaviour of runoff rates as a function of time. The runoff rate increases rapidly in the cultivated for 8 and 20 yr, between 15 min and 27 min after the start of the rainfall simulation. Runoff became very high in these plots at the end of the simulation, reaching 55.2 mm h^{-1} and 59.7 mm h^{-1} respectively. The soil under the forest is clearly different from the other cultivated soils, with a low water runoff (2.0±0.8 mm h^{-1}), due to the dense vegetation cover, litter and root system that facilitate water infiltration. Thus, the emergence of cannabis cultivation has led to a loss of interest in livestock farming, which is significantly regressing. This regression has reduced both the compaction of the soil under the forest by the animals, and favors the installation of dense undergrowth that represents a barrier to raindrops, and favours the infiltration of water into the soil. These results are consistent with several studies in the Mediterranean region (Al Karkouri et al., 2000; Martinez-Mena et al., 2008 and Kavian et al., 2014) , which found that conversion of forests to agricultural land increases runoff and soil erosion.

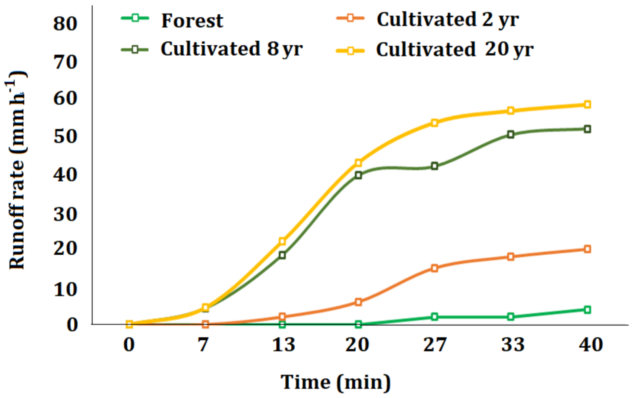

Figure 3. Evolution of runoff in the experimental sites as a function of time

Similarly, soil loss calculated at the microplot scale of the simulation shows that conversion of natural forest to agricultural land significantly increases soil erosion. The erosion rate becomes higher in the cultivated the 8 and 20 yr cultivation, with an average of 219.60 ± 19.3 and 989.17 ± 68.4 g m^{-2} h^{-1} respectively. Soil cultivated for 2 yr with an average of 10.6 g $m^{-2}h^{-1}$ recorded a low value of land loss compared to long-term cultivated soils, due to their high SOM content which facilitates water circulation within the soil and, consequently, reduces soil erosion (Moussadek et al., 2011). Several studies have found similar results. Indeed, (Bensalah et al., 2012) showed that cultivated soils in the Bouregrag watershed (Morocco) show very different hydrological behaviours compared to natural forest soil depending on their textural nature and changes in their surface states. Martinez-Mena et al. (2008) found that conversion of forest to agricultural land in a semi-arid area of southeastern Spain increased the average sediment concentration seven times more than forest. (Kavian et al., 2014) showed that soil erosion in cultivated land is 1587 times higher than the forest in northern Iran.

Correlation between physical-chemical properties, runoff and soil erosion

Table 4 shows the different correlations between the components of physical and chemical properties, runoff and soil erosion. The linear correlation analysis showed a significant correlation between 29 of the 55 pairs of soil attributes (P<0.05).

Table 4. Correlation matrix for physicochemical soil, runoff and soil erosion

	MWD	MO	K	BD	Sand	Silt	Clay	TN	P_2O_5	Ca^{2+}	K_2O	Na	Mg	pH w	KR	Erosion
MWD	1															
MO	0,731**	1														
K	-0,603**	-0,637**	1													
BD	-0,375*	-0,570**	0,401*	1												
Sand	-0,015	-0,060	0,570*	0,214	1											
Silt	0,270	0,205	-0,371*	-0,162	-0,387*	1										
Clay	0,660**	0,023	-0,418	-0,176	-0,586*	0,213	1									
TN	0,340*	0,447*	0,035	0,596**	0,047	0,034	0,262	1								
P_2O_5	-0,055	-0,645*	0,511*	0,237	0,270	-0,120	-0,548**	0,060	1							
Ca^{2+}	0,457**	0,490**	-0,434**	-0,346	-0,160	0,040	0,317	-0,580**	-0,039	1						
K_2O	-0,230	-0,310	0,268	0,122	0,155	-0,070	-0,041	-0,393	0,622	-0,191	1					
Na	0,455**	0,350*	-0,340	-0,171	-0,261	0,285	0,376*	-0,263	-0,644**	0,053	-0,859**	1				
Mg	0,266	0,197	-0,556	-0,379*	-0,255	0,265	0,131	0,312	-0,454**	0,427*	-0,241	0,313	1			
pH w	0,344*	0,156	-0,343	-0,378*	-0,430**	0,172	0,317	-0,590**	-0,514*	0,540**	-0,174	0,281	0,280	1		
KR	-0,530**	-0,760**	0,619**	0,287*	0,710**	-0,259	-0,648**	-0,230	0,115	-0,462**	0,360*	-0,394	-0,172	-0,400*	1	
Erosion	-0,780**	-0,640**	0,536**	0,194	0,750**	-0,305*	-0,711**	0,490*	0,670*	-0,414*	0,318	-0,350*	-0,102	-0,460**	0,740**	1

Soil organic matter and MWD showed highly significant negative correlations with runoff (-0.530**) and soil erosion (0.780**). This result is compatible with good agreement of other authors (Sabir et al., 2004; Martinez-Mena et al. (2008). The influence of organic matter, which mainly acts on structural stability, is important for high contents that increase macroporosity and decrease soil erosion. Significant correlations were also found between SOM and soil physical and chemical properties (P<0.05) such as structural stability, bulk density, soil porosity, total nitrogen and exchangeable bases (Ca^{2+}, Na). Bulk density shows a significant positive correlation with runoff (0.287*). Increasing bulk density reduces soil porosity and water and air storage capacities and increases surface runoff. Runoff showed a highly significant positive correlation with water erosion rate (0.740**). Clay content shows a significant negative correlation with runoff (-0.648**) and erosion (-0.711**). Sand content was positively correlated with runoff (0,710**) and soil erosion (0.750**). Sand particles have larger sizes, so they are resistant to movement (Kavian et al., 2014). These results are similar to those found by several authors, among others Bensalah et al. (2012); Moussadek et al. (2011), who showed that the erosion of Moroccan soils is strongly related to soil texture.

Conclusion

The chronosequence study of the physico-chemical, hydrodynamic and erosion properties of the soil highlighted the transformations of soil after deforestation followed by cultivation. The intended results of the study show that the transition from natural forest to cultivation has a negative impact on the structural stability of the soil, on the physico-chemical properties and on the hydrodynamic behaviour of the soil. This study suggests that well-conserved forests provide good soil cover, enrich soil OM, improve soil stability, and provide excellent protection against erosion. In contrast, successive tillage is the main factor in modifying soil structure and depleting the fertility of cleared and cultivated land. Soils become extremely degraded by the eighth year after conversion of forests to agricultural land. Organic matter decreased by 82%, nitrogen and exchangeable bases were reduced alarmingly, soil acidity increased by 0.78 units, and bulk density increased by 0.54 g cm^{-3}; making runoff and erosion risks very high (989.17±68.4 g m^{-2} h^{-1}). In this context, a set of measures should be put in place to reduce the anthropic pressure on forests, in order to reduce the degradation of natural environments in the Central Rif. This leads to the search for viable solutions focused on the safeguard and rehabilitation of degraded forest ecosystems and socio-economic development.

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