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Relative importance of plant traits and ecological filters in road embankment revegetation under semiarid Mediterranean conditions

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ABSTRACT

Revegetation in semiarid road embankments is not always successful because most of the sown species disappear and only a few survive. To improve hydroseeding success, there is a need to understand the underlying ecological processes that determine the outcome of sown species in restoration works.

The objective of this work is to determine the relative importance of different factors in determining the final species composition after sowing in road embankments and with this aim, we conducted three different experiments: (1) experimental sowing in road embankments to determine species performance in field conditions; (2) greenhouse sowings, with the same species than the road embankment experiment, to study the effect of ecological filters (water stress and plant coexistence) on the performance of the species; and (3) analysis of relations between plant traits of the sown species (specific seed mass and specific plant biomass) and sowing success and competitive abilities in the greenhouse experiment. Relative success of the species in the embankments was compared with the relative success of the same species in greenhouse experiments and with the seed density sown in the road embankments.

Plant coexistence, water stress and plant traits affected aboveground plant biomass production per species in the greenhouse experiment. However, the effects of plant traits on aboveground plant biomass were lower than the effect of plant coexistence but higher than the effect of water stress. The performance of the species in the water stress monoculture treatment at the greenhouse correlated positively with the performance of the species in the field 2 years after they were hydroseeded, thus indicating that water stress was the most influencing factor on species performance in road embankments. At the same time, plant traits as specific seed mass and plant biomass indirectly affected plant performance in the field since they affected aboveground plant biomass in the greenhouse experiment. On the contrary, species coexistence and seed density at sowing had influence on species performance in the road embankments neither 1 nor 2 years after hydroseeding.

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1. Introduction

Road building produces large amounts of unvegetated soils often forming embankments. In Mediterranean semiarid lands, revegetation of these slopes is fundamental since they are very vulnerable to erosion. One of the most used methods of revegetation is hydroseeding. However, in many cases, revegetation by hydroseeding leads to species poor stands due to the dominance of a few species over all the other sowed or spontaneous species (Andrés and Jorba, 2000; Kleijn, 2003; Waldron et al., 2005). Although erosion control may be reached even in low-diversity stands, high species richness is, however, the preferable outcome because a wide range of species that respond differently to different environmental perturbations increase the likelihood of the new ecosystem to be resistant and/or resilient to future conditions and disturbances (Hilderbrand et al., 2005; Hooper et al., 2005). In particular, Boeken and Shachak (2006) demonstrated that minor species (sensu Grime, 1998) facilitate the recruitment and abundance of dominant ones during recolonization after disturbance. Moreover, two other factors should be taken into account: on the one hand, certain combinations of species are complementary in their patterns of resource use and can increase average rates of productivity and nutrient retention. On the other hand, susceptibility to invasion by exotic species is strongly influenced by species composition and, under similar environmental conditions, generally decreases with increasing species richness (Hooper et al., 2005).

Understanding the factors influencing species performances will help to produce more diverse and functional stands in restoration works. This knowledge will help restoration managers to manipulate factors that heavily determine the output of restoration, like selection of suitable species and sowing date. Different ecological filters in semiarid climates were identified as influencing the relative performance of species. Water stress is a critical factor in revegetation in arid and semiarid environments (Sharma et al., 2000; Le Houerou, 2000; Snyman, 2003), especially in the establishment stage (Koop, 2004). It is also relevant for road embankment colonization (Bochet and García-Fayos, 2004; Tormo et al., 2006) and revegetation (Bochet et al., 2007; Karim and Mallik, 2008). Coexistence among sown species can be an important factor in determining the final composition and the relative abundance of individual species (Bakker and Wilson, 2001; Humphrey and Schupp, 2004). In addition, environmental factors (Brose and Tielborger, 2005) such as water stress not only contribute to plant community composition and structure (Shilo-Volin et al., 2005; Weigelt et al., 2005) but, in some cases, they may also reverse the competitive hierarchies of plant species (Fynn et al., 2005).

Human can also influence specific vegetal cover by deciding the amounts of the different species in seed mixtures. The relative amount of seeds sown is an important factor (Stevenson et al., 1995). It is expected that species with the highest sowing proportion in a mixture of seeds will produce the highest vegetal cover or biomass. However, this is not always the case. Snyman (2003) found that other factors influencing germination rate or plant growth might be more important than sowing proportions in determining the relative vegetal cover of the sown species.

Plant traits, such as specific plant biomass, can also influence relative cover of a species in restoration works (Navas and Moreau-Richard, 2005). In relation to seed size, large seeded species have better establishment rates than small seeded ones in natural ecosystems (Fynn et al., 2005; Moles and Westoby, 2006). Nevertheless, Montalvo et al. (2002) obtained opposed results for species establishment in embankments, since the largest seeds showed the lowest establishment performance.

The fate of sown species is not determined by only one of the factors mentioned, but by a hierarchy of factors. To improve hydroseeding success, there is a need to understand the underlying ecological processes that determine the outcome of sown species in restoration works.

We propose that species success after embankment hydroseeding in Mediterranean semiarid conditions may be affected by three possible groups of factors or a combination of them:

- The first group of factors depends on the amount of sown seeds per species used in the hydroseeding (seed density). We hypothesize that species sown at higher densities will contribute more to the final vegetal cover than those sown at lower densities.
- The second group of factors, derived from environmental stress and species coexistence, may also influence the relative performance of the species. We hypothesize that the competitive hierarchy of the species will determine the relative contribution of the species to the total vegetal cover but this hierarchy will be altered by water stress.
- The third group of factors depends on plant traits. We hypothesize that specific plant biomass and seed mass will also influence the outcome of relative vegetal cover of sown species.

The objective of this work is to determine the importance of the three groups of factors on the outcome of the hydroseeded species in road embankments under semiarid Mediterranean conditions. We applied rank correlation to the results of relative species performance obtained from field and greenhouse experiments to ascertain the hierarchy of factors influencing the final outcome of the sown species in road embankments.

2. Material and methods

2.1. Studied species

The species used in the experiments were *Avena barbata* Pott. Ex Link, *Dactylis glomerata* L., *Bromus rubens* L. (Poaceae), *Diplotaxis erucoides* (L.) DC (Brassicaceae), *Anacyclus clavatus* (Desf.) Pers. (Asteraceae), *Plantago albicans* L. (Plantaginaceae), *Medicago sativa* L. and *Medicago minima* (L.) L. (Fabaceae). All species are ruderal species that grow naturally in the road embankments of the study area. *D. glomerata* is a perennial herbaceous grass, *P. albicans* is a rhyzomatous perennial herb and *M. sativa* is a perennial herbaceous legume with nitrogen fixing ability that has been widely used in revegetation of road