

## EARLY GROWTH DYNAMICS OF SOME FREQUENTLY HYDROSEEDED SPECIES IN COAL RECLAMATION: THE INFLUENCE OF ASPECT IN MEDITERRANEAN ENVIRONMENTS

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**Abstract:** Although it is well known that aspect of a site influences the vegetation dynamics of natural communities, little is known about the role of aspect in the development of vegetation on reclaimed coal mines, particularly in the Mediterranean region. We investigated the effect of aspect (north vs. south) on the establishment and development of various frequently hydroseeded species on the steep slopes of coal reclamation area in Spain. The dynamics of hydroseeded species, soil properties and weather conditions were monitored in three permanent plots of 20 m<sup>2</sup> on north- and south-facing slopes, every two months during the first year after hydroseeding. Aspect was related to total plant cover during early revegetation, and south-facing slopes had the lowest cover. Aspect also influenced the early dynamics of hydroseeded grasses and legumes establishing on these slopes. Grass cover was greater on the north slope throughout the study, but differences in plant cover between north and south slopes appeared later for the legumes. Aspect also affected the relative contribution of both of grasses and legumes to the total plant cover, with grasses dominant on both northern and southern slopes, except during the summer on the southern slope. These results suggest that in coal mine reclamation areas of Mediterranean climates, differences in the development of hydroseeded species depended on the aspect of slope of the coal mine reclamation areas, and this information is of importance to managers in selecting species for use in reclamation.

**Keywords:** restoration of surface coal mined lands, grassland formations, vascular plants, extraction of soils and minerals, (re-)introduction, biomanipulation.

### Introduction

The vegetation dynamics of natural communities are affected by aspect (Kutiel 1992; Bennie et al. 2006; Martínez-Ruiz & Marrs 2007), mainly caused by the differences in solar radiation received that influenced evaporation rate and soil moisture (Kirby et al. 1990). However, in the Mediterranean region there is a lack of knowledge about the role of aspect in the development of vegetation on reclaimed coal mines.

The large scale destruction of natural areas has created a large amount of bare slopes with differing aspects in Spain (González-Alday et al. 2008), in which vegetation re-establishment plays an important role controlling soil loss and runoff (Singh et al. 2002). Usually restoration practitioners use sowing techniques to enhance vegetation establishment (Davy 2002), being hydroseeding one of the most used methods to revegetate coal mine areas in Spain (González-Alday et al. 2008). At the same time, aspect is one site factor that has been implicated as critical in determining the success of hydroseeding in land reclamation (Andrés et al. 1996; Martínez-Ruiz et al. 2007). Therefore, the objective was to investigate the effect of aspect (north vs. south) on the establishment and development of hydroseeded species on the steep slopes of a coal reclamation area in Spain.

### Materials and methods

The study was carried out from 2004 to 2005 in 'Pozo Sell', a restored open-pit coal mine in Palencia, northern Spain (1185 m a.s.l.; 42°50'N, 4°38'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).

After coal extraction finished, the final open pit was filled with coal wastes from nearby mines. The site was graded to a slope of 25°, and the surface was covered with 50-100 cm of finer textured sediments and cattle manure (30 t ha<sup>-1</sup>). 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<sup>-1</sup> of soluble chemical fertilizer (8N:15P:15K), and 210 kg ha<sup>-1</sup> of a seed mixture containing grasses (81% in weight) and herbaceous legumes (19% in weight) (for more details see Fig. 2 and González-Alday et al. 2008).

The vegetation development was examined in three permanent plots of 20 m<sup>2</sup> on both north- and south-facing slopes (aspects). Within each plot, eight 0.25 m<sup>2</sup> 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 January 2005.

The possible effects of aspect (north or south), month (7 levels) and interaction between aspect and month (fixed factors) on total plant cover and hydroseeded grass and legume cover were analysed using Linear Mixed Models (LMM) with the Restricted Maximum Likelihood method (REML). In all cases permanent plots were treated as random factors. DCA (Detrended Correspondence Analysis) was also used to summarize the overall multivariate species response. Besides indirect interpretation of the ordination axes, sample ordination scores of the first two axes were used as derived variables and tested for a significant relation with the explanatory variables (aspect and month) by means of LMM. All statistical computations were implemented in the R software environment (version 2.6; R Development Core Team 2007), using the NLME package for LMM (Pinheiro et al. 2007) and the VEGAN package for DCA (Oksanen et al. 2007).

## Results and discussion

The analysis of total plant cover showed a significant aspect by month interaction ( $F_{[6,24]} = 4.52, p < 0.01$ ). Total plant cover was always greater on the northern slope than on the southern one, except for May, and increased from January 2004 to January 2005 a 340% on the northern slope, and a 287% on the southern slope (Figs. 1a-b). In general, southern slope showed approximately 20% lower plant cover than northern one. Given that both aspects were treated in the same way, and had similar edafic and macroclimatic conditions (González-Alday et al. 2008), the influence of aspect was probably mediated through its effects on microclimate (Bennie et al. 2006). Overall, the differences in microclimate between aspects, as a result of the differing amounts of solar radiation received (Kutiel 1992) that influenced the dynamics of water availability (Kutiel 1992; Sternberg & Shoshnashy 2001), produced lower vegetation cover on southern slopes compared to northern ones.

The cover of the hydroseeded grasses showed a significant aspect by month interaction ( $F_{[1,4]} = 2.64, p < 0.05$ ). Grass cover was always greater on the northern slope than on the southern one throughout the study (Figs. 1a-b). Therefore, aspect influenced the

development of grass cover, and this result was in agreement with other studies (Martínez-Ruiz et al. 2007; Martínez-Ruiz & Marrs 2007).

For legumes, only differences between aspects were found from September to November of 2004, with legume cover lower on the southern than on the northern slope (Figs. 1a-b); thus, differences in cover induced by aspect took longer to develop on the legumes (González-Alday et al. 2008).

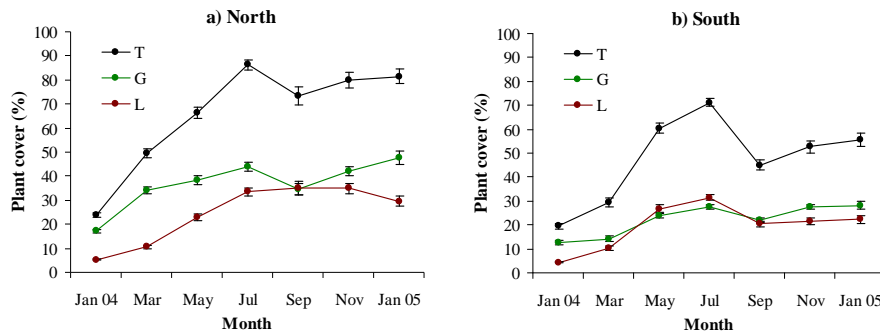


Figure 1. Total plant cover (T) and hydroseeded grass (G) and legume (L) cover from January 2004 through January 2005 on the north- and south-facing slopes of the 'Poza Sell' open-pit mine.

Comparing grasses vs. legumes within each aspect, the north slope had greater grass than legume cover ( $F_{[1,4]} = 8.20$ ,  $p = 0.045$ ; Fig. 1a), but on the south slope grass and legume cover did not differ ( $F_{[1,4]} = 2.71$ ,  $p = 0.175$ ; Fig. 1b). However, the results showed greater grass cover in southern slope during winter and autumn, whereas in spring and early summer legume cover was higher than grass cover (Fig. 1b). Thus, aspect influenced the relative contribution of hydroseeded grasses and legumes to the total plant cover, although on the southern slope there is a seasonal variation in this relative contribution, as reported by Andres et al. (1996).

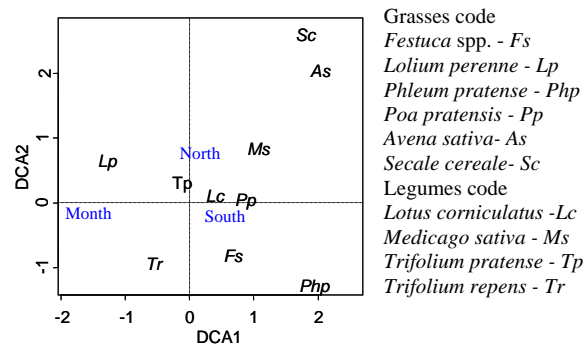


Figure 2. The first two dimensions of DCA species scatter plot (DCA1 explained 63% of the variation and DCA2 the 14%). See side code for species identification.

The first two axes of the DCA explained 77% of the variation. The scatter of species in the DCA biplot illustrated both aspect and time effects (Fig. 2). Axis 1 reflected a highly significant gradient associated with month ( $F_{[6,24]} = 83.15$ ,  $p < 0.001$ ), with

species more abundant at the beginning on the right of axis 1 as *Avena Sativa*, *Secale cereale* and *Phleum pratense* which decreased later, and species increasing their cover with time on the left hand area of the diagram as *Lolium perenne*, *Trifolium repens* and *T. pratense*. Axis 2 showed a significant gradient associated with aspect ( $F_{[1,4]} = 15.49$ ,  $p = 0.017$ ), with species clearly preferring the north slope throughout on the upper hand area of the diagram (*L. perenne*, *T. pratense*, *A. Sativa* and *S. cereale*), and those showing seasonal variation in cover according to aspect on the lower hand area (*Poa pratensis* and *P. pratense*).

### Conclusions

In coal mine reclamation areas of Mediterranean climates, differences in the development of hydroseeded species depended on the aspect of slope of the reclaimed areas. Therefore, managers should take into account the aspect of slope when selecting species for use in reclamation, particularly by hydroseeding. Otherwise short-term vegetation establishment will be substantially reduced under the more severe conditions on south-facing slopes.

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