ECOLOGICAL INTERACTIONS BETWEEN PLANT AND SOIL CHARACTERISTICS: IMPLICATIONS FOR THE DESIGN OF NEW RESTORATION STRATEGIES AT THE ROADSIDE.

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Abstract:
Roadsides are commonly difficult to restore because they are often drastically disturbed (all topsoil and biological activity removed), creating multiple plant growth limiting conditions. Soil conditions such as nutrient content, texture and water content are requirements for the establishments of plants. At the same time, plant traits also impact these characteristics of soil resources. Therefore, combining the frameworks that use traits to predict plant effects on, and plant responses to soil conditions, a successional approach to restoration can be designed to improve the success of restoration efforts. According to this, we designed an experimental set-up on two highways (M-12 and M-13) in Madrid. We considered two types of roadslopes: roadcuts, constructed by excavation, and embankments, by heaping and compacting materials. We selected 9 roadcuts and 6 embankments for the soil and cover sampling using 18 quadrat plots (50 x 50 cm) per roadslope, according to a nested design. All the soil samples were analyzed for pH, soil conductivity, nitrate, soil texture, nitrogen and organic matter, and the vegetation cover was estimated during the spring. We found significant differences in soil features by roadslope type. The vegetation establishment was related to the soil fertility (soil organic matter, soil nitrates and total nitrogen) mainly in the first stages. Improving soil nutrients contents by techniques like topsoiling reduces the microsite limitation to plant establishment.

Keywords: Edaphic features, Plant cover, Hydroseeding, Roadslopes, Site quality, Succession.

Introduction

One of the main impacts of road construction is the creation of bare, steep slopes that are exposed to the direct action of rainfall and high rates of water erosion (Bochet & García-Fayos 2004). These slopes, roadcuts (constructed by excavation) and embankments (by heaping and compacting materials), usually have low contents of soil nutrients (Trahan & Peterson 2007), high rates of water erosion linked to low water retention (Tormo *et al.* 2006), and soil compaction (Navarro & Ugalde 1995). These conditions are harsh for seedling recruitment and vegetation development, so a wide variety of reclamation methods have been investigated to determine which are most effective to promote plant establishment and increase soil stability on disturbed roadsides (Petersen *et al* 2004). Many studies have emphasized the role of vegetation in controlling soil loss and runoff for the stabilization of motorway slopes (Bochet & García-Fayos 2004). Accordingly, hydroseeding has been widely used in Mediterranean conditions in the last decades in order to provide plant cover by sowing seeds of fast-growing commercial species (Bochet & García-Fayos 2004, Tormo et al. 2007). Nevertheless, recent studies in Mediterranean environments, have questioned whether vegetation establishment on roadcuts and embankments is a process limited by seed input or by microsite availability (Andrés & Jorba 2000; García-Fayos & Gasque 2006). For instance, Bochet *et al.* (2007) concluded that seed dispersal from neighbouring vegetation is important for the colonization dynamic. However, Tormo *et al.* (2006) found that the arrival of seeds to road embankments under Mediterranean conditions was not enough to ensure colonization success of plants due to water stress. The soil properties also impact on plant establishment and growth (Montalvo *et al.* 2002), as they have effects on plant community and functions (for example, nutrient cycling and carbon retention). Consequently, monitoring changes not only in vegetation but also in soils could portray the overall success of the restoration process more accurately (Pothoff *et al.* 2005).

The present study was founded by OHL (Obrascón Huarte Laín S.A.) and the Spanish Ministries of Education and Science in the course of the project CLEAM. The aim of the present study was to reappraise hydroseeding method for revegetation under adverse conditions from the diagnosis of the ecological processes that limit plant recruitment at the roadsides. More specifically, this study was focused in the soil features addressing the following questions i) Are vegetation establishment at roadslopes limited by soil features? ii) Are soil features conditioned by the type of roadslope, treatment or position along the roadslope? iii) Which is the temporal evolution of soil features in early stages?
Finally we established the most appropriate management options for maximizing roadside plant cover.

*Figure 1***.** Soil perturbations in roadslopes. A) Roadcut B) Embankment.

Materials and methods

The study area was located in Central Spain, near Barajas International Airport (40º 29´N, 03º34´W) 12 km from Madrid Centre. The regional climate is Continental Mediterranean with cold winters, and dry summers. Mean annual temperature and total annual temperature are 12.5ºC and 500 mm respectively. The substrate is detritic consisting mainly of coarse sand. The surrounding landscape is a mosaic of abandoned croplands, therophytic grasslands, and some remnant patches of *Retama sphaerocarpa* and sparse *Quercus Ilex*. The experimental design was set up within the construction process of two highways, M-12 and M13, built from 2002 to June 2005 to provide access to Barajas airport. We considered two types of roadslopes (roadcuts and embankments). Topsoil was spread only on the embankments. We selected 9 roadcuts and 6 embankments with similar slopes angles, and lengths. In each roadslope we applied three hydroseeding treatments, one plot was hydroseeded with a standard seed mixture planned for revegetation at the infrastructure project, a second plot was hydroseeded with an alternative seed mixture of autochthonous species, and a third one remained untreated.

Edaphic features and vegetation cover was measured at three different positions on the roadslope (top, middle and bottom), by 18 quadrat plots (50 x 50 cm) per roadslope (2 sample x 3 positions x 3 treatment) according to a nested factorial design.

Soil samples were air-dried and sieved through a 2-mm mesh. We determined soil pH (Ph/ion meter 781 Metrohm), conductivity (Crisom CM 35 conductivity meter), texture (Bouyoucos hydrometrer method), carbon content (% C) by Anne method adapted to microplate reader (Nelson & Sommers, 1982), organic matter (% OM) using widely accepted coefficient 1.72 (Van Bemmelen factor), nitrogen content (Kjeldhal) and nitrate content by an ion-selective electrode (Metrohm Ltd.,Herisau,Switzerland).

Statistical differences in vegetation cover and soil features between roadslope types, hydroseeding treatment, and position along the roadslope length were analyzed using three-way ANOVA. A forward stepwise multiple regression was used to elucidate the contribution to plant cover of soil features. Besides, those variables found to be repeatedly significant in the previous analysis were used as covariates in separate one-way ANCOVARs to test whether they accounted for differences in final plant cover between roadslope types. Finally we compared the edaphic features measured in the current experiment with previous results obtained four years ago (2004) in the same study area by the research team. To this aim, we carried out a three-way repeated-measures analysis of variance (ANOVAR). All statistical analyses were performed using STATISTICA 6.0 (StatSoft, Inc.Tulsa,OK).

Results and discussion

Edaphic properties of the study roadslopes are summarized in Table 1. The chemical status of these slopes indicated a very low fertility (low nitrogen, and organic matter content), according to previous results in the studied area (Gascó, *et al* 2002). However, our results showed higher values of soil nutrients (carbon, nitrogen, nitrates and OM), lime, clay and vegetation cover in embankments than in roadcuts. Probably, these differences between types of roadslopes, can be explained by the spread of topsoil on the embankments, which likely improved the physical and chemical properties of the soil (Balaguer 2002, Tormo *et al.* 2007).

There were no significant differences between types of treatment. The addition of fertilizer by the hydroseeding technique had no effects on soil nutrients or vegetation cover. Similar results was observed by Petersen *et al.* 2004, as they found that fertilization provided an initial effect on vegetation development but disappeared throughout the time.

The position along roadslope had significant effects on the texture, with the highest values of limes on the bottom and of clay on the top. However, this effect was only presented on roadcuts as showed by the significant interaction between roadslope type and position ($P < 0.01$). The higher accumulation of limes in the base of the roadcuts suggests higher rates of erosion, as previously reported by Bochet & García-Fayos (2004). The lack of this process in embankments supports the idea that topsoiling had a positive effect in soil structure and embankments became less prone to erosion.

Table 1. Mean (±SE) soil characteristics. Significant differences (three - way ANOVA) between roadslope type, hydroseeding treatments and position across the roadslope are indicated by * $P < 0·05$, **$P < 0.01$ or *** $P < 0·001$. Significant interaction was found between type and position for lime and clay($P < 0.01$) and between type and position for nitrate($P < 0.01$).

	Type		**Treatment**			**Position**		
	Embankment	Roadcut	Standard	Untreated	Alternative	Top	Middle	Bottom
pH 1:2,5	8.53 ± 0.03	8.16 ± 0.04 ***	8.31 ± 0.04	8.27 ± 0.05	8.34 ± 0.05	8.30 ± 0.06	8.31 ± 0.04	8.3 ± 0.04
Conductivity 1:5 (µS/cm)	65.46 ± 2.57	43.87 ± 1.90 ***	53.83 ± 2.76	54.38± 2.78	55.77 ± 2.77	60.03 ± 2.79	52.04 ± 2.76	51.93 ± 2.76
% C	0.19 ± 0.01	0.11 ± 0.01***	0.14 ± 0.01	0.13 ± 0.009	0.14 ± 0.01	0.15 ± 0.01	0.14 ± 0.01	0.12 ± 0.01
% OM	0.32 ± 0.01	0.18 ± 0.01***	0.26 ± 0.02	0.24 ± 0.02	0.26 ± 0.02	0.27 ± 0.02	0.25± 0.02	0.23 ± 0.02
% N	0.02 ± 0.001	0.01± 0.001***	0.017 ± 0.001	0.016 ± 0.001	0.015 ± 0.001	0.017 ± 0.0001	0.016 ± 0.001	0.015 ± 0.001
Nitrate (mg kg^{-1})	8.12 ± 0.43	5.76 ± 0.35***	7.21 ± 0.48	6.62± 0.48	6.98 ± 0.49	6.89 ± 0.49	6.69 ± 0.48	7.24 ± 0.48
% Sand	68.48 ± 0.71	75.86 ± 1.15***	72.76 ± 1.39	73.14 ± 1.38	72.83 ± 1.27	72.25 ± 0.96	75.33 ± 1.20	71.18 ± 1.72
% Lime	21.63 ± 0.61	16.25 ± 0.95***	18.58 ± 1.10	18.11± 1.17	18.50± 1.08	17.28 ± 0.82	16.63 ± 0.92	21.24 ± 1.44*
% Clay	9.89 ± 0.34	7.90 ± 0.37***	8.66 ± 0.52	8.75 ± 0.42	8.67 ± 0.44	10.47 ± 0.44	8.04 ± 0.43	7.59 ± 0.45***
% Cover 2007	71.11 ± 2.55	42.17 ± 1.8***	53.39 ± 2.58	50.42 ± 3.17	57.53 ± 3.25	56.56 ± 2.80	52.27 ± 3.06	52.43 ± 3.20
% Cover 2008	68.93 ± 2.24	41.80 ± 1.83***	59.31 ± 2.51	53.17 ± 2.50	53.62 ± 2.52	56.33 ± 2.51	55.49 ± 2.51	54.28 ± 2.51

In order to elucidate relationships between plant cover and soil features a forward stepwise multiple regression was used. Vegetation cover measured in 2007 was explained by nitrate, nitrogen, carbon and clay content in soil (adjusted $R^2 = 0.4$, $P < 0.001$). In addition, the separated ANCOVA results showed that the effects of those variables on the evolution of plant cover (2007) were highly significant ($P < 0.001$) even independently of the type of roadslope ($P < 0.001$). Similar relations (with carbon content) were found when considering the vegetation cover measured in 2008, but the proportion of variability explained was lower (adjusted $R^2 = 0.3$). These results show the role of organic matter and nitrate on the vegetation development, according to previous studies in Mediterranean conditions (Montalvo *et al.*2002). Nevertheless, those relationships become weaker through time. According with this, in a previous study (performed after the construction of the roadslopes) in the same experimental set-up, we obtained that vegetation cover was related with soil nitrate content, organic matter and total nitrogen (adjusted $R^2 > 0.6$). This result are agree with the hypothesis that soil features plays an important role in vegetation establishment mainly in the earliest stages, but once vegetation have been established other factors like biotic interactions likely play a major role. Therefore, nutrient demand and plant response changes with age and successional status (Whisenant 1999).

Table 2. Forward stepwise multiple regression analyse with a P value of 0.05 as the inclusion criterion. (* = P<0.05). Standardized β coefficients indicate the relative contribution of the predictor variables.

	Vegetation cover (%) (target variable)			
	jun 2007		jun 2008	
Predictor variable	ℵ	P	ℵ	P
%C	0.579	<0.05	0.528	<0.05
NITRATE	0.161	<0.05	-	-
%CLAY	0.145	<0.05	-	-
%N	-0.144	<0.05	-	-
pH 1:2,5	-	-	0.121	<0.05
Adjusted R^2	0.4	P<0.001	0.3	P<0.001

On the other hand, we analysed the temporal evolution of soil features by repeated measures ANOVA considering data obtained in 2004 (in the same experimental set-up) and data obtained in the current experiment. These results showed an increase through time ($P_{time} < 0.05$) of nitrogen and carbon content, but a drop in nitrate, K, Na and Mg (Figure 2). These trends are likely the result of plant-soil interaction, as indicated by a more evident increase in nitrogen and carbon content on embankments with higher vegetation cover. In other words, our results suggest that vegetation colonization finally improved the soil fertility as previously reported by Whisenant (1999).

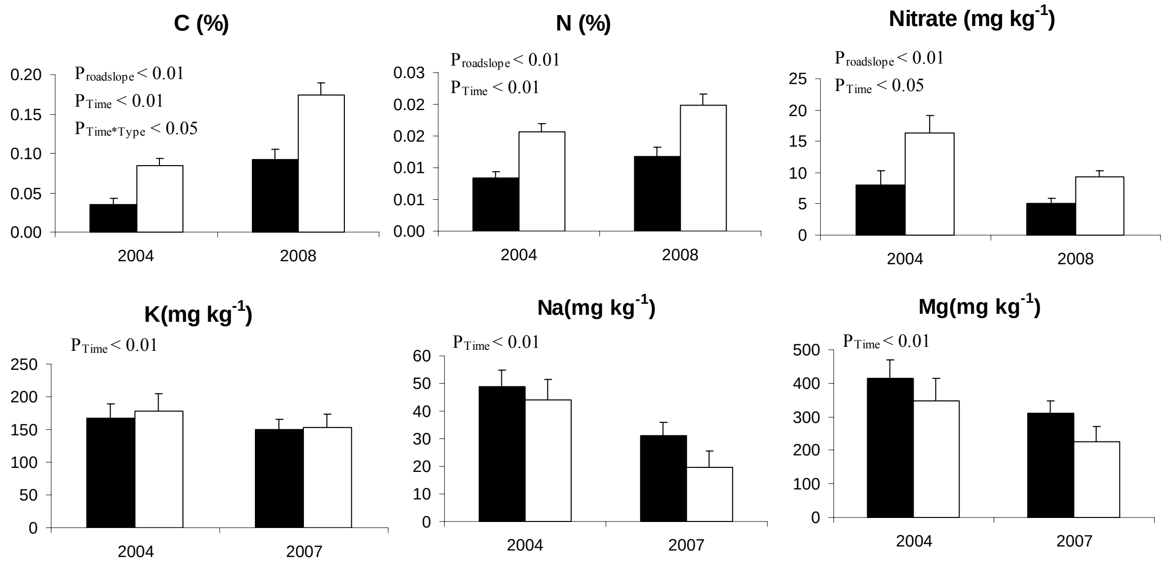

Figure 2. Soil features evolution between 2004 and 2008. Mean ± SE of soil features in roadcuts (■) and embankments(□). Only significant results ($P < 0.05$) in the ANCOVAR are shown.

Conclusions

The addition of fertilizer by the hydroseeding technique had no effects on soil nutrients or vegetation cover. Seedling recruitment, however, was limited by microsite suitability as the content of organic matter, nitrogen and nitrate in the soil. Efforts should be directed towards improving microsite fertility mainly in the first stages. Techniques that improve the soil nutrient content, like topsoiling, reduce the microsite limitation to plant establishment. Furthermore, differences between roadslope types should be considered in future plant restoration programs. Additional studies are needed for the diagnosis of microsite limitation factors, biotic interactions and their temporal evolution.

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