THE DYNAMICS OF LAND USE CHANGES IN MOROCCAN AND TUNISIAN SUB-HUMID AND SEMI-ARID REGIONS AND THE IMPACT ON EROSION RATES AND OVERLAND FLOW GENERATION.

Coelho, C.A.O[1] Laouina, A[2], Ferreira, A.J.D.[1,4], Regaya, K.[3], Chaker, M.[2], Nafaa, R.[2], Naciri, R.[2], Boulet, A.-K.[1], Carvalho,T.M.N. [1],

[1] – CESAM, Departamento de Ambiente e Ordenamento da Universidade de Aveiro, P-3810-193 Aveiro, Portugal.
Phone: +351 234 370 200, Fax : +351 234 429 290, E-Mail: Coelho@dao.ua.pt
[2]- Faculté des Lettres et Sciences Humaines, Université Mohammed V, BP2122 Ryad, 10104 Rabat, Morocco.
Phone: +212 37771893, Fax : +212 37772068, E-Mail: cugn@wanadoo.net.ma
[3]- Institut National Agronomique de Tunisie, 43 Avenue Charles Nicolle, 1082- Tunis-Mahrajène, Tunisia.
Phone: +216 1 289 431 ; Fax : +261 1 799 391, E-Mail: regaya@excite.com
[4] – Environmental Technology Sector, Department of Pure and Environmental Sciences, ESAC, IPC, P-3040-316 Coimbra, Portugal.
Phone: +351 239 802 949, Fax : +351 239 802 979, E-Mail: aferreira@mail.esac.pt

Résumé

Les zones marginales du Maghreb font l'objet de modifications majeures d'usage des sols, celles-ci résultent d'une pression démographique croissante occasionnant de grands changements socio-économiques et environnementaux.

La tendance est au remplacement des forêts traditionnelles par des espèces exotiques ou par des usages de sol plus intensifs comme les cultures sèches ou le pâturage intensif, en dépit de sol pauvres et à haut potentiel d'érosion.

Cette substitution s'accompagne d'une réduction de la fixation du carbone par le sol (les terres agricoles ne présentent pas d'arbres, d'arbustes ou de litter, le pâturage intensif réduit drastiquement le couvert arbustif et de litter et les espèces exotiques présentent des couverts arbustifs et de litter très réduits). La réduction de la matière organique et du couvert végétal a pour conséquence une compaction du sol et une production plus importante de ruissellement dans les zones surpâturées, des quantités élevées d'érosion dans les zones labourées.

Ce papier présente les coefficients d'érosion et les caractéristiques hydrologiques de divers usages de sol au Maroc et en Tunisie, couvrant un panel d'usages de sol traditionnels et nouveaux dans des environnements sub-humides et semi-arides. Les résultats ont été obtenus par simulations de pluie sur le terrain utilisant le simulateur portable conçu par Cerdà *et al (1997)*. Les caractéristiques de la couverture végétale et de litter du sol, la résistance mécanique à la pénétration et à la torsion ont été mesurés sur des transects de 25m pour chaque usage de sol étudié.

Les systèmes traditionnels de gestion des sols –qui typiquement impliquent une combinaison d'agriculture, d'élevage et de sylviculture- produisent les quantités les plus faibles de ruissellement ainsi que les coefficients d'érosion les plus bas. Quelques stades

de surexploitation de ces systèmes ont apparemment de faibles implications en terme d'impact hydrologique et érosif. Le surpâturage, les maquis dégradés produisent des quantités de ruissellement considérables mais à l'échelle du plot de simulation de pluie, les pertes correspondantes en sédiments sont relativement insignifiantes. Cependant à une échelle plus large, la présence de ravines témoigne du pouvoir d'érosion de ces grandes quantités de ruissellement. Concernant les sites où la structure du sol a été fragmentée (cf. labour), les coefficients d'érosion peuvent être très élevés si des mesures de conservation du sol n'ont pas été prises. (Coelho and al, 2001)

Mots clés

Changement d'usage de sol, érosion, simulation de pluie, Maghreb

Abstract

The marginal areas in the Maghreb are undergoing major land use changes as a result of an increasing demographic pressure that result in major socio-economic and environmental changes.

The tendency is for the replacement of traditional forests, by exotic species or by more intensive land uses such as dry farming or overgrazing, despite the poor quality of soils and their potentially high erodibility.

This replacement is accompanied by a reduction of carbon sequestration above the soil (agricultural land has no trees, shrubs or litter above it, overgrazing sharply reduces shrub and litter cover and the exotic forest stands have less shrub and litter cover). The reduction of organic matter and vegetation cover results in soil compaction and higher overland flow generation, in the overgrazing areas, whilst in the ploughed areas erosion yields are high.

This paper reports on erosion rates and soil hydrological characteristics of a variety of land uses in Morocco and Tunisia, covering a set of traditional and new land uses under sub-humid and semi-arid environments. The results were obtained through rainfall simulation experiments carried out in the field using a portable simulator following the design of CERDA *et al.* (1997). Soil cover by vegetation and litter characteristics and mechanical resistance to penetration and shear stress were measured along 25 meters transects at each of the studied land uses.

The traditional land management systems - typically involving a combination of agriculture, animal husbandry and forestry – produce the least amounts of overland flow and the lowest soil erosion rates. Some degree of over-exploitation of these systems apparently has only minor hydrological and erosional impacts. Heavily grazed, degraded "maquis" shrublands, on the other hand, produce very considerable amounts of overland flow. Nevertheless, at the plot scale of the rainfall simulation experiments, the corresponding sediment loads are rather insignificant. At a larger scale, the presence of gullies witnesses the erosional power of these high amounts of overland flow. At places were the soil structure was disrupted (e.g. ploughed land), the erosion rates can be very high if soil conservative measures are not taken (Coelho and al, 2001)

Keywords

Land use change, erosion, rainfall simulation, Maghreb

Introduction

The ongoing intensification as well as replacement of the traditional land management systems in the Maghreb has brought to the forefront the fundamental role of land use change in determining soil erosion hazard.

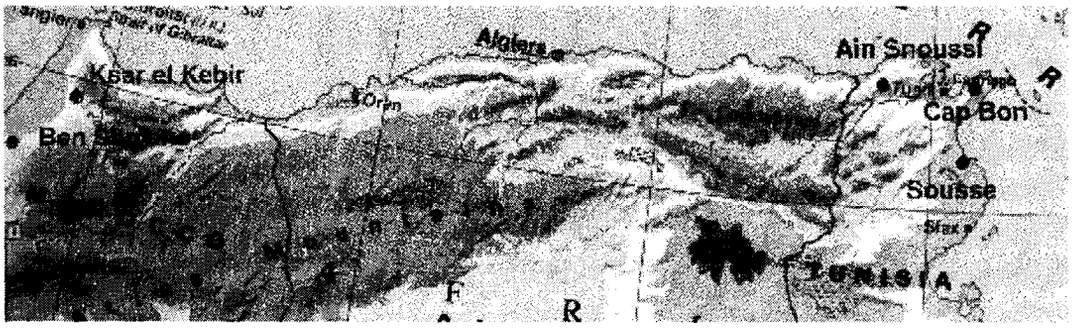
The present paper reports on erosion rates, organic matter displacement and overland flow yields characteristics of a variety of land uses in Morocco and Tunisia. The results were obtained through rainfall simulation experiments carried out in the field using a portable simulator following the design of CERDA *et al.* (1997).

The traditional land management systems - typically involving a combination of agriculture, animal husbandry and forestry, has the soils with highest organic matter content, and the smaller soil erosion rates and overland flow yields. Some degree of over-exploitation of these systems apparently has only minor hydrological and erosional impacts. When the natural vegetation totally disappears, overland flow and the erosion of sediments is significantly enhanced. The lower organic matter content displaced by erosion is an indicator of low availability and soil degradation. The increasing pressure over marginal areas (due to population growth and the use of the better soils for commercial crops) leads to the use of steep slopes for agriculture purposes. This represents the highest risk for soil sustainability.

Study Areas Characterization

All the studied areas lay within the climax distribution regions for *Quercus suber* L. (i.e. with annual rainfall amounts between 500 and 1200 mm, with the exception of the semi-arid Sousse study area (Figure 1). All the areas have a marked summer dry period, that extends to over 6 months in the semi-arid region of Sousse (Table 1).

Figure 1 - Study areas location



Morocco

The *Ben Slimane* area, in Morocco, is the most southerly *Quercus suber* L. forest along the Atlantic coast, covering some 22700 hectares. The underlying lithology is mainly composed of schist, with some quartzites. Soils are weakly developed lithosols. Rainfall varies between 400 and 550 mm per year, with 50 to 60 rainy days and 5 to 6 dry months. This region has a low human density area, although being in the outskirts of Rabat and Casablanca. There is a high grazing pressure in some places, and planting of

eucalyptus spp. forest stands, in order to provide wood to the local populations. Being in the limit of the natural distribution of *Quercus suber* L., trees are currently under water stress and re-growth is difficult. The main land uses are: *Quercus suber* forest with overgrazing, re-growth *Quercus suber* stands, where grazing is forbidden by law, mature *Eucalyptus* stands and re-growth *Eucalyptus* stands.

The area of Ksar El Kebir is placed in the southern foothills of the Rif Mountain in Morocco. Once covered by cork oak, pine and cedar forest stands, these trees have retreated drastically in the region during the 20th century. At the present, natural land uses are restricted to the more inaccessible slopes and summits of the Rif Mountain. The underlying rock material is composed of limestone and mudstones. Soils are lithosols and yermosols with high clay content. Rainfall varies from 600 to 800mm per year, exceeding 2000 mm in the Rif summits, with 60 to 80 days of rainfall per year, and 3 to 4 dry months ($P \leq t$). Since the more fertile low lands are used for commercial crops (i.e. sugar cane, sugar beet, ...), an increasing population (population density is over 100 inh.km^{-2}) is forced to get hold to more marginal land such as the steep foothill and the southern slopes of the Rif mountains. Currently, most of the foothill slopes are ploughed, the natural vegetation are increasingly degraded shrub land areas, constantly decreasing in area, either because gullies and badlands are formed or because the "natural areas" are increasingly being used for agriculture. This leads to an increasing grazing pressure over the remaining very degraded shrub land.

Table 1 - Study areas location

Study Areas	Geographic co-ordinates	Average yearly rainfall (mm)	Soil Types	Dominant land uses	Demographic Trend
Ksar el Kebir (Morocco)	34°59'N 05°50'W	600 – 800	Lithosols and yermosols	Agricultural land with highly degraded grazing "garigue" areas	Population Increase
Ben Slimane (Morocco)	33°36'N 07°06'W	400 – 550	Lithosols	*Quercus suber*, *eucalyptus*, grazing	Population Increase
Ain Snoussi (Tunisia)	36°47'N 8°58'E	1000 -1500	Lithosols	Quercus suber, grazing areas	Population Increase
Cap Bon (Tunisia)	36°57' N 11°02' E	450-700	Lithosols	Agriculture, grazing maqui areas, forest stands	Population Increase
Sousse (Tunisia)	35°49'N 10°37' E	300-500	Lithosols	Olive groves with agriculture, eucalyptus stands	Population Increase

Tunisia

Ain Snoussi is located in the Eastern Atlas mountains, in the northern part of Tunisia, in a sub-humid to humid environment. This area, in the frontier of the Ain Draham and Tabarka Districts, has a lithology of sandstones and schists, and has very poor developed lithosols. Annual rainfall varies from 1000 to 1500 mm. The main land uses are cork oak trees and pasture land. This region has a high human density that lives mainly from agriculture and grazing (the exploitation of cork at the cork oak forest stands is reserved for the government). The high pressure is witnessed by the impressive

and extensive soil degradation features, which include badlands and gullies. The landscape is still dominated by *Quercus suber* L. stands with a high tree density. In a steep mountain region, the high grazing pressure over the land, although under a very conservative cork oak forest, results in impressive and wild spread erosion features such as gullies and badlands.

The *Cap Bon* region, in the north-east region of Tunisia, has a mediterranean sub-humid climate, with the annual rainfall amount ranging from 450 to 700 mm. Agriculture and grazing areas are the dominant land uses. Soils are formed from underlying limestone and mudstone, and in places from aeolian sands. The landscape is mainly composed of small hills. The measured eucalyptus stands were located on weakly developed sand dune soils, with a high percentage of soil without an A horizon or any kind of litter or vegetation cover. This area has a high population density, living mainly from agriculture. Crops use a high percentage of the available land. This includes steep slopes that are frequently ploughed from the top to the bottom of the slope. Grazing is mainly performed in land under fallow and on the few remaining degraded "garigue" areas. The impressive number of landslides observable throughout the landscape witnesses a very high pressure over the land.

Sousse is located in the eastern coast of Tunisia in a semi-arid region. Annual rainfall amount is low (300-500 mm). Limestone, sandstones form the local lithology together with non-consolidated sand deposits. The soils where the experiments were performed are lithosols with a very thin or non-existent litter layer. Population density is high. Agriculture fields are typically small, well delimited and the high number of olive trees makes the use of machinery difficult. Most of the management practices are still traditional and animal powered. The main land use at Sousse is olive groves consociated with agriculture. Areas with poor soils are generally planted with *eucalyptus spp.* in order to provide firewood for the local populations.

Methodology

Overland flow amounts and erosion rates were determined with the help of a rainfall simulator, (CERDÀ *et al.* 1997). This consists in a sprinkling device placed at 2 meters above the soil, able to provide a reasonably spatial homogeneous rainfall intensity of 50.5 mm per hour over a 1 m^2 area. A small 0.24 m^2 round plot is inserted carefully in the soil. Inside the plot, a TDR Theta probe is inserted in the soil to a depth of 6cm. Measurements of overland flow and soil moister content were made each minute. Overland flow samples were collected for sediment determination, three within the first 15 minutes after the beginning of overland flow production, the fourth in the middle of the experiment, and a fifth in the end of the experiment. Rainfall simulation experiments were performed for one hour.

A soil sample was collected after the rainfall simulation, and 20 measurements of soil resistance to penetration and to torsion were performed at each experiment, in likely places around the plot. Soil resistance was assessed through the use of a pocket penetrometer and by a torvane. A 2mm sieve was used to divide the soil samples. Then a Coulter LS Particle Size Analyzer performed soil texture for the fraction under 2 mm. Organic matter content was determined by Loss on Ignition at 550°C during 120 minutes.

Results and discussion

Soil Characteristics

Table 2 presents the soils characteristics for the study areas. Soils are predominantly lithosols. They have typically densities ranging from 0.85 to 1.2 $g.cm^{-3}$, and organic matter contents below 12%. Ben Slimane soils are very stony soils (stones represent in average more than 30% of the dry weight). Ksar el Kebir' soils have a silty clay loam texture, since soils are formed from limestones and mudstones. The soils from Cap Bon are mainly sandy soils with minor percentages of stones, silts or clays. The other Tunisian soils are comparable to the Ben Slimane soils in terms of soil density, percentage of stones and sand, presenting a smaller percentage of silts and higher clay content.

Table 2 – Study areas soil characterization

		Soil density g/cm3	Organic Matter content (%)	Texture			
				>2 mm (%)	Sand (%)	Silts (%)	Clays (%)
Ksar el Kebir (Morocco)	Max.	1.2	8.5	2.3	16.9	55.1	40.5
	Avr.	1.0	7.5	1.3	10.6	52.5	34.8
	Min.	0.9	6.5	0.3	2.6	49.9	33
Ben Slimane (Morocco)	Max.	1.4	9.4	41.5	49.5	17.8	6
	Avr.	1.2	8.2	34	48.0	13.2	4.8
	Min.	0.9	5.8	30.1	45.7	6.9	2.9
Sousse (Tunisia)	Max.	1.53	5.5	35.9	78.2	23	25.5
	Avr.	1.05	3.9	22.6	46.9	12	18.3
	Min.	0.71	2.4	9.2	15.6	1	11.0
Cap Bon (Tunisia)	Max.	1.2	9.8	13.2	93.9	2	6
	Avr.	0.83	5.2	7.6	86.6	1.8	4
	Min.	0.45	2.0	2	79.2	1.5	2
Ain Snoussi (Tunisia)	Max.	1.54	8.9	38.3	52.7	12	29
	Avr.	1.03	6.6	32.1	39	10.3	18.6
	Min.	0.66	4.7	26.9	32	6.6	12.5

Land use trends

The socio-economic dynamics in the Maghreb countries, traduced by an increase in the number of inhabitants, leads to an overwhelming pressure on the "marginal" areas, where soils are not suitable for agriculture. These areas would traditionally have forests and shrub land.

The increasing demographic pressure, enhanced by the use of the best soils for commercial crops, leads to the use of the poor lithosols in an unsustainable way.

In this study land uses were divided in traditional land uses (those preponderant before the demographic explosion and the use of the best soils for commercial crops lead the population to intensify their activities on marginal hilly and mountain areas), and the new land uses resultant from that intensification.

The land use changes are driven by three factors that often work together to enhance soil degradation and erosion: (i) – Ploughing of steep slopes, generally in the direction of the highest slope angle; (ii) Overgrazing on the shrub land ("*Maquis*" and "*garigue*")

areas, as a result of the increase of agriculture area; (iii) Afforestation with exotic species. As an example, in the Ksar el Kebir region, this land use change is responsible for a sharp reduction on the area of cork oak forest and shrub land (Nafaa et al. 2000). Two of the land use change driving processes are intimately related to the occurrence of erosion features such as rills and gullies (i.e. ploughing of steep slopes and overgrazing).

Overland flow generation

The *Quercus suber* stands are the more conservative land uses, with the smaller overland flow amounts, inferior to 10% of rainfall in average. An increase on grazing pressure, within *Quercus suber* stands, leads to significantly higher overland flow amounts. Nevertheless, the total disappearing of trees enhances overland flow generation to the double of overgrazing within forest stands. Olive groves, traditionally ploughed once a year, present one of the highest overland flow rates (39.7% of rainfall). Fallow overland flow reaches a maximum of 53.5% of rainfall. This land use is frequently ploughed, and when in fallow, is used to graze sheep, goats and cows. Therefore the soil is extremely compacted and produces high overland flow rates. The same pattern happens for the *garigue* land use types. Although not ploughed, the extreme grazing pressure enhances overland flow production. The introduction of new forest stands increases the amount of overland flow, in some cases due to soil water repellence or to the little understorey vegetation and litter layer.

Table 3 – Overland flow generation, erosion rate and organic matter yield.

		Overland flow (%Rainfall)	Total Erosion rate (g/ m^2/ h)	Organic Matter eroded (g/ m^2/ h)
Garigue	Max.	51.6	8.5	1.4
	Avr.	**48.6**	**8.2**	**1.3**
	Min.	45.6	7.9	1.26
Olive grove	Max.	51.4	37.6	3.33
	Avr.	**39.7**	**24.6**	**2.4**
	Min.	17.1	7.1	0.83
Regeneration of	Max.	21.7	1.7	0.51
Quercus suber	**Avr.**	**4.3**	**0.3**	**0.1**
stands	Min.	0	0	0
Mature Quercus suber	Max.	15.5	2.2	0.66
Forest stands	**Avr.**	**7.7**	**0.7**	**0.2**
	Min.	0	0	0
Quercus suber stands	Max.	46.0	21.4	4.63
under stress	**Avr.**	**18.6**	**7.0**	**1.4**
	Min.	0	0	0

Eucalyptus stands	Max.	69.7	172.5	2.78
	Avr.	**28.3**	**31.9**	**1.2**
	Min.	0	0	0
Fallow	Max.	53.5	75.5	6.8
	Avr.	**24.3**	**18.6**	**2.1**
	Min.	0	0	0
Grazing	Max.	72.1	79.7	5.54
	Avr.	**32.6**	**25.4**	**2.4**
	Min.	0	0	0
Ploughed	Max.	44.9	2260.4	72.6
	Avr.	**20.9**	**439.0**	**13.9**
	Min.	0	0	0

Sediment and organic matter erosion yields

Although overland flow amounts have a strong influence on erosion yields, the relation is not linea. In fact, the *Quercus suber* stands present the lowest erosion rates (less than 1 $g.m^{-2}.h^{-1}$ in average). Despite the high overland flow amounts, the relatively undisturbed *garigue* areas present low soil erosion rates (typically inferior to 10 $g.m^{-2}.h^{-1}$), which means that the vegetation has an important impact on soil's internal coherence and on sediment trapping. For these relatively undisturbed soils, the eroded organic matter typically represents more than 10% of the total eroded sediments, in some cases this value represents 30%. This means that the soil has an important top organic matter layer that is mobilized during particularly intense rainfall invents.

The pressure increase over the soil is traduced by enhanced soil erosion rates. An increase on the number of grazing animals increases ten times the erosion rate within mature *Quercus suber* stands although with similar proportions of displaced organic matter. The total absence of vegetation increases the sediment yield even further, to erosion rates of 25.4 $g.m^{-2}.h^{-1}$ in average. In these cases, the eroded organic matter represents less than 10% of the total sediment yield, which accounts for the poorer soil organic matter content. Fallow slightly improves the soil, with lower sediment yields and a higher organic matter percentage

The introduction of the *Eucalyptus* species increases soil erosion even further, although the amount of organic matter mobilized suffers a sharp decrease.

Ploughed land presents the highest erosion rates from all the studied land uses. Ploughing completely destroys vegetation and litter layer cover, and breaks-up the soil structure, sharply reducing soils' coherence and therefore theirs' shear strength and compaction. Under these circumstances, erosion yields are expected to be important. The more deleterious land uses are those where steep slopes are used for agriculture and where ploughing is performed following the highest slope angle. Under these situations, erosion rates can exceed 2000 $g.h^{-1}.m^{-2}$.[1]

Conclusion

Northern African' marginal regions are undergoing important land use change processes with deep impacts on ecosystem sustainability, traduced by an important

[1] The zero values were measured at places where ploughing was made along the contour.

increase of the amounts of overland flow and erosion rates. The traditional land uses are very conservative with very small overland flow yields and erosion losses. An important part of the sediments is composed by organic matter, a symptom that the soils have an important understorey vegetation and litter layer.

The percentage of organic matter displaced is smaller for the disturbed land uses, despite the higher overland flow and erosion amounts. Land uses were the vegetation has disappeared, present the highest amounts of overland flow and erosion, which means that vegetation plays an important role in maintaining the soil's coherence and trapping displaced sediments. The worst case is the ploughed land. The high erosion amounts together with the low organic sediments displaced is an indicator of the unsustainability of these systems, since the sediment yield is enormous for the top to down slope ploughing technique, the most popular amongst local farmers due to the shape of the individual plots, and the low organic matter content indicate that the soils are close to exhaustion.

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