Evolution of Soil Cover in a Restoration with Shrub and Sludge in Gypsiferous Soils in Madrid (Spain).

Jiménez L, Marqués MJ, Pérez-Rodríguez R, Bienes R
Dep. Investigación en Desarrollo Rural. IMIDRA.
Finca El Encín. Carretera N-II, km 38.2; 28800- Alcalá de Henares, Madrid. Spain.
luis.jimenez@madrid.org

Summary
We studied two restoration techniques in gypsiferous soils in semiarid conditions of Mediterranean climate: revegetation with shrubs and application of heat dried sludge. An inverse lineal correlation between the quantity of soil cover and the slope has been observed. It can be due to a feedback effect of the erosion, increased for the drought. The shrub combination with sludge has been effective to increase the soil protection.

Résumé
Nous avons étudié deux techniques de restauration dans des sols gypsiques dans des conditions semiarides du climat Méditerranéen: la revégétation avec des arbustes et l' application de boue séché d'épuratrice. On a observé une corrélation linéale inverse entre la quantité de couverture végétale et la pente du sol. Cela peut être due à un effet de retroalimentation de l'érosion, augmentée par la sécheresse. La combinaison de l'arbuste et de la boue s'est montrée comme une bonne technique de restauration pour augmenter la protection de ce genre de sol.

Introduction
Restoration is very difficult in gypsiferous soils in semiarid conditions of Mediterranean climate. Hydric stress limits the development of vegetation (Issar and Resnick, 1996), then soil cover can not be sufficient to control soil erosion. Erosion can generate water loss, which is essential for development of vegetation. Restoration of vegetation cover is the best form of avoiding soil degradation, according to the scientific community. For this, it is necessary to use restoration techniques which restore vegetation cover and reduce the water loss. We studied two techniques: revegetation with shrubs and application of heat dried sludge. Shrub revegetation is rarely used, limited to arid areas in the past (Vallejo *et al*. 2003). In many restorations, tree survival is low (Carreras *et al*. 1997). However, in other restorations with shrubs the survival is usually bigger (Vallejo *et al*. 2003). Addition of organic amendment of sludge can increase organic matter and nutrient content in the soil, which favours the development of vegetation (Ingelmo *et al*. 2002; Marqués *et al*. 2004). This vegetation, shrubbery and herbaceous, forms a screen that protects the soil surface against the impact of raindrops, reducing their capacity to detach the soil (Kirkby, 1993), improves the conditions of soils (Woo *et al*. 1997) and can reduce runoff and sediment loss (Bochet *et al*. 1998).

Material and Methods
The study plots are located in Aranjuez (Madrid, Spain). The soil was situated on gypsic marl (Bienes *et al*. 2001). The soil was Xeric Haplogypsid (USDA, 2003). The climate is Mediterranean semiarid. The mean annual rainfall was 427 mm (Marqués *et al*. 2004). The field site was dominated by *Stipa tenacissima*, it was burnt in 1993 and the

spontaneous vegetation grew until 2003. After a chisel contour plow was carried out twice over the study area.

Two restoration techniques were applied: shrub revegetation ("*Retama sphaerocarpa*", "*Atriplex halimus*" and "*Santolina chamaeciparisus*") planted in 2003 and application of heat dried sludge (20 t ha^{-1} on the surface; one single initial dose in March of 2004). The treatments were: Combined use of sludge and shrub ("COMB": 15 plots), Sludge alone (SLU: 5 plots), Shrub alone (SHR: 15 plots) and control (CONT: without shrub neither sludge: 5 plots).

We established 40 plots (2 m × 0.5 m). We planted 2 shrubs of the same species in each plot with a separation of 1.0 m (treatments COMB and SLU).

We measured the cover of live herbaceous vegetation (live cover), death herbaceous vegetation (death cover) and shrub by the *visu* analysis in the field. Death cover was the sum of litter and withered herbaceous vegetation. The total soil cover was the sum of those three covers. We used quadrats of 0.5×0.5 m side with subdivisions of 0.1 m × 0.1 m. We have measured all surface plots (4 measurements each).

The slope was measured with a reliefmeter which was made in IMIDRA (designed similar to Kuipers, 1957). It can measure 0.5 lineal meters and had a precision of ± 1 mm. We sampled 4 consecutive measurements (2 m in total).

The statistical analysis employed was the MANCOVA, in which the covariate was the slope. The analyses post hoc were adjusted by Bonferroni to control the increase of the type error I due to the multiple esteems of probability.

Results and Discussion

The multivariate results of MANCOVA for total soil cover were significantly different between treatments ($p<0.001$) and for slope ($p<0.001$; covariate).

Total soil cover had an inverse correlation with slope (all treatments), so that, soil cover values decrease as slope increased. The slope increases the runoff velocity. The water loss was greater in plots with higher slope, increasing the hydric stress. The available water for vegetation is smaller in this plots and the vegetation growth can be reduced. This fact can be due to a feedback effect caused by erosion. These water loss are more important in semiarid climate. When the rain was plentiful, correlation between soil cover and slope was weak: April of 2004 ($p<0.05$) and June of 2005 ($p<0.01$). Nevertheless, the drought began in autumn of 2004 and this correlation was more intense since September of 2004. The drought can increase the erosion feedback effect and cause non linear associations in the future, for example, exponential relations.

We compared the values of total soil cover and live cover one year after we made the restoration (Figure 1 and 2). We observed a progressive increment in total soil cover in all treatments (COMB and SLU: $p<0.001$; SHR: $p<0.01$, in June between 2004 and 2005; COMB, SLU and SHR: $p<0.001$; CONT: $p<0.01$ in September between 2004 and 2005) and a decline in live cover in all treatments (COMB and SHR: $p<0.001$ in June between 2004 and 2005; COMB: $p<0.001$ in September between 2004 and 2005). The increment of total soil cover was due to the progressive accumulation of death herbaceous vegetation. The live vegetation was shrivelled and died, but it was degraded slowly. The live cover depends on the depth of rain and its decline was due to the drought effects.

This progressive increment in total soil cover was different between treatments in each sample (Figure 1 and 2). The spring of 2004 was humid and we did not observed differences in total soil cover between treatments. The amount of rain was smaller since autumn of 2004 and the total soil cover was different between treatments since

December of 2004 until September of 2005. The amount of total soil cover in the treatment COMB was higher with respect to the treatment CONT (December of 2004; $p<0.001$, March of 2005: $p<0.05$, June of 2005: $p<0.001$ and September of 2005: $p<0.001$) and with respect to the treatment SHR (December of 2004: $p<0.001$, June of 2005: $p<0.05$ and September of 2005: $p<0.05$). The amount of total soil cover in the treatment SLH was greater than the treatment CONT (December of 2004; $p<0.05$).

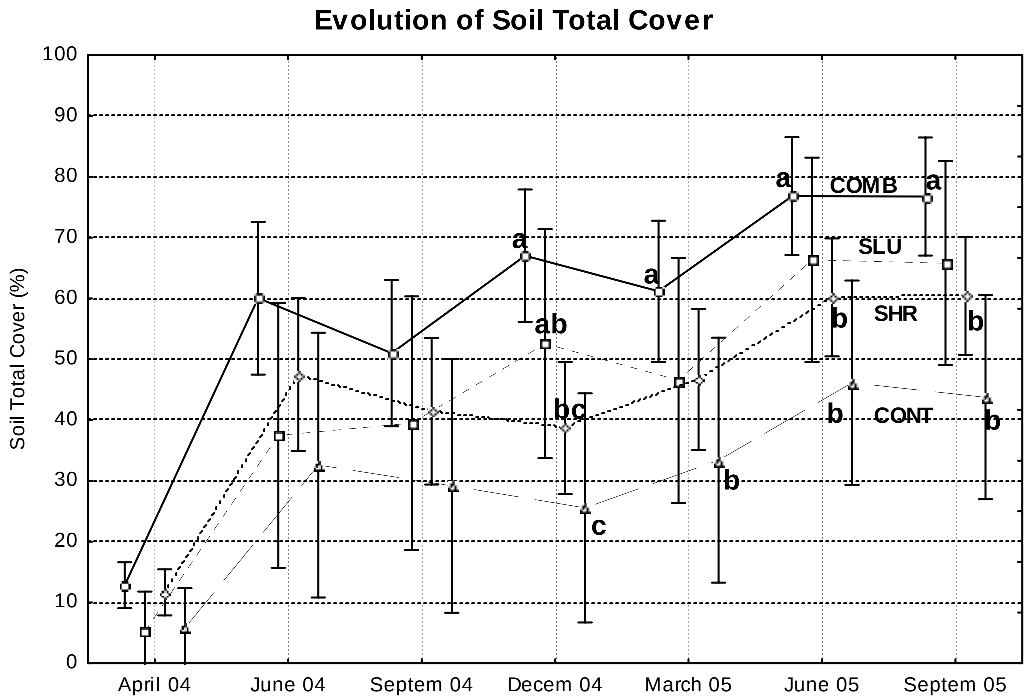

Figure 1. Evolution of soil total cover (%) for each treatment. Different letters indicate significantly differences between each treatment.

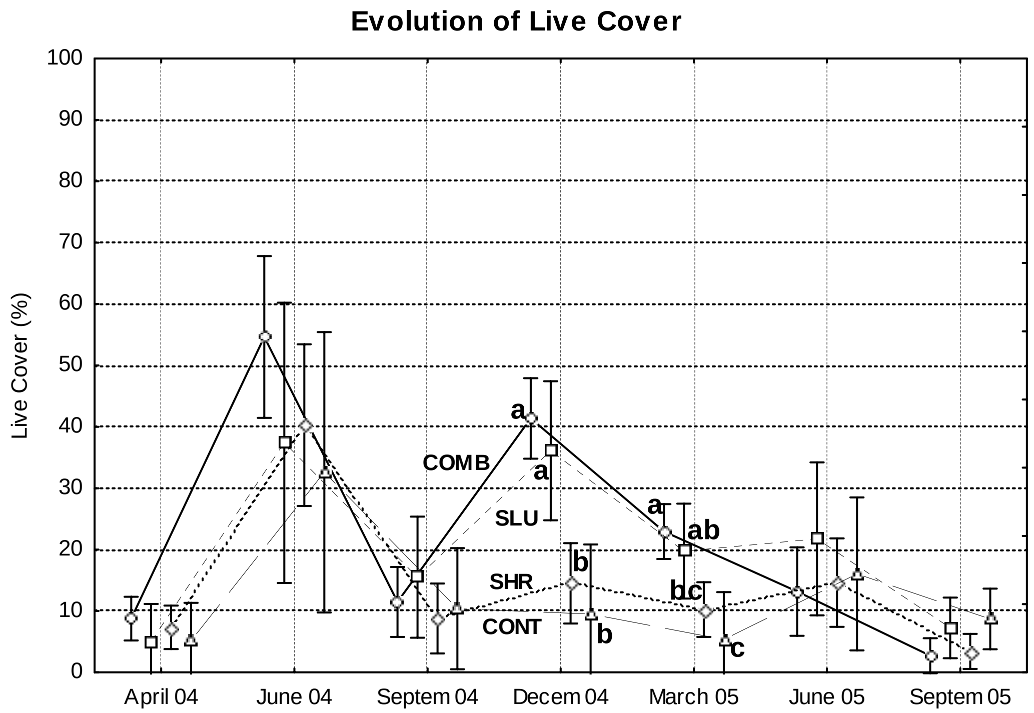

Figure 2. Evolution of live cover (%) for each treatment. Different letters indicate significantly differences between each treatment.

Those differences can be due to a higher infiltration in the treatment COMB. In previous papers (Jiménez et al. 2005), we observed that runoff coefficients were higher in the treatment CONT with respect to the treatment COMB ($p<0.05$) in the autumn of 2004, in the same plots. After these autumn rainfalls, we observed an increase in total soil cover in the treatments COMB ($p<0.001$) and SLU ($p<0.01$). Those results can be related with the losses by runoff. The increment of infiltration caused by the applied techniques can favour the vegetation growth.

The difference between treatments was also significant during the drought and can be originated by the feedback effect too.

Conclusions

We observed two processes that can act together: the feedback effect caused by erosion, due to the water loss by runoff, and the drought that can increase the effects of the losses of water.

We observed an inverse linear correlation between total soil cover and slope. The slope favoured the runoff and increased the hydric stress.

The combined use of shrubs and sludge was the best restoration technique that we applied to improve soil cover. It is interested used combined both restoration techniques in spite of the increment of the economic cost.

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