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# Natural and man-induced revegetation on mining wastes: Changes in the floristic composition during early succession

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ABSTRACT

The performance of introduced species when interacting with colonising herbs and shrubs from the surrounding areas has become an important issue in plant ecology and restoration management. In this paper, we examined the influence of hydroseeding a commercial seed mixture on the revegetation of uranium mine wastes under a semi-arid Mediterranean climate in West-Central Spain. Eight dump slope sites differing two by two in revegetation treatment (hydroseeding or not) and aspect (north/south) were monitored annually during 3 years. There was a combined effect of treatment and aspect on the floristic composition during early succession. Particularly, hydroseeding increased differences in floristic composition between aspects, being the contribution of sown species to these differences small and short. Hydroseeding increased plant cover and diversity significantly only 2 years after its application on the north-facing slopes, favoured the perennial species (mainly hemicryptophytes), and had a different effect depending on the aspect favouring grasses and legumes on the north- and south-facing slopes, respectively. The species mixture was not suitable and the use of local seeds should be tested in future revegetation projects at this zone. The importance of improving natural colonisation for ecological restoration is emphasised.



## 1. Introduction

The damage to soil and vegetation caused by mining, unless prevented by careful planning, is usually extreme, because the original ecosystems have had to be grossly disturbed or buried by the mining process (Bradshaw, 2000). To achieve a successful restoration the soil has to be remediated and the vegetation re-established (Bradshaw, 1997). The presence of an initial plant cover will clearly be important in beginning the process of stabilisation and accumulation of finer material (Bradshaw, 2000; Parrotta and Knowles, 2001; Nicolau, 2002). However, in areas with a semi-arid Mediterranean climate, the low and irregular distribution of rainfall is the major factor limiting plant growth (Noy-Meir, 1973; Zohary, 1973) and vegetation cover tends to be low and sparse (Schelesinger et al., 1990).

To enhance vegetation establishment and stabilising inaccessible steep slopes, such as that caused by mining, the hydroseeding technique has become widely used (Sheldon and Bradshaw, 1977; Roberts and Bradshaw, 1985; Albadalejo et al., 2000; Brofas and Varelides, 2000). This involves spraying a homogeneous slurry of seed, fertilizer, binder and mulch

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from a high-pressure hose (Sheldon and Bradshaw, 1977). The steepness of the slopes and the nature of the surfaces prevent the use of conventional agricultural machinery of seed and fertilizer application (Hanson and Juska, 1969). However, hydroseeding represents a specialised and costly technique, which can have limitations (Roberts and Bradshaw, 1985).

The major factors affecting the success of hydroseeding, in a particular region, are technical: components used and rates of application (Sheldon and Bradshaw, 1977; Roberts and Bradshaw, 1985; Merlin et al., 1999), sowing time and prevailing weather conditions (Andrés et al., 1996; Cano et al., 2002); and intrinsic to the site: angle of slope (Leavitt et al., 2000), aspect that will affect energy relations and soil moisture (Andrés et al., 1996; Cano et al., 2002) or roughness and material hardness (Cano et al., 2002).

Under semi-arid Mediterranean conditions in Spain, soil stabilization on roadsides and mining wastes is often achieved by using commercial mixtures of non-native seeds (Andrés et al., 1996; Andrés and Jorba, 2000; Nicolau, 2002). However, the behaviour of these species in providing rapid vegetation cover of exposed substrate in a regime of scarce and markedly seasonal rainfall, and their performance when competing with colonising species invading from nearby are still poorly understood (Andrés et al., 1996). Also the capacity of species characteristic of later successional stages to displace the initial ground cover should be better understood (Marrs and Le Duc, 2000; Bakker et al., 2002). We hypothesize that the dynamics of early revegetation in such semi-arid Mediterranean conditions will be affected by both the hydroseeding of non-native species and site aspect. To understand these factors, we compared natural and man-induced community development on uranium waste dumps of differing aspect in West-Central Spain. We also investigated the effectiveness of introduced species in providing plant cover and diversity during early succession according to the aspect.

## 2. Methods

### 2.1. *Site description and sampling*

The study was carried out at a uranium-mine in Salamanca province, Spain (40°37′N, 6°38′W), disused 10 years ago. The climate at the site is semi-arid Mediterranean with a mean annual rainfall of 500 mm, and acute summer droughts where there is only 12% of the annual rainfall. The mean annual temperature is 12.7 °C, the mean minimum in the coldest month (January) is −0.34 °C and the mean maximum in the warmest month (August) is 31 °C (Martínez-Ruiz, 2000). The soils are slightly acidic loams (pH 5.5–6.7) overlying slate bedrock, with a predominance of dystric cambisols (Dorronsoro, 1992). The natural vegetation of the area is a 'Dehesa' formation which is a mixture of grassland, shrubby vegetation (*Cytisus multiflorus-dominated*) and woodland (*Quercus ilex* subsp. *ballota*); shrub and tree species occur at low densities (Martínez-Ruiz, 2000).

The waste generated from the uranium ore mining was heaped into different dumps at an incline angle of 37°. The waste consisted of slate bedrock fragments up to 80 cm in diameter, although there was a small amount of finer material between the larger particles (10% <2 mm). Restoration of vegetation by the mining company (E.N.U.S.A., State-owned Company of Uranium Ltd.) involved, where possible, covering the waste with a ca. 30 cm deep layer of finer textured sediments, excavated from a 10–150 cm depth from a nearby Arkoses pit, consequently this material may contain some seeds and plant remains. The cover material was a sandy-loam with loose granular structure; it had good soil aeration and low compaction, and its chemical properties (Table 1) were intermediate between the mine wastes and the Dehesa soils (Martínez-Ruiz, 2000).

The mining company applied hydroseeding in autumn 1992 to two spoil dumps (4–15 m high, and with both northern and southern slopes available), although only to some parts of the areas previously covered by the arkosic material. Two well-defined areas with comparable soil properties were distinguished on the same dump slope, one was hydroseeded the other not, both of which were in the process of revegetation. Small areas of naturally coloniser vegetation near the bases of the dumps chosen for the study provided a source of propagules.

The hydroseeding slurry contained: 450 kg ha$^{-1}$ of short fibre mulch, 300 kg ha$^{-1}$ of soluble chemical fertilizer (15N:15P:15K), 400 kg ha$^{-1}$ of organic tackifier, 5000 million g$^{-1}$ of legume inoculum and 275 kg ha$^{-1}$ of a commercial seed mixture of grasses and legumes. About 70% of seed weight was *Festuca arundinacea*, *Lolium perenne*, *L. rigidum*, *Dactylis glomerata*, *Lupinus hispanicus* and *Medicago sativa* in a 2:1:1:1:1:1 proportion. The rest of the seed mixture comprised eight species in lower proportions: *Avena sativa*, *Agrostis stolonifera*, *Poa pratensis*, *Lotus corniculatus*, *Trifolium repens*, *Retama shaerocarpa*, *R. monosperma* and *Cytisus scoparius*. Autumnal rainfall after hydroseeding in 1992 was very low (112 mm) as well as the total rainfall during that year (304 mm). Annual rainfall registered from June of the preceding year to May of each sampling year (1994–1996) was higher for the first and third years (588 and 755 mm, respectively) than for the second one (230 mm).

**Table 1 – Site soil analysis (mean of *n* = 6)**

| | pH ($H_2O$) | CEC | Organic matter (%weight) | Water-soluble | Total (mg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | P | N | K | Zn | Cu | Pb | Cd |
| Waste material | 3.3 | 8.0 | 0.15 | 0.41 | 290 | 848 | 137 | 58 | 42 | 0 |
| Covering substrate | 4.6 | 15.6 | 0.23 | 0.25 | 460 | 1147 | 30 | 9 | 12 | 0 |

Data provided by the mining company (in Martínez-Ruiz, 2000); CEC, cation exchange capacity (meq/100 g).