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Bare Soil Rehabilitation of Semiarid Regions in Central Spain. Use of Simulated Rainfall to assess the consequences in Runoff Coefficient and Sediment Loss.

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Summary
Among the agricultural lands of the semi-arid center of Spain, some cultures maintain the soil bared or are abandoned. The rehabilitation measures (shrubs and organic matter application) on 8 plots of 80m^2, showed a reduction in erosion rates, especially in runoff coefficient, reduced from 35% the first year to the 2% the second one. The shrub *A. halimus* was the best, followed by *R. sphaerocarpa*; *M. strasseri* was a failure.

Résumé
Parmi des zones agricoles du centre semi-aride de l' Éspagne, quelques cultures maintiennent le sol nu ou sont abandonnées. Les mesures de rehabilitation adoptées (arbustes et apport de matière organique) sur 8 parcelles de 80m^2 ont montré une diminution de l'erosion, surtout du coefficient d'écoulement, réduit du 35% la première année au 2% la seconde. Par rapport aux arbustes *A. halimus* a été le meilleur, suivi par *R. sphaerocarpa* ; *M. strasseri* a été un échec.

Introduction
Among the traditional agricultural exploitations in the semiarid region of the center of Spain, there are several ones that present crops with bare soil exposed to the erosivity action of rainfall and wind. This is the case of the south of the region of Madrid, with olive trees, vines or melons exploitations and also that of the abandoned lands due to the lack of profitability. In these abandoned lands plants do not spread along the time; usually plant cover is scarce, around 40% (Marqués et al, 2005). Gypsic marl is underlying shallow soils with a silty clay loam texture on the surface; it is classified as *Xeric Haplogypsid* (USDA, 2003) and presents an organic matter content around 2% (Bienes, 2001). The aim of this work is to know the consequences of the maintenance of soil bared and the effect of rehabilitation treatments of the land with the addition of organic amendment and the plantation of three different species of shrubs, more tolerant to the drought (Francis and Thornes, 1990).
According to the data recorded by the *Instituto Nacional de Meteorología* based on the last 30 years, the annual rainfall of the area studied is around 400 mm, distributed in about 60 days with at least 1 mm of rain; but rainfall is very irregular, with frequent storms. In this paper we have simulated a frequent and moderate storm, and we have estimated its erosion effects in this degraded soil as well as the suitability of the rehabilitation measures suggested.

Material and Methods
Sampling and plots
In the year 2003 a chisel contour plow was carried out twice over the study area (slope gradient 9%), then 8 closed plots of 80 m^2 were defined (4 m width x 20 m length). Species of shrubs planted were *Atriplex halimus* (Chenopodiaceae), *Retama sphaerocarpa* and *Medicago strasseri* (both Leguminosae), aged two years (Table 1). Half of the plots were treated with Glyphosate to maintain the soil bared only the first year; this herbicide is only

effective when it comes into contact with the green, growing parts of plants; it was applied such a way that shrubs were not affected.

Table 1. Plant distribution in the eight plots (39 shrubs per plot). 4 plots were treated with herbicide and in the other 4 plots the growth of natural vegetation was allowed.

A.halimus + Bare Soil	*R.sphaerocarpa* + Bare Soil	*M.strasseri* + Bare Soil	*A.h.*+ *R.s.*+ *M.s.*+ Bare Soil
A.halimus + nat. veget.	*R.sphaerocarpa* + nat. veget.	*M.strasseri* + nat. veget.	*A.h.*+ *R.s.*+ *M.s.* + nat. veget.

With the aim of improve the organic matter content in the soil, all the plots were treated with a surface addition of sewage sludge thermally treated, in a single initial dose of 40 t ha^{-1}. Sewage sludge characteristics were studied and heavy metal contents were in keeping with the EU limits (Marques et al., 2005).

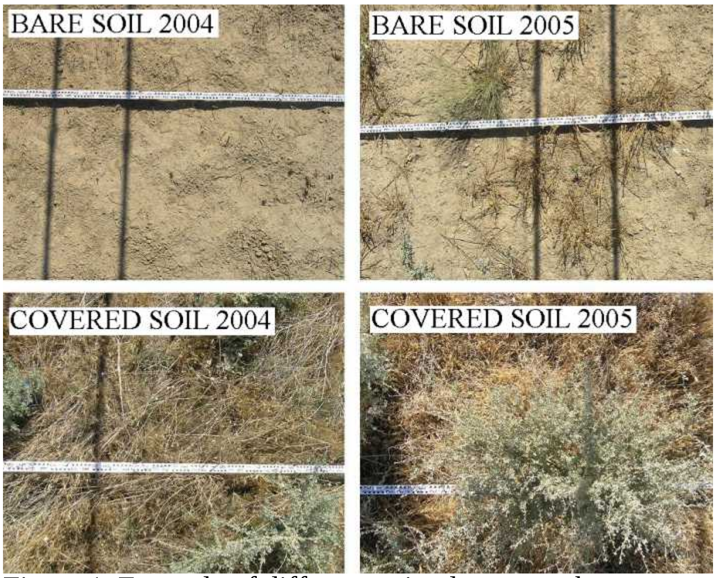

Figure 1. Example of differences in plant cover between years 2004 and 2005.

Dry weight of sludge contains 36% organic matter, 1.7% total N and 2.7% total P.

In the summer of 2004 the first rainfall simulation on the plots was carried out (n=16). Later on, vegetation could grow in the 8 plots and in the summer of 2005 we carried out the second rainfall simulations (n=16).

Simulated rainfall characteristics

We have realized the maximum intensity of the natural rain takes place in storms of 20 minutes length (hourly data from the *Inst. Nacional de Meteorología)* (Marqués et al., *in press*), however, in the previous calibration of the rainfall simulator, we realized the steady state runoff took place just after 6 minutes, therefore we limited the simulation trial to 10 minutes in order to improve the cost/effectiveness ratio as well as to save water. The trial procedure was: 5 min. to get soil damp + 5 min. of break + 10 min. trial. Simulated rainfalls were made in the summer; no rainfall events were recorded in the previous weeks, therefore soil moisture was as minimum as possible every year.

The collected materials were: 1) water runoff which volume was recorded each minute until it was completely stopped; 2) suspended sediment in this runoff water during 10 minutes, and 3) the sediment yield retained in the collecting channels of the erosion plots.

The pressurised water rainfall simulator, produced a rainfall intensity (1.3 mm min^{-1}) quite uniform on the whole plot: 80% uniformity according to Christiansen (1942). The kinetic energy was 13.5 J mm^{-1} m^{-2} calculated with the indirect model from Eigel and Moore (1983) based on diameter and velocity of drops (raindrop median is 0.34 mm, D50 is 1.6 mm) and corresponds to frequent rainfalls along the year.

Plant cover

It was evaluated by the *visu* analysis of orthogonal photographs took for the whole plot surface, with a camera hanged at 2.5 m height (Figure 1) making use of the structure of the rainfall simulator. Height and smaller and larger diameter of shrubs were also recorded.

Results and Discussion

Plant cover evolution.

The size of young shrubs was too small and we could not significantly evaluate their effect on the soil protection up to now. Nevertheless, we observed *M. strasseri* grew with difficulty the first year (Table 2) but they did not resist the drought of the year 2005 and all the specimens died.

Table 2. Number and size of shrubs in the studied period. At the moment of plantation in the year 2003, shrubs did not exceed 20 ± 5 cm height and 12 ± 3 cm diameter.

Year	2003	2004			2005		
Shrub species	*n*	*n*	Diameter *(cm)*	Height *(cm)*	*n*	Diameter *(cm)*	Height *(cm)*
A. halimus	*104*	*104*	37 ± 26	40 ± 21	*102*	51 ± 36	74 ± 36
M. strasseri	*104*	*56*	25 ± 12	35 ± 12	*0*	0	0
R. sphaerocarpa	*104*	*95*	25 ± 9	22 ± 8	*82*	34 ± 17	37 ± 23

The plantation of *A. halimus* was a success in the first year, and in the second year its survival rate was 99%. *R. sphaerocarpa* whose survival was of 91% 2004, fell to 79% in 2005. We can state they are good candidates for revegetations aimed to the soil protection in this in gypsipherous soils.

As far as natural vegetation is concerned, plant cover from bare soil was 4% in 2004, and reached 20% in 2005. The average height was 5 and 15 cm respectively. The rest of plots (whithout herbicide) were almost completely covered by vegetation, the mean height the first year was 1 m, the secod one 50 cm, because 2004 was more rainy.

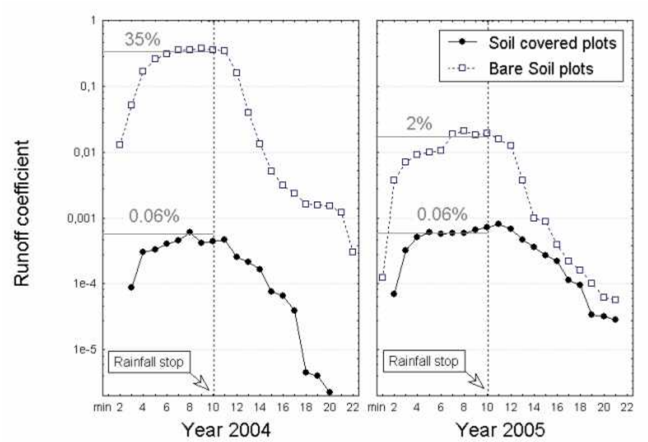

Figure 2. Mean of Runoff coefficient (liter per liter) along the rainfall trial. (*n=8*).

Water erosion

In the figure 2 it can be noticed that runoff takes place shortly after the start of trials, as have been seen in other similar works (Bergkamp et al., 1996). The growth of vegetation in bare soil in one year has produced a significant reduction of runoff coefficient from 35 to 2%. This decrease could be also due to the different annual rainfall since September to May which was 518 mm in 2004 and 195 mm in 2005 (normal rainfall is around 400 mm). After these heavy rains in spring of 2004, a fine mud left on the ground; in the summer it was dry and formed a crust that sealed the soil surface.

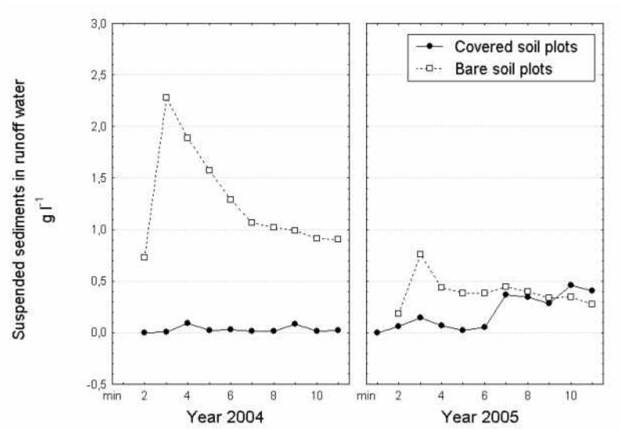

Figure 3. Mean suspended sediments in water runoff. The maximum takes place at the minute 3. (n=8)

Other works in gypsipherous soils have cited similar runoff coefficients ranging from 14 to 25% in slopes around 13% (Nicolau et al., 2002 and Desir, 2002 respectively). The runoff produced in the rest of plots, which were nearly completely covered by vegetation since 2004, did not present significant differences between years, being their runoff stabilized at 0.06 % in both cases. The evolution of soil loss (g l^{-1}) along the simulation trial can be seen in figure 3. The maximum is found at minute 3.

Figure 4 shows the changes produced between years 2004 and 2005. The sediment yield (17 kg ha^{-1}) in 2004 was no significantly lesser in 2005, but both were much greater than those produced in plots with vegetation (0.2 kg ha^{-1}). Suspended sediments were 42 kg ha^{-1} the first year in bare soil, but after the recovery of the vegetation in one year, they significantly diminish to 1.1 kg ha^{-1}; nevertheless they continue being higher than those produced in plots with vegetation (less than 0.01 kg ha^{-1}). As far as water runoff is concerned, one year has been enough to significantly reduce his volume from 3.5 to 0.14 mm, although it is higher than the volume produced in plots with soil covered since the first year (around 0.006 mm).

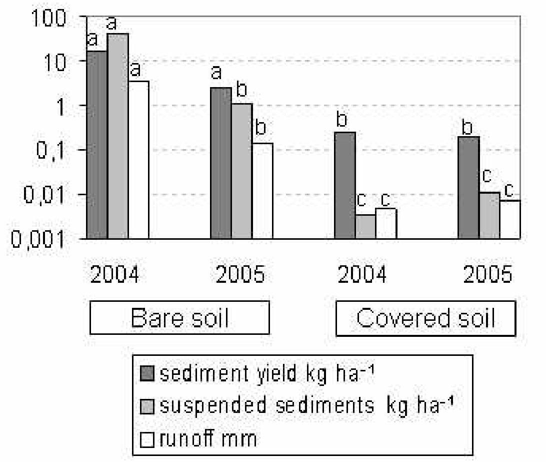

Figure 4. Sediment yield; suspended sediments and runoff water due to simulated rainfall. Changes between years. Different letters indicate significant differences between years or soil cover (n=8, $p < 0.01$).

We have to emphasize that this erosion rates are produced by a single simulated rain storm of 13 mm in 10 minutes. Soil annual loss in this land due to natural rainfall range between 1.3 and 28 t ha^{-1} (Nicolau *et al.*, 2002).

Conclusions

A runoff coefficient of 35% for bare soil with a gently slope is a nonsense in this sub-humid area. The organic amendment promotes the growth of natural vegetation (from 40 to almost 100% plant cover) and virtually prevent the soil loss and runoff.

The plant recovery from the bare soil in a single year and the lack of rainfalls preceding the simulation trials, allowed to reduce runoff and suspended sediments, although no significant difference have been found with the sediment yield in this period. Runoff occurred 2 minutes after the start of rainfall, and one minute later is the moment of the highest sediment concentration de 2.3 g l^{-1} in bare soil.

M. strasseri cannot be recommended to revegetation in gypsipherous semiarid soils, but *A. halimus* and *R. sphaerocarpa* can be useful.

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