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Effects of reclamation measures on plant colonization on lignite waste in the eastern Pyrenees, Spain

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Abstract. This paper deals with vegetation establishment on waste dumps in the montane and submontane belts of the eastern Pyrenees, where submediterranean *Quercus humilis* forests, *Pinus sylvestris* forests and mesoxerophilous pastures make up most of the landscape; these are considered as target communities for reclamation. The waste consists of marl and lime regolith, very poor in nutrients and structure (Poch et al. 1989). The dumps were terraced in 1985-1986; some were left for spontaneous re-colonization and others were reclaimed in various ways. In 1992 we took 36 vegetation samples on the dumps, based on the point quadrat procedure, to evaluate the colonization status and the differences between reclamation techniques. The samples were analysed on the basis of their species composition (ecological groups and multivariate analysis) and structural aspects (coverage, diversity, etc.). Reclamation treatment results varied widely, most of the dumps showing a low degree of naturalness. Colonizing vegetation ranged from a mixture of opportunist and stress-resistant taxa, forming poorly covered surfaces on the dumps where colonization has been poor, to dense grasslands dominated by one (or a few) introduced competitive grass species, where reclamation procedures had been intensive. Sowing treatments, where pasture species were sown onto dumps, produced intermediate results, as resulting vegetation cover was similar to control plots and naturalness was low, but in a few cases they yielded more interesting swards, fairly dense and diverse, and including high numbers of spontaneous species. Choice of sown species and proximity to undisturbed vegetation accelerate succession.

Keywords: Landscape restoration; Mining waste; Mountain vegetation; Pasture; Plant succession.

Nomenclature: de Bolòs et al. (1993).

Introduction

Waste dumps from mines are generally hard to revegetate. Physical and chemical deficiencies or extremes, very low levels of organic matter, and low diaspore immigration rates are common handicaps (Bradshaw 1983). In climates involving dry periods colonization levels are very low (Nicolau 1992; Russell & La Roi 1986). Reclamation of mining areas should produce the changes in plant succession, in order to sooner obtain semi-natural communities that fit the surrounding landscape regarding both structure and function (Ash et al. 1994). In the present study, the mining strips and dumps studied are spread over a mountain area, characterised by a diverse landscape. Some of these disturbed lands are even included in the 'Cadí i Moixeró' Natural Park, and others are close to it. Achieving high plant cover quickly on the dumps is a priority in the area, as torrential rains produce high erosion rates from bare soils (Poch et al. 1989).

Although since 1983 mining firms operating in Catalonia have been obliged to reclaim the land they have altered, in most cases the procedures are inadequate, or cover little more than the geomorphic aspects. Generally any investment is devoted to studying the development of these areas after their reclamation, and little is known about the reasons for the results obtained, or about possible alternative solutions. In the area studied, the mining firms have followed various reclamation protocols on the terraced dumps based on the sowing of mixtures of generalist meadow species, which are not always the most suitable for the prevailing submediterranean conditions.

Some years after restoration or abandonment the reclaimed dumps under study varied in their colonization status, but in most cases the plant cover was low and/or the degree of naturalness was also low (Poch et al. 1989). In this study, our aim was (1) to analyse the vegetation covering the dumps in terms of species composition and some structural parameters, with special attention to the colonization of native species, and (2) to test the effectiveness of the various reclamation practices. Discussion of these aspects may be applicable to other reclamation work in submediterranean or Mediterranean conditions, where a lack of such knowledge is apparent.

Material and Methods

Site conditions and study areas

In the eastern Pyrenees waste from lignite mining is found in the upper Llobregat basin, ca. 42° 10' N, between 900 and 1750 m a.s.l. (Carreras et al. 1994, 1997). Depending on the altitude, mean annual temperature ranges from 11 to 6.5 °C, and annual rainfall from about 850 to 1100 mm. The climate is submediterranean mountainous with a cold period of 3 - 5 months and typically dry and warm mediterranean conditions from June to August; irregular periods of drought occur, mainly at lower altitudes.

The landscape of the area has remnants of the potential communities: mesoxerophilous oak forests (*Buxo-Quercetum pubescentis*) on thermal slopes, and pine forests (*Primulo-* and *Polygalo-Pinetum sylvestris*) on north-facing aspects. But the most common vegetation units in the area are managed pine forests of *Pinus sylvestris* with diverse undergrowth, mesoxerophilous pastures (submediterranean *Aphyllanthion*, central-European *Bromion*) sometimes including scrub, and cultivated surfaces occupied by hay meadows and cereal or alfalfa (*Medicago sativa*) crops (Fig. 1). As a general path for the progressive succession from bare soil, we can assume the next stage to be a sward including a mixture of opportunists and colonisers, which grew into a semi-natural pasture (alliances *Aphyllanthion* and *Bromion*). Where the starting point was a sown pasture, we expect that the cultivated species will be progressively replaced by native pasture species. Hence the next stage would be a pasture similar to the ones mentioned before. Such pastures may be relatively stable, but progressive invasion of shrubs and tree saplings could lead to *Quercus humilis* or *Pinus sylvestris* forests, depending on site conditions. Since reclaimed dumps are destinated for extensive grazing, and a natural return to forest (including soil development) takes a long time, the pastures are considered the target communities here.

The lignite waste consists of Eocene marls (carbonate lutites), with sparse gravel (limestone) and some coal fragments. Between 1985 and 1986 they were transformed into flat or gently sloping terraces, to facilitate reclamation, and steep, short taluses. The reclaiming procedures followed may be grouped into three basic treatments:

1. No further treatment (Control): Surfaces were left for spontaneous colonization.

2. Sowing: Surfaces were scarified and sown in 1986 with 125 - 250 kg/ha in various proportions of

Dactylis glomerata, Festuca ovina, F. rubra, Phleum pratense, Lolium perenne, Lotus corniculatus and *Trifolium pratense.*

In 1987 and 1991, some of these areas were re-sown; some were fertilised (N:P:K, 8:15:15 or 15:15:15), and others received neither re-sowing nor fertilization.

3. Hydro-sowing: On these surfaces the treatment (in 1987) consisted of spreading top soil (stockpiled from before the mining activity) and sowing with a mixture of mulch (2500 kg/ha of straw and cellulose), stabilizer (100 kg/ha), compost, fertilizer (600 kg/ha of N:P:K) and meadow seeds (150 kg/ha:

25 % *Dactylis glomerata,* 15 % *Festuca ovina,* 15 % *Lolium perenne,* 10 % *Lotus corniculatus,* 10 % *Trifolium pratense,* 15 % *T. repens,* 10 % *Onobrychis viciifolia.*

Sampling and data analysis

In 1992 we surveyed the largest areas covered by the mining spoils, namely 13 surfaces ranging in size from 6 to 56 ha. Then we selected 36 sampling sites corresponding to the three reclamation procedures considered (Fig. 1). At each site, a 5 m × 10 m plot was delimited (50 m^2) and all vascular plants growing in it were identified. Cover was estimated through the point quadrat method (Gounot 1969); all the species intercepted by a 4+mm diameter pin were recorded on 4 parallel rows of 50 points each. Some physiographic features (altitude, aspect, slope, neighbouring vegetation units, present land use) were also recorded. Field sampling was done from June to September, coinciding with the maximum canopy span of the vegetation.

Species cover in each sample was estimated as the number of times a species was contacted by the pin, divided by the number of sampling points and expressed as a percentage. Treatments were compared in terms of species composition, taking into account the main ecological species groups present (from their phytocoenological assignment, in de Bolòs et al. 1993). Total cover (after angular transformation) and ratio of spontaneous vs. introduced species were compared between treatments through ANOVA, with a Tukey test as a *post hoc* test. Similarity among samples was analysed with Correspondence Analysis (CA; Benzecri 1973), as a multivariate tool to compare the samples in terms of their species composition. Species diversity of the samples was calculated through the Shannon index:

$$H' = -\sum_{i=1}^{n} p_i \log_2 p_i \qquad (1)$$

For comparison with species richness of the neighbouring landscape, we considered the number of main adjacent plant associations, weighted both by their relative contribution to the landscape and by an estimation of their species richness (data from Carreras et al. 1994, 1997).

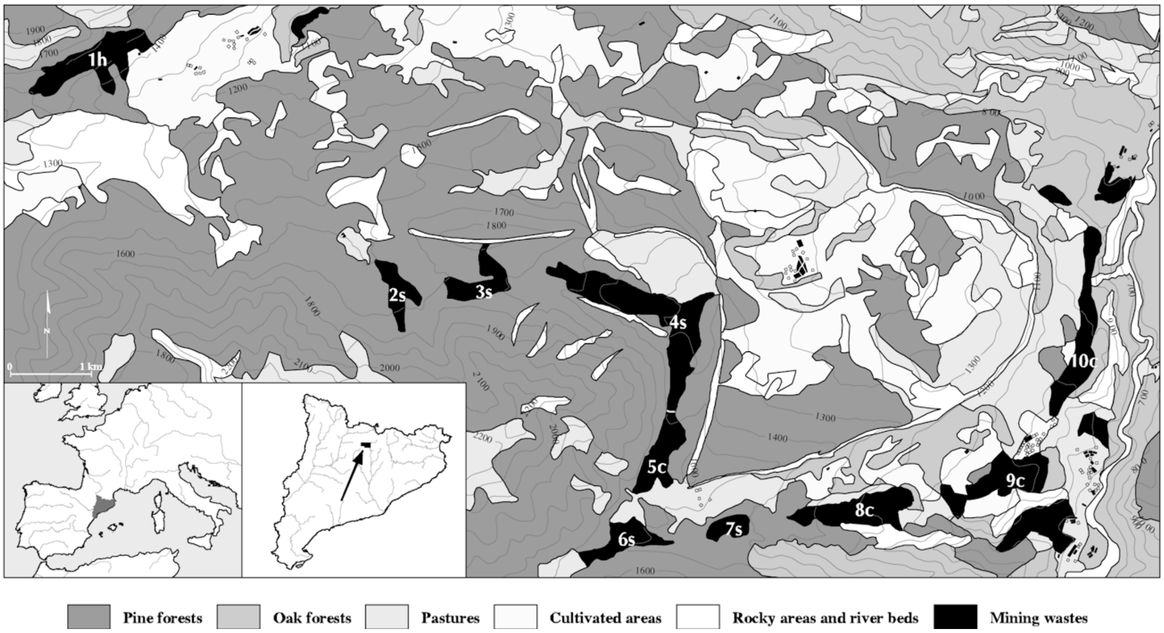

Fig. 1. Location of the waste surfaces studied (in black); numbers from 1 to 10 identify each sampled dump, whereas letters indicate control (c), sown (s) or hydro-sown (h). Large vegetation units are simplified from Carreras et al. (1994, 1997).

Results

Hydro-sowing led to the highest cover values, which were significantly different from those obtained in control and in sown samples (Table 1), with introduced species abundant and very few spontaneous species present. Cover values obtained in the sown plots were only lightly higher than those observed in the control plots. The cover of the sown species was also higher in hydro-sowing samples (Fig. 2). In contrast, spontaneous species were more abundant in sown samples, although their cover was similar to that of introduced species. Species diversity was higher in control samples, as was total species number and none showed any dominance, such as frequently occurs in the hydro-sowing and sown plots. The plant richness of the neighbouring landscape was clearly higher for the control dumps if evaluated from the number of main plant associations adjacent, but results were similar with the hydro-sowing plots when considering species richness (Table 1).

The diffuse presence of supposedly sown-in species in the control plots may be explained as contamination from nearby hay fields or reclaimed dumps, in the case of *Medicago sativa*, *Onobrychis viciifolia*, *Lolium perenne*, *Festuca arundinacea*; or even from spontaneous populations, in the case of species also occurring in the natural vegetation (*Dactylis glomerata*, *Lotus corniculatus*, *Trifolium pratense*, *T. repens*, *Festuca rubra*). As for the reclaimed dumps, the presence of introduced species not included in the restoration guidelines (*Festuca arundinacea*, *Medicago sativa*, *O. viciifolia*) indicates divergences between guidelines and treatments eventually applied.

The success of introduced species was variable in terms of establishing a soil cover, and at least in some cases this depended on the treatment; *F. ovina* showed the best results among species in the hydro-sowing dump (90 % cover in one sample), contrasting with the very low

Table 1. Main site and vegetation features corresponding to the three dump types.

Treatment	Control	Sown	Hydro-sown
Altitude	1096.3 ± 159.0	1455.4 ± 148.8	1546.2 ± 32.0
Number of dumps	5	6	1
Number of samples	15	13	8
Slope (%)	16.56 ± 15.8	21.0 ± 13.5	13.1 ± 19.0
Neighbouring associations per dump	8 ± 2.4	4 ± 0.9	4
Neighbouring plant richness value	3.61 ± 0.62	2.87 ± 0.46	4
Vegetation cover	60.3 ± 19.1 (a)	65.0 ± 15.2 (a)	83.9 ± 15.1 (b)
Species diversity	2.39 ± 0.68	1.26 ± 0.60	1.87 ± 0.49
Number of introduced species	3.9 ± 2.1	3.2 ± 2.2	6.3 ± 1.0
Number of spontaneous species	14.8 ± 6.3	9.5 ± 4.8	5.1 ± 3.4

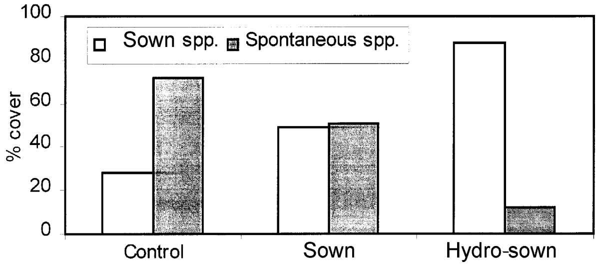

Fig. 2. Total cover of sown versus spontaneous species in the control and treated dumps.

values achieved in sown dumps (0 % in a number of samples, where *Festuca arundinacea* gave the best results). Among the legumes *O. viciifolia* showed similar results for sown and hydro-sowing plots (8.5 % and 9.1 % respectively), but *Lotus corniculatus* yielded poorer results in reclaimed than in control plots, where it would have arrived spontaneously. No native species showed high cover values in any plot, when compared with the most successful of the introduced species. The highest cover was achieved by *Tussilago farfara* in some sown plots (49 % in one sample), which corresponded to particular environmental conditions (clayey soils).

The most common species colonizing the waste surface were classified into four ecological groups (Table 2).

1. *Introduced species*, although not sharing strong ecological affinities, are taxa frequent in mesophilous meadows (order *Arrhenatheretalia* s.l.). Most are fast-growing herbs or grasses (*Trifolium pratense, Dactylis glomerata*, etc.), and rather competitive; others show low turnover of structures, such as the turf-forming, stress-tolerator *Festuca ovina*. Their frequency was diverse between and even within treatments. On the other hand, their presence even in the spontaneously vegetated plots reveals a certain colonizing ability, whether as diaspores from treated wastes or by re-invasion from semi-natural meadows.

2. *Taxa from mesoxerophilous pastures* (alliances *Aphyllanthion* and *Bromion*). They show a diffuse presence on the waste; their species number is relatively high, but individual frequencies are low to very low and they are mainly pasture generalists (companions or class or order species). They are hemicryptophytes, more rarely chamaephytes, able to endure some water stress, and with low vegetative expansion and low dispersal abilities.

3. *Opportunists*, showing a diffuse presence in all the plots. These are mainly short-lived perennials with good production and/or high dispersal ability of diaspores.

4. *Species of clayey soils*. They are mainly loose rhizomatous perennials, able to thrive in dense substrates which change from flooded in winter and spring to dried out in summer. Their occurrence is low in the hydro-sowing plots and irregular in the others. In special cases

Table 2. Species composition (cover percentage for the most general species) of the vegetation resulting from spontaneous colonization (control) and from the two treatments. * = Species originating from the reclamation treatment.

Treatment	Control	Sown	Hydro-sown
Introduced species			
Dactylis glomerata	4.4	4.8*	12.5*
Lotus corniculatus	6.9	1*	5*
Trifolium pratense	2	1*	4.4*
Festuca arundinacea	4	21.8	7.2
Onobrychis viciifolia	1.7	8.5	9.1*
Festuca rubra s.l.	1.7	4.9*	0.1
Festuca ovina s.l.	0	0.2*	64*
Medicago sativa	2.2	0	8.4
Trifolium repens	0.6	0.2	2.1*
Lolium perenne	1	2.2*	0.7*
Phleum pratense	0	4.9*	1.2
Species of pastures			
Sanguisorba minor s.l.	3	1	1.6
Plantago lanceolata	4.5	0.1	0.9
Medicago suffruticosa	1.2	0.7	0.9
Medicago lupulina	1.6	0.8	0
Onobrychis supina	2.1	0.4	2.6
Plantago media	0.7	0.2	0
Anthyllis vulneraria	0.4	0.2	0
Achillea millefolium	0.3	0	0.2
Hippocrepis comosa	0.4	0.2	0
Opportunists			
Picris hieracioides	4.6	1.9	1.4
Daucus carota	2.1	0.6	0.9
Picris echioides	1.3	0	0
Echium vulgare	0.1	0.2	0.2
Taraxacum officinale s.l.	1.3	0.1	0
Erucastrum nasturtiifolium	0	0.2	0.2
Elymus caninus	1.7	0.2	0
Species of clay soils			
Tussilago farfara	3.9	14.9	0
Cirsium arvense	0.6	1.8	0.2
Tetragonolobus maritimus	5.4	2	0
Agrostis stolonifera	3.5	2.7	0
Centaurea jacea	3	0.6	0
Melilotus officinalis	0.4	2.1	0.4
Leucanthemum vulgare	1.3	0.1	0
Potentilla reptans	2	0.1	0
Carex flacca	0.2	1	0

they dominate the vegetation, mainly through *T. farfara*.

The two first axes of the Correspondence Analysis (CA) used to determine similarity among vegetation samples (Fig. 3) depict the samples more or less ordered according to the treatments. The peripheral positions of the samples is due to the presence of uncommon species. The concentration of the hydro-sowing samples in the lower part is linked to high values of cultivated taxa, rare or absent in control and even in sown plots (*Festuca ovina, Medicago sativa, Trifolium pratense*). The four samples at the top right corner correspond to the *T. farfara* stands commented on above, which also include other particular species like *Cirsium arvense* or *Equisetum arvense*. Control samples show high dispersion, corresponding to noticeable differences between plots in site conditions. In general, the vertical axis corresponds to increasing soil moisture or seasonality in edaphic water

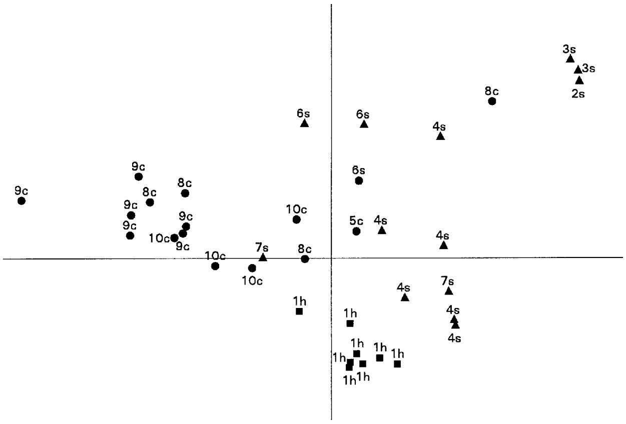

Fig. 3. Diagram of the first two axes of the Correspondence Analysis of the vegetation samples. For each sample, the reclamation treatment is designated by circle (control), triangle (sowing) or square (hydro-sowing); the dumps are identified by the same numbers and letters as in Fig. 1.

content from the hydro-sowing nucleus upwards. But the CA also reveals a design problem, as the distribution of the samples obtained is partially in accordance with the location of the dumps. This is the most evident in the grouping of all the samples from dump 1, which also coincides with the hydro-sowing treatment. Samples from some other dumps remain more or less grouped (e.g. 9c, 10c), whereas those from others (e.g. 4s, 7s, 8c) were dispersed. So, species composition of the samples expresses in part the nature of the dumps, on which the effect of the treatment is superimposed, and weakens the comparison between sowing and hydro-sowing.

Discussion

The number of species settling spontaneously on these waste areas was considerable, though most of them were species of the initial stages of the succession. Where no treatment was applied vegetation cover was ca. 60 %, which is mainly due to herbaceous species. Although this value was relatively high it probably cannot guarantee enough protection against soil erosion (Albadalejo et al. 1991). In fact, patches of uncovered soil can be observed, big enough to allow gully formation and consequent soil loss (Poch et al. 1989).

Species from the surrounding forest were almost all absent 7 yr after the creation of these wastes in the three dump types, although a few forest trees and shrubs show some invading ability in open habitats; for example, *Pinus sylvestris* has been identified as a good colonizer in other local perturbed habitats (Guàrdia & Ninot 1992) such as highly eroded slopes and road cuttings, but always as saplings with low growth rates. Probably the lack, in the dumps, of adequate microhabitats prevents the occurrence of seedlings or saplings, even of the best dispersing or best colonizing species, from nearby forest

The choice of reclaiming species has an important role in the succession towards semi-natural pastures (Brenner et al. 1983; Mitchley et al. 1996). Some of the commercial species used in waste reclaiming (chiefly *Festuca ovina* and *F. arundinacea*) showed particularly good cover in the early stages. They are turf-forming grasses showing low turnover and good biomass accumulation; however they yield dense communities with little chance for natural establishment of the native species, i.e., they slow down the succession. By contrast, plants such as *Lolium perenne, Dactylis glomerata* and *Trifolium repens,* successfully used in restoration practices or in swards (Chapman et al. 1985), did not present high cover values 7 yr after they were sown. Probably they act as facilitating species, growing fast in the first years after sowing, but gradually vanishing when more competitive species enter (Mitchley et al. 1996; Vallejo 1996). Since even in the most dense communities, above-ground gaps within grass turfs or between clumps are frequent, the low immigration rates of native species suggest that the negative effect of competition from cultivated species acts at below-ground levels, enhanced by presumably low nutrient contents and low seasonal moisture. The same effect was found in waste colonization after achieving medium covers, both in natural succession and in reclaimed areas in other studies (Ash et al. 1994; Brenner et al. 1983; Prach 1986). As pointed out in other studies (Borgegård 1990; Ash et al. 1994), fertility must be a key factor, but the physical conditions of the soil (surface moisture, organic matter content, structure, temperature fluctuation) probably also play an important role (Nicolau 1992; Russell & La Roi 1986; Brenner et al. 1983).

Where reclamation had been less efficiently (mostly at the sown dumps), heterogeneous assemblages resulted, including moderate amounts of sown plants, various opportunist species and some pasture species. Locally unfavourable conditions (dense soils, floodable depressions, shady north-facing steep slopes) seem to have led to particularly open, poor communities, both in sown and control plots. In these cases, populations of *Tussilago farfara* or similar taxa adapted to seasonally wet soils, represent a succession path unlikely to lead to more mature vegetation. In less extreme sites, the sowing treatment produced intermediate communities, both in terms of general plant cover and in spontaneous species immigration. Control plots gave a wide range of results; the most positive aspect is that species number was higher there than in treated plots, involving higher number of spontaneous pasture species and more equal frequency distribution.

The landscape surrounding each dump must have played some role in colonization by naturally occurring taxa. The heterogeneous distribution over the landscape of both reclamation procedures and control treatments over the landscape hinders a direct comparison. Thus, the most intensively reclaimed dumps (hydro-sowing and some of the sowing plots) are included in a forested matrix, and at high altitudes, whereas control dumps, showing a higher degree of naturalness, are located within a more diverse landscape, mainly agricultural and pastoral. Nevertheless, low dissemination effectiveness in pasture species must be a limiting factor in the succession towards the semi-natural pastures expected, considering the moderate role played by these species even in the control plots. In fact, in pasture communities there is a strong tendency towards short-range dispersal (Hensen 1997), a situation improved under traditional pasture management, as this implies large distance dispersal (Poschlod et al. 1998). The contribution of true pasture taxa in most of the areas sampled was relatively low, even in the most natural assemblages. A similar situation has been described in other reclamation studies (Ash et al. 1994; Bradshaw 1983), suggesting the importance of the use of topsoil saved during pre-mining reclamation preparation.

Conclusions

Spontaneous colonization of the dumps created the most natural communities, but did not produce enough cover for adequate site stability at medium term.

In a mountain area under submediterranean conditions, involving torrential rain impacting on steep slopes, hydro-sowing seems to be the most useful treatment to prevent soil erosion. However, the choice of sown species should avoid some turf-forming grasses which yield dense, unnatural swards allowing very few spontaneous pasture species, and which slow down the succession.

The sowing treatment cannot guarantee better cover results than spontaneous colonization, at least some years after treatment, as in most areas adverse substrates and soil moisture regimes control vegetation succession. Nevertheless, the use of tested species able to endure some dryness should result in a higher efficiency of sowing treatments.

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