HYDROSEEDED AND NATIVE SPECIES ON COAL RECLAMATION IN MEDITERRANEAN ENVIRONMENTS: SHORT-TERM SPECIES RESPONSES

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Abstract: Understanding the response of established species during the first years of ecosystem development is crucial to the successful of the ecosystem restoration. Particularly, more information about the success of hydroseeded and natives species in terms of establishment and development on reclaimed coal mines in the Mediterranean region is needed. We described the species response curves of various frequently hydroseeded and native species on a coal reclamation area in Spain. The percentage of cover of hydroseeded and native species were monitored in three permanent plots of 20 m^2 on north- and south-facing slopes, and on a flat area, every two months during three years after hydroseeding. There were differences in the response among the hydroseeded species, especially for two annuals (*Avena sativa* and *Secale cereale*) that appeared only during the first two years after hydroseeding. Native species showed also differences in their response models, whereas *Trifolium* species showed similar responses, there were some species which only were important during one year. The knowledge of this information is very important for the correct management of those areas and to improve species selection to be used in future reclamations.

Keywords: Species response models, grassland formations, mining activities, restoration of surface coal mined lands, (re-)introduction, hydroseeding.

Introduction

One of the major challenges of restoration ecology is to change degraded systems into ones that will be sustainable in the long-term (Aronson & van Andel 2006; Hobbs & Norton 1996). The components that must be restored for long-term sustainability include some form of plant cover (Hobbs & Norton 1996). The re-establishment of plant cover in large-scale degraded areas, as in open-pit coal mines, is complicated, because there is often a lack of seed bank and dispersal limitations from seed sources (González-alday et al. 2008). As a result, restoration practitioners use sowing techniques, as hydroseeding, to enhance vegetation establishment (Davy 2002). However, there is a lack of knowledge about the success of hydroseeded species and the performance of native ones. An understanding of the response of those established species during the first years of ecosystem development is crucial for a successful ecosystem restoration and to improve seeds mixtures. Therefore, the objective was to describe the development of hydroseeded and some native species on a coal reclaimed area in the Mediterranean Spain.

Materials and methods

The study was carried out from 2004 to 2006 in ‘Pozo Sell’, a restored open-pit coal mine in Palencia, northern Spain (1185 m a.s.l.; 42º50’N, 4º38’W). The climate is sub-humid Mediterranean, with the most rains falls during spring and autumn, and with a dry season in July and August. The vegetation surrounding the study area consisted of a complex matrix with grasslands, crop fields, shrubland remnants and small patches of *Quercus pyrenaica* woodlands (González-Alday 2005).

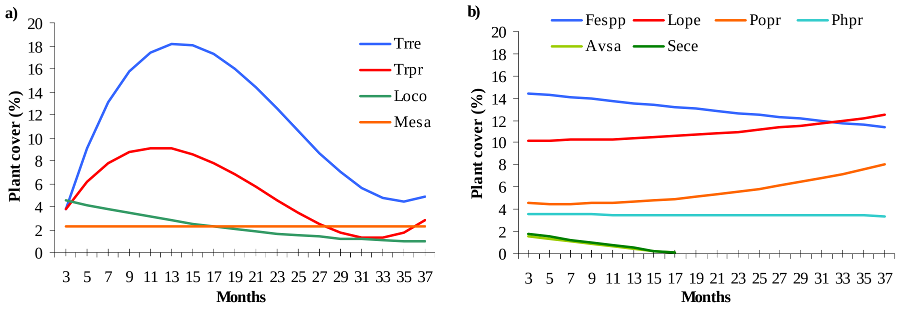

Figure 1. GLMM model predictions for the plant cover of the hydroseeded species, relative to months after hydroseeding. Species codes: a) Legumes: *Trifolium repens*-Trre; *T. pratense*-Trpr; *Lotus corniculatus*-Loco; *Medicago sativa*-Mesa; b) Grasses: *Festuca* spp.-Fespp; *Lolium perenne*-Lope; *Poa pratensis*-Popr; *Phleum pratense*-Phpr; *Avena sativa*-Avsa; *Secale cereale*-Sece.

After coal extraction finished, the final open pit was filled with coal wastes from nearby mines. The site was graded to a slope of 25º, and the surface was covered with 50-100 cm of finer textured sediments and cattle manure (30 t ha^{-1}). Thereafter, the site was hydroseeded by the mining company (U.M.I.N.S.A.) at the end of October 2003. The hydroseeding slurry contained: 150 kg ha^{-1} of soluble chemical fertilizer (8N:15P:15K), and 210 kg ha^{-1} of a seed mixture containing grasses (81% in weight) and herbaceous legumes (19% in weight) (for more details see Fig. 1 and González-Alday et al. 2008).

The vegetation development was examined in three permanent plots of 20 m^2 on north- and south-facing slopes, and on a flat area. Within each plot, eight 0.25 m^2 quadrats were positioned randomly and marked permanently on the first sampling date. The cover (%) of all species present in each quadrat was estimated visually by the same observer, every two months from January 2004 to November 2006.

Generalized linear mixed models (GLMM) were built for model the plant cover response of hydroseeded and most important native species (present in more than 80 plots) over the first 3 years after hydroseeding. The factor variable Plot (with 9 levels) and the continuous variables Month were used as random factors. Fixed effect predictor of plant cover was Month. However, often the relationship between them is not a straight line; therefore polynomial regression was used (including quadratic and cubic terms). Since there is a temporal dependence among observations, we used the first-order autoregressive correlation structure (corAR1()) to model this dependence (Pinheiro & Bates 2000), and the variance function varPower for modeling heterocedasticity (Pinheiro & Bates 2000). The model simplification guidelines of Crawley (2007) were used. The minimal adequate models (MAMs) were derived through fitting of a full model and deleting the variables one at time, and then comparing the depleted model with the previous one using ANOVA function. Also, the Akaike's Information Criterion (AIC) was used to aid model selection (Pinheiro & Bates 2000). The Restricted Maximum Likelihood method (REML) was used to calculate the estimates of coefficients of the MAMs. Modeling results were interpreted by graphs of predicted species plant cover as function of Months. All statistical computations were implemented in the R software environment (version 2.7; R Development Core Team 2008), using the LME4 package for GLMM (Bates & Sakar 2007).

Results and discussion

According to the best GLMMs for hydroseeded species (Fig. 1), *T. repens* and *T. pratense* showed similar cover shape with a large increase until summer of 2004, and a maximum through winter of 2004 to spring of 2005 (18% for *T. repens* and 8% for *T. pratense*), decreasing later. The other two legumes showed different responses, whereas *M. sativa* maintained constant cover over time (2%), *L. corniculatus* decreases slowly (Fig. 1a). Three types of response through time were observed among grasses (Fig. 1b), (1) a constant cover nearly of 4% (*P. pratense*); (2) a decrease in cover through time, as *Festuca* spp. that reduced slowly its cover (from 14% to 12%), and especially for the two annual species (*A. sativa* and *S. cereale*) that disappeared at September of the second year after hydroseeding; and (3) a steady increase in cover through time as *L. perenne* (from 10% to 12.5%) and *P. pratensis* (from 4.25% to 7.5%) (Fig. 1b).
The differences in cover response through time among hydroseeded species have important implications for mine restoration by hydroseeding. Undoubtedly, the use of exotic species that increase or maintain the plant cover (*L. perenne* and *P. pratensis* or *M. sativa* and *P. pratense*) could produce problems for vegetation composition in the medium- to long-term restoration of target semi-natural communities (D'Antonio & Mayerson 2002). Especially, in the case of *P. pratensis* and *L. perenne* that has been reported as highly competitive species (Hoffman 2004), which prevent the establishment of native species (MacDougall & Turkington 2005, Matesanz et al. 2006).

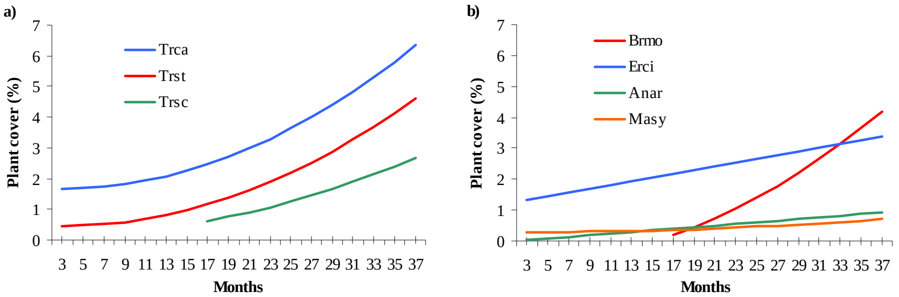

Figure 2. GLMM model predictions for the plant cover of the native species, relative to months after hydroseeding. Species codes: a) Legumes: *T. campestre*-Trca; *T. striatum*-Trst; *T. scabrum*-Trsc; b) Others: *Bromus mollis*-Brmo; *Erodium cicutarium*-Erci; *Anthemis arvensis*-Anar; *Malva sylvestris*-Masy.

Of the remaining hydroseeding species, the decrease in plant cover through time of *Festuca* spp., *T. repens* and *T. pratense*, as well as the important cover values reached during the first years, suggest their use for hydroseeding, because they provide stabilization and protection against erosion (Tordof et al. 2000). *L. corniculatus* and the two annual species (*A. sativa* and *S. cereale*), also decreases through time, nevertheless, the small cover values reached not ensure soil protection, suggesting their use in hydroseeding with more protective species or by increasing their amounts of seeds.
The GLMMs for native species showed in all cases increasing responses of cover through time (Fig. 2). *Trifolium* species showed similar cover shape, with a slight increase in cover during the first year, but increasing more markedly later (*T. campestre* and *T. striatum*; Fig. 2a). Similar response showed *T. scabrum* but only during the second and third years. Of the remaining native species *E. cicutarium*, *A. arvensis* and

M. sylvestris showed linear increase of cover through time, only important in the case of *E. cicutarium* (Fig. 2b). Whereas, *B. mollis* showed the large increase of cover through time, regarding that appeared in the spring of the second year (Fig. 2b). Therefore, the positive developments of native species, as *Trifolium* spp. and *B. mollis*, could be an option to improve seed mixtures for use in future coal reclamation areas, reducing the use of more competitive foreign species (González-Alday & Martínez-Ruiz 2007). However, further investigations are needed to asses the dynamics of the remaining hydroseeding species in the longer term or their competition with native species, and the effectiveness of including some native species in the seed mixtures.

Conclusions

In coal mine reclamation areas of Mediterranean climates, the commercial species added through hydroseeding must be chosen with care, because may hinder the establishment of autochthonous species or create low diversity communities. At the same time, managers should take into account the success of some native species, as *B. mollis*, *T. campestre* and *T. striatum*, when selecting species to be used for reclamation.

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