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SPECIAL FEATURE: VEGETATION RESTORATION

Vegetation recovery of gypsum quarries: short-term sowing response to different soil treatments

Miguel Ballesteros, Eva M. Cañadas, Ana Foronda, Emilia Fernández-Ondoño, Julio Peñas & Juan Lorite

Keywords
Ecological restoration; Gypsophiles; Gypsum habitat; Seed mixture; Restoration techniques; Bedding material; Surface treatment

Abbreviations
BM = bedding material; TR = topsoil removal; GS = gypsum spoil; TA = topsoil addition; RG = raw gypsum; ST = surface treatment; C = control; S = sowing; SO = sowing plus organic matter addition; SB = sowing plus organic blanket

Nomenclature
Blanca et al. (2009)

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Lorite, J. (corresponding author, jlorite@ugr.es), **Ballesteros, M.** (miguelballesterosjimenez@gmail.com), **Cañadas, E.M.** (ecanadas@ugr.es), **Foronda, A.** (anforva@hotmail.com) & **Peñas, J.** (jgiles@ugr.es): Dpto. de Botánica, Facultad de Ciencias, Universidad de Granada, 18071, Granada, Spain
Fernández-Ondoño, E. (efernand@ugr.es): Dpto. de Edafología y Química Agrícola, Facultad de Ciencias, Universidad de Granada, 18071, Granada, Spain

Abstract

Question: How does the sowing of native species under different soil treatments contribute to the recovery of gypsum habitats affected by quarrying in Mediterranean environments?

Location: Mediterranean gypsum outcrops in Granada (SE Spain; 37º2′ N, 3º45′ W).

Methods: We conducted an experimental sowing of native perennial species from gypsum habitats (both gypsophiles and gypsovags) considering two factors: bedding materials and surface treatments. For bedding material we used: gypsum spoil, topsoil addition on gypsum spoil, raw gypsum and topsoil removal. The surface treatments were: control, sowing, sowing plus organic matter and sowing plus an organic blanket. There were five replicates per combination treatment (80 plots in total, of 25 m^2 each). The sowing was performed in Nov 2009. All subplots were monitored to estimate density, richness, survival, growth of seedlings and herbaceous biomass, in two monitoring periods (Jul and Oct).

Results: No gypsophiles or gypsovags were found in the control plots (no sowing or surface treatment), and therefore natural succession proved ineffective in the first year. In contrast, sowing was very satisfactory, especially on gypsum spoil, where mean density was of more than 15 individuals m^{-2}. This result is noteworthy as this material remains after the end of gypsum mining activity. Spreading topsoil over gypsum spoil proved to be no more positive, since it provided not only seeds of target species but also of competitor species. Also, with regard to herbaceous species, this treatment produced a highly significant increase of biomass. The organic blanket increased plant density, whereas the addition of organic matter had significant positive effects on survival and growth of the seedlings. The global high survival rate is remarkable, especially for the gypsum spoil treatment.

Conclusions: We highlight the importance of implementing recovery measures in gypsum habitats. An appropriate selection of seed mixture and density, as well as the use of gypsum spoil (the most favourable bedding material, according the results), is sufficient to ensure presence of the key species. Both technical solutions tested, organic blanket installation and organic matter addition, improved the results in terms of density, survival and growth of the seedlings.

Introduction

Gypsum outcrops have a scattered distribution in arid and semi-arid areas throughout the world, covering about 100 million ha (Boyadgiev & Verheye 1996). Due to their particular chemical and physical properties, they harbour a unique flora, with a high degree of rare and endemic taxa (Parsons 1976; Meyer 1986; Guerra et al. 1995; Mota et al.

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2004; Akpulat & Celik 2005; Moore & Jansen 2007). Consequently, this habitat type is included in the European Habitat Directive (Anonymous 1992) as a priority for conservation. In turn, many of the characteristic plant species are under different degrees of threat and thus are included in red lists and red books (e.g. Gómez-Campo 1987; Cabezudo et al. 2005; Moreno 2008) and are protected by international, national or regional legislation (e.g. Anonymous 2003). However, gypsum is also a major economic resource for mining (Al-Harthi 2001; Mota et al. 2003, 2004; Pulido-Bosch et al. 2004). Quarrying activities generally inflict heavy impact at both landscape and community level, leading to soil loss, topographical alteration and vegetation removal (Bradshaw 1997, 2000; Correia et al. 2001; Milgrom 2008). Thus, gypsum quarries typify the conflict of interest between mining and conservation (e.g. Mota et al. 2004).

The recovery of areas at the end of mining activity by means of natural succession has shown poor results, especially in substrates under unfavourable conditions (Bradshaw 2000). In fact, gypsum outcrops usually occur in arid environments (Parsons 1976) where natural succession processes are particularly slow (Fowler 1986). Moreover, vegetation development is severely restricted by inherent gypsum features, such as physical (e.g. high soil compaction) or chemical (ion imbalance or toxicity) constraints (Meyer 1986; Meyer et al. 1992; Merlo et al. 1998; Escudero et al. 1999, 2000; Guerrero-Campo et al. 1999; Romao & Escudero 2005; Palacio et al. 2007; Pueyo et al. 2007; Drohan & Merkler 2009; Herrero et al. 2009). As a result, plants of gypsum environments have a low natural colonizing power, as found in previous studies (Mota et al. 2003, 2004).

Despite the many papers dealing with ecological issues in gypsum areas (e.g. Escudero et al. 1999, 2000; Caballero et al. 2003; Pueyo & Alados 2007), few works are available on ecological restoration. Some studies deal with the ecological regeneration on gypsum outcrops by means of natural succession (Mota et al. 2003, 2004; Dana & Mota 2006), but research methodologies to recover the flora and vegetation of these areas has been inconclusive for restoration projects. Marqués et al. (2005) focused on the combined use of organic amendment and revegetation to reduce erosion in gypsic soils. Castillejo & Castello (2010) suggested that gypsum quarry rehabilitation in semi-arid environments can be accelerated by using organic amendments to improve physical (structure) or chemical (nutrient content) soil properties, although these authors did not use characteristic species of gypsicolous habitats. Matesanz & Valladares (2007) studied the combination of native species with commercial fast-growing species, typical in hydroseeding mixtures, to revegetate gypsum slopes under Mediterranean conditions. They highlighted the need for further studies focusing on the suitability of using herbaceous species tolerant of gypsum soils. In this context, many issues remain unknown and new approaches are needed to provide technical solutions for the ecological restoration of gypsum quarries.

This work presents a field experiment that seeks to develop measures to contribute to the recovery plan of a gypsum quarry under Mediterranean conditions. As a requirement to authorize mining, the company that operates the quarry is compelled to recover the native species in the habitat of Community interest 1520 'Iberian gypsum vegetation, *Gypsophiletalia*', (Habitat Directive 92/43/EEC). Given the close link between vegetation and the soil where it occurs (Parsons 1976; Kazakou et al. 2008; Mota et al. 2008), the cornerstone for restoration is first to recover the specific substrate. The restoration plan includes filling pits created during the extraction with gypsum spoil, and covering with topsoil removed and preserved at the beginning of the operation. Thus, it seems appropriate to test the performance of the native species on these materials. We opted for sowing, as it has been suggested as an economical and reliable method to propagate plants during restoration works (e.g. Jochimsen 2001; Novák & Prach 2010; Bochet et al. 2010), and results in a random plant distribution and natural-looking vegetation (Ghose 2004). In addition, the properties of the materials on which sowing is conducted may be enhanced by technical solutions, including surface treatments to increase the organic matter and nutrient content, or protecting the soil from seed removal or erosion (Muzzi et al. 1997; Vetterlein & Hüttl 1999).

The aims of the study are: (1) to improve restoration of the most characteristic native species in the study area that are included in the habitat of Community interest 1520 'Iberian gypsum vegetation, *Gypsophiletalia*'; (2) to test the applicability of sowing to revegetate after quarrying operations; and (3) to test the performance of gypsum native species under different combinations of bedding material generated by quarrying, and soil surface treatments (organic matter addition or organic blanket overlays).

Methods

Site description

The experimental area is located in a gypsum outcrop area in Escúzar (Granada, SE Spain; 37º2′ N, 3º45′ W) at 950 m a.s.l. The climate type is continental Mediterranean, with relatively cold winters, hot summers and 4 mo of water deficit. The mean annual temperature is 15.1 °C, with an average monthly minimum temperature in Jan of 7.6 °C and a maximum of 24.2 °C in Aug. Annual rainfall averages 421.1 mm, occurring mainly in winter. The area is in the Neogene sedimentary basin of Granada, the dominant substrates being lime and gypsum from the late Miocene,

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the latter in combination with marls (Aldaya et al. 1980). The predominant soils in gypsum outcrops are gypsisols (Aguilar et al. 1992). The vegetation of the area is a mosaic of scattered patches of natural plants growing over gypsum outcrops, surrounded by fields containing crops (almond and olive trees and cereals).

Target habitat

The aim of the study is to test measures to recover the most characteristic species of the habitat included in the European Habitat Directive (92/43/EEC) as 1520 'Iberian gypsum vegetation, *Gypsophiletalia*.' Specifically, in the study area the target habitat is characterized by three gypsophile species: *Ononis tridentata* subsp. *crassifolia* (local endemic), *Helianthemum squamatum* and *Lepidium subulatum* (widespread in gypsum outcrops of the Iberian peninsula). In addition, there are also other frequent non-exclusive species of gypsum outcrops (gypsovags) such as *Stipa tenacissima, Helianthemum syriacum, H. violaceum, Thymus zygis* subsp. *gracilis, Teucrium capitatum* subsp. *gracillimum, Rosmarinus officinalis, Hippocrepis bourgaei* and *Fumana thymifolia* (according Marchal et al. 2008).

Experimental design

The quarry to be restored was under exploitation at the time of our study. Therefore an experimental area was set on a cereal old field consisting of marls next to the quarry (see site description for further details), using the materials generated during gypsum extraction to mimic possible post-quarrying conditions. The sowing experiment considered two factors: bedding material and surface treatment. Four flat plots (15 m × 60 m), each provided with a bedding material, were prepared over the experimental area, including: (1) topsoil removal (TR), removing the upper 30 cm to eliminate the topsoil, and thereby the seed bank within it; (2) gypsum spoil (GS), placing a 0.5-m layer of the byproduct obtained after gypsum is processed in the quarry; (3) topsoil addition (TA), placing a layer of topsoil (ca. 10 cm), previously retrieved from the natural habitat, on top of a 0.5-m gypsum spoil layer; and (4) raw gypsum (RG), consisting of a 0.5-m layer of coarse gypsum (i.e. the same material used in the factory to be processed). The projected recovery plan includes filling quarry pits with gypsum spoil and placing habitat topsoil on top at the end of the activity. Therefore GS and TA treatments represent the most likely options to perform for restoration work. TR and RG represent extreme situations regarding gypsum content (i.e. TR having the lowest and RG the highest gypsum content).

Each plot was divided into 20 subplots (5 m × 5 m), where the surface treatments were randomly applied. The surface treatments were: (1) Control (no sowing or surface treatment) (C); (2) Sowing (S); (3) Sowing plus organic matter addition (SO); and (4) Sowing plus organic blanket (SB). The organic matter was added in the form of commercial substrate (organic matter = 85.4%, pH 6–7, N 260 mg·kg^{-1}, P 389 mg·kg^{-1}, K 2000 mg·kg^{-1}, Mg 678 mg·kg^{-1}, Fe 15 mg·kg^{-1}) at 160 l per subplot. The organic blanket was a natural biodegradable net made of straw and alpha grass (*S. tenacissima*). Five replicates per combination treatment were performed (four bedding material types × four surface treatments × five replicates = 80 subplots in total).

For sowing, seeds of the most characteristic species of the target habitat in the study area were selected. The nearest natural seed source to the experimental area was more than 300 m away. Seeds were manually harvested in the surrounding area between Jun and Sep 2009. Due to disperse flowering and availability, we included few *Ononis* seeds in the mixture. The sowing was performed in Nov 2009, using 500 seeds·m^{-2}. The proportion used was 60% gypsophile species: *Helianthemum squamatum* (180 seeds·m^{-2}), *Lepidium subulatum* (120 seeds·m^{-2}), *Ononis tridentata* subsp. *crassifolia* (6 seeds·m^{-2}), and 40% gypsovag species: *Helianthemum syriacum* (50 seeds·m^{-2}), *Rosmarinus officinalis* (50 seeds·m^{-2}), *Stipa tenacissima* (50 seeds·m^{-2}) and *Thymus zygis* subsp. *gracilis* (50 seeds·m^{-2}). Gypsovag species are widely commercialized (except *H. syriacum*), which should facilitate implementation of the future restoration plan.

Data collection

All subplots were monitored to estimate perennial plant density and species richness, as well as survival and growth of target species in two monitoring periods, Jul and Oct 2010. For determination of density and richness, a set of 15 random samples in quadrats of 0.5 m × 0.5 m were taken per subplot, counting all individuals per species in each quadrat. We recorded sown species as well as other spontaneous perennial species (chamaephytes and hemicryptophytes). For monitoring survival and growth, we marked and measured 30 to 40 seedlings per sown species in each combination of soil mixture and soil surface treatment (depending on seedling availability; see Table 3). In addition, to estimate herbaceous biomass, the above-ground part was harvested in two samples of 0.5 m × 0.5 m per subplot, oven dried for 48 hr at 70 °C and weighed using a precision scale (0.1 mg).

Statistical analysis

To evaluate differences in plant density, species richness, herbaceous biomass and plant growth with respect to each of the bedding materials (BM), surface treatments (ST),

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and their combination (BM x ST), we fitted generalized linear models (GLMs), assuming a Poisson error distribution and log link function. Regarding density and richness, we used data recorded in October for both total perennial species and only target species. To assess the effect of the monitoring period, we used only target species, since the presence of other perennial species was generally very low (except in the topsoil addition treatment).

The data for monitored seedlings (only when more than ten seedlings per species and treatment were available; see Table 3) were used to analyse survival and growth. For survival analysis, a non-parametric Wilcoxon test was computed to check the effects of the treatments. We analysed both total survival and survival per species. Moreover, the effect of treatments on overall growth as well as on growth by species was analysed using a GLM. All statistical analyses were performed using JMP 7.0 (SAS Institute, Cary, NC, USA).

Results

Plant density and richness

There were significant differences in the performance of bedding material (BM), surface treatments (ST) and their combined effect, on both plant density and species richness, although in the case of target species the interaction between BM and ST had no effect on richness (Table 1). The results were very similar whether considering all perennial species or just the target species. The presence of other perennial plants was only higher (although not significant) in the topsoil addition treatment, due to colonizing hemicryptophytes (such as *Picnomon acarna, Onopordum nervosum, Carthamus lanatus* or *Centaurea calcitrapa*). For this reason, we present results only for target species.

For the duration of the present experiment, topsoil addition (TA), and especially quarry gypsum spoil (GS), were the bedding materials that performed best. In both cases the organic blanket (SB) enhanced species richness and density, whereas the addition of organic matter had no significant effect on the sowing in either case (GS and TA). The density exceeded 35 individuals m^{-2} for the most effective treatment combination (GS + SB). In contrast, the option of no sowing (control) proved ineffective (Fig. 1). Plant density by species was also favoured on gypsum spoil combined with the organic blanket (see Fig. 2). In this option, the density was also high for most of the sown species (between 7.09 ± 1.04 and 8.85 ± 1.15 individuals m^{-2}). The density was lower for *O. tridentata* subsp. *crassifolia*, *H. syriacum* and *S. tenacissima*, even in the more effective treatments.

The monitoring period influenced plant density for target species in relation to both bedding material (χ^2 =51.8339, $P < 0.0001$) and surface treatment (χ^2 = 19.9610, $P = 0.0002$), increasing the density during the summer in all treatments, except in raw gypsum. The greatest increase was found in the gypsum spoil bedding material (Fig. 3a) and sowing plus organic blanket surface treatment (Fig. 3b). A combination of these three factors (monitoring period, bedding material and surface treatment) also had a significant effect on plant density (χ^2 = 265.8673, $P < 0.0001$) but not on target species richness. Monitoring period affected richness only in relation to bedding material ($\chi2$ = 8.2891, $P < 0.0404$; Fig. 3c).

Herbaceous biomass

Herbaceous biomass was significantly higher (χ^2 = 10175.702, $P < 0.0001$) in the topsoil removal (77.89 ± 5.02 $g{\cdot}m^{-2}$) and topsoil addition treatments (113.81 ± 8.06 $g{\cdot}m^{-2}$) than in the gypsum spoil (1.30 ± 0.46 $g{\cdot}m^{-2}$) and raw gypsum (0.01 ± 0.01 $g{\cdot}m^{-2}$). There were no significant effects between surface treatments, but the combination with bedding material treatments showed significant differences (χ^2 = 249.541, $P < 0.0001$). The organic blanket increased the herbaceous biomass in the topsoil addition treatment while limiting it in topsoil removal (Fig. 4).

Survival and growth

The survival rate of the total monitored seedlings was very high (92.7%). Despite the low mortality, some significant effects were found in the survival analysis. Regarding the bedding material (Wilcoxon tests: χ^2 = 29.7653, P < 0.0001), higher mortality occurred in topsoil addition and raw gypsum treatments. In relation to surface treatments

Table 1. Summary of the GLM testing the effect of soil treatments on density and richness of total perennial species or only target species.

Source	*df*	Total perennial species				Sown species			
		Density		Richness		Density		Richness	
		χ^2	*P*	χ^2	*P*	χ^2	*P*	χ^2	*P*
Bedding material (BM)	3	3008.6115	0.0000	1922.7606	0.0000	572.2521	<0.0001	112.7458	<0.0001
Surface treatment (ST)	3	1781.5965	0.0000	1076.9627	<0.0001	2396.2708	0.0000	387.2644	<0.0001
BM X ST	9	506.13922	<0.0001	230.7508	<0.0001	84.15706	<0.0001	7.9321	0.5410

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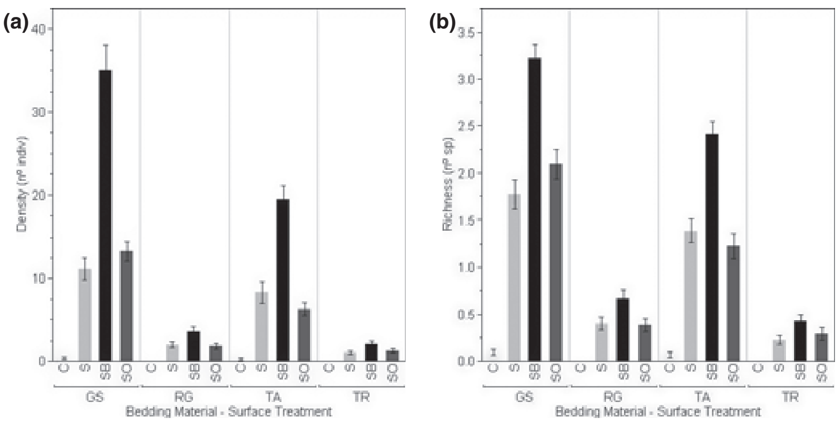

Fig. 1. Mean density (±SE) (individuals m^{-2}) (**a**) and mean richness (±SE) (species/0.25 m^{2}) (**b**) of all target species by soil treatment. Bedding material: GS (gypsum spoil), RG (raw gypsum), TA (topsoil addition), TR (topsoil removal); surface treatment: C (control), SB (sowing plus organic blanket), SO (sowing plus organic matter), S (sowing).

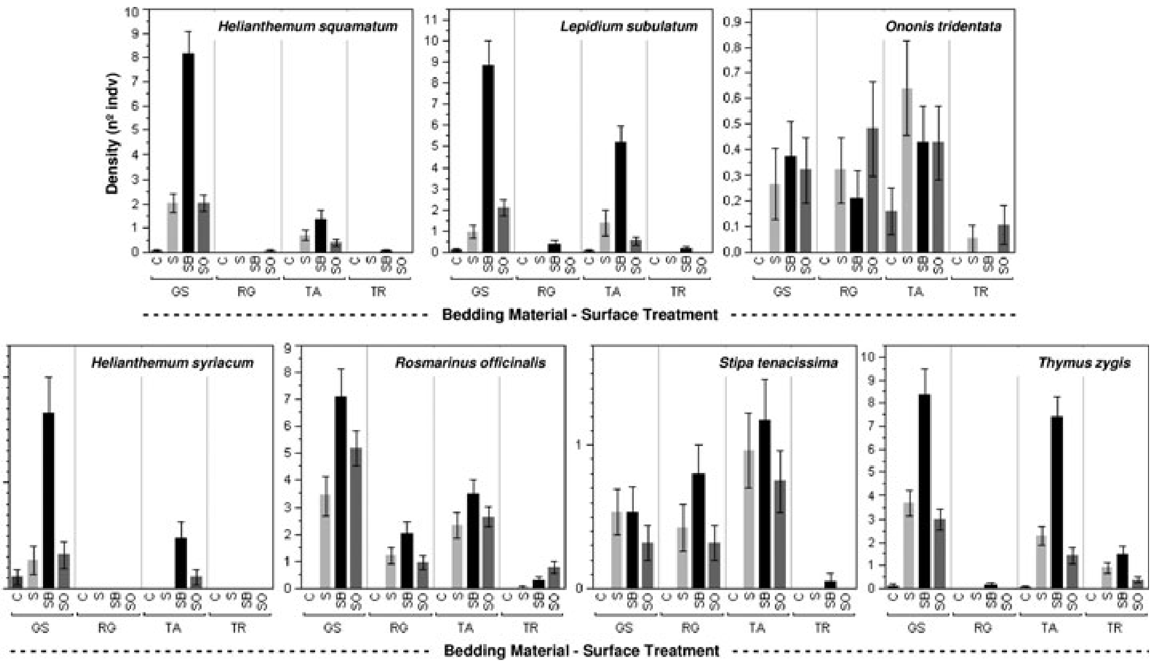

Fig. 2. Mean density (±SE) (individuals m^{-2}) of target species by soil treatment. Bedding material: GS (gypsum spoil), RG (raw gypsum), TA (topsoil addition), TR (topsoil removal); surface treatment: C (control), SB (sowing plus organic blanket), SO (sowing plus organic matter), S (sowing).

(Wilcoxon tests: $\chi^2 = 0.9858$, $P = 0.6109$), we only found significant differences in gypsum spoil plots (Wilcoxon tests: $\chi^2 = 10.1886$, $P = 0.0061$); in this bedding material, mortality was higher in sowing plus organic blanket (Fig. 5).

The survival analysis by species showed that the bedding material influenced species survival more than did the surface treatments (Table 2). A significant effect of surface treatment on bedding material was detected only on *T. zygis* subsp. *gracilis*. For this species, mortality was higher in the organic blanket plots (12.5%; Table 3). Regarding the survival rate by species, *O. tridentata* subsp. *crassifolia* had the highest survival for all treatments.

For monitored seedlings, the bedding materials and surface treatments, as well as their combined effect, significantly affected growth in all species except *S. tenacissima*. The growth of the gypsophile species (*H. squamatum, L. subulatum* and *O. tridentata* subsp. *crassifolia*) and *R. officinalis* proved higher in sown plots plus organic matter (SO) (see Tables 2 and 3).

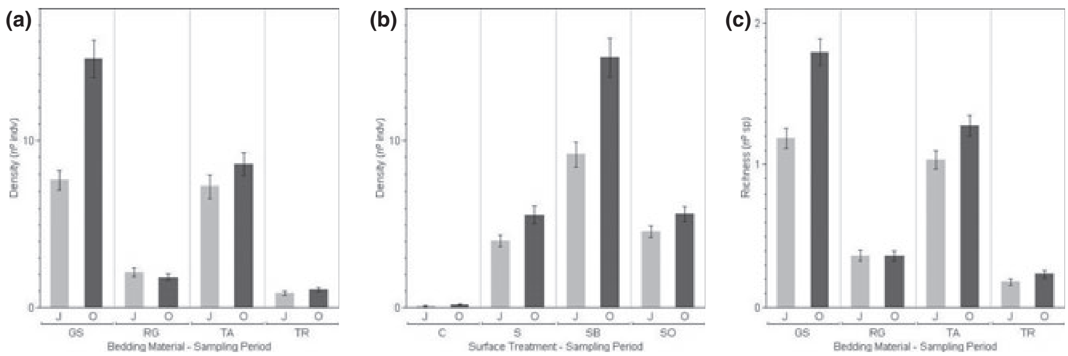

Fig. 3. Mean density (±SE) (individuals m^{-2}) of target species by monitoring period and bedding material (**a**) or surface treatment (**b**), and mean richness (±SE) (species/0.25 m^{2}) by monitoring period and bedding material (**c**). Monitoring period: JUL (Jul 2010), OCT (Oct 2010). Soil treatments: Bedding material: GS (gypsum spoil), RG (raw gypsum), TA (topsoil addition), TR (topsoil removal); surface treatment: C (control), SB (sowing plus organic blanket), SO (sowing plus organic matter), S (sowing).

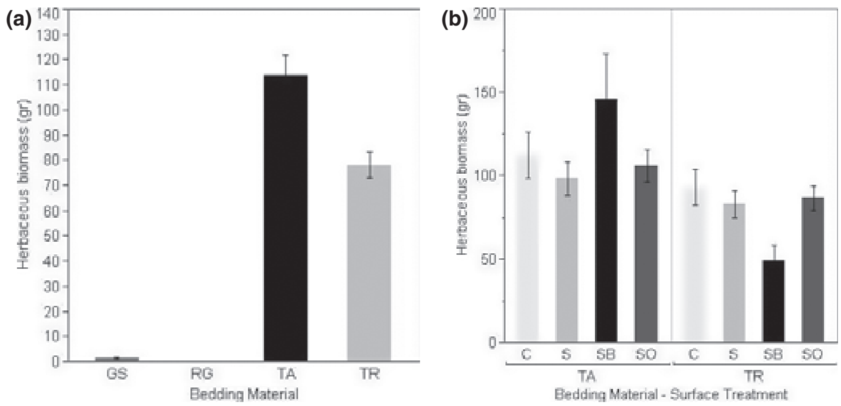

Fig. 4. Mean herbaceous biomass (g m^{-2} ±SE) by soil treatments. Bedding material: TA (topsoil addition), TR (topsoil removal); surface treatment: C (control), SB (sowing plus organic blanket), SO (sowing plus organic matter), S (sowing).

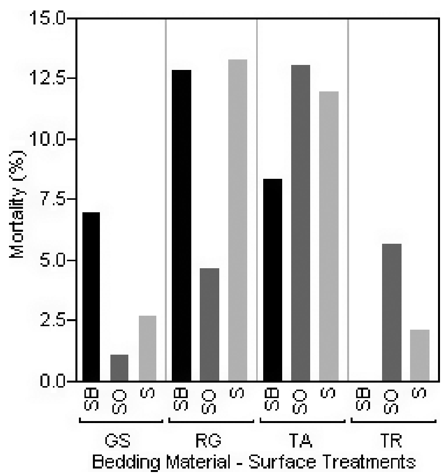

Fig. 5. Plant mortality (%) by soil treatment combinations. Bedding material: GS (gypsum spoil), RG (raw gypsum), TA (topsoil addition), TR (topsoil removal). Surface treatment: C (control), SB (sowing plus organic blanket), SO (sowing plus organic matter), S (sowing).

Discussion

Short-term results of the experiment point to the need to take active measures to encourage rapid gypsum habitat recovery, since natural colonization proved ineffective in the first year. The need to apply restoration measures has also been pointed out by Tormo et al. (2007) in semi-arid roadfills, due to the resulting low vegetation cover in untreated plots. This result is consistent with studies on spontaneous plant succession in abandoned gypsum quarries (Mota et al. 2003, 2004), where gypsophile species registered low establishment rates. After more than 25 years, the average cover of all gypsophiles was 25%, while the cover of species characteristic of our study area, such as *L. subulatum* and *H. squamatum*, was less than 2.5% (Mota et al. 2004). In fact, we found no plants characteristic of gypsum habitats during the first year in the control plots (no sowing or surface treatment).

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Table 2. Summary of the survival analysis (Wilcoxon test, left) and GLM (right) examining the effects of bedding materials and surface treatments on survival and growth, by species. Species: Hsq (*Helianthemum squamatum*), Hsy (*Helianthemum syriacum*), Ls (*Lepidium subulatum*), Ot (*Ononis tridentata* subsp. *crassifolia*), Ro (*Rosmarinus officinalis*), St (*Stipa tenacissima*), Tz (*Thymus zygis* subsp. *gracilis*).

Species	Survival						Growth					
	Bedding material			Surface treatment			Bedding material			Surface treatment		
	df	χ^2	*P*	*df*	χ^2	*P*	*df*	χ^2	*P*	*df*	χ^2	*P*
Hsq	1	16.0391	<0.0001	2	4.3925	0.1112	1	10.3806	0.0013	2	9.2379	0.0099
Ls	1	14.1048	<0.0002	2	4.2193	0.1213	1	90.0910	<0.0001	2	62.6413	<0.0001
Otc	2	0.8603	0.6504	2	3.7033	0.1570	2	11.1760	<0.0001	2	11.2217	0.0037
Ro	2	8.3197	0.0156	2	0.8677	0.6480	2	355.2281	<0.0001	2	40.0315	<0.0001
St	2	13.2074	0.0014	2	0.1474	0.9289	2	3.5631	0.1684	2	5.7693	0.0559
Tz	2	1.9941	0.3690	2	6.1973	0.0451	2	92.4410	<0.0001	2	34.1107	<0.0001

In contrast, sowing of native species (both gypsophiles and gypsovags) gave highly satisfactory results. The advantages of using native species in revegetation have been highlighted in several studies (e.g. Harper-Lore 1996; Matesanz & Valladares 2007; Bochet et al. 2010). In our study, sowing performed better in quarry gypsum spoil (GS) and topsoil addition (TA) bedding materials, significantly increasing species richness and density in contrast to raw gypsum (RG) and topsoil removal (TR). It is noteworthy that these two options (GS and TA) represent the most predictable situations at the end of mining activity. On the other hand, despite the guidelines suggesting the use of raw gypsum as a bedding material option in the recovery plan (technical unpublished document), this gave the lowest sowing success, with similar results to topsoil removal, so that both of these bedding materials proved to be ineffective.

The replacement of topsoil has been widely proposed as a valuable source of seeds in restoration works (e.g. Bradshaw 1997; Tormo et al. 2007), and its preservation and storage (stockpiling) are regarded as one of the most important practices in land reclamation (Abdul-Kareem & McRae 1984; Kundu & Ghose 1994; Ghose 2004).

Topsoil provides a source of seeds, favouring the presence of target species, but also promotes the spread of possible competitors, which could reduce the performance of gypsum species (Matesanz & Valladares 2007). In our study, the presence of colonizer hemicryptophytes and herbaceous plants was significantly higher in the topsoil addition treatment than in the other bedding materials. Therefore, when topsoil contains large numbers of seeds of undesirable species, then it could be better to use the subsoil as a substrate for restoration (Biswas & Mukherjee 1989; Ghose 2004). In this sense, our results indicated that in gypsum spoil without added topsoil, the density, richness, survival and growth were higher, suggesting a negative effect of the topsoil, which restricted establishment and growth of the target species.

Although topsoil does not appear to be advantageous at an early stage in our study, over the long term it could become positive. On the one hand, herbaceous species play an important hydrological role by enhancing soil infiltration and protecting soil against erosion (Nicolau 2002). Tormo et al. (2007), studying roadfill revegetation in a semi-arid Mediterranean environment, found that plots with topsoil addition were less prone to erosion than plots without such additions, although these differences were not significant. On the other hand, apart from seeds, organic matter and plant nutrients (Ghose 2004), topsoil also contains cyanobacteria, green algae, lichens, mosses and other organisms that are closely integrated with the soil particles, resulting in the formation of biological soil crusts (Belnap & Lange 2003). The ecological roles and ecosystem services of these crusts have been well documented (Eldridge & Greene 1994; Bowker et al. 2005; Li et al. 2010), including the positive effects of biological soil crusts on vascular plants (Su et al. 2009). Therefore, experimental plots must be monitored over time to achieve a more complete evaluation of the results.

Nevertheless, the results were positive for sowing on both bedding materials (GS and TA), especially on gypsum spoil (see Results). These two treatments in combination with the organic blanket enhanced the presence of target species, whereas the addition of organic matter had no significant additional effect on plant density. The survival and growth analysis by species indicated that gypsum spoil was also the most effective bedding material, but jointly with sowing plus organic matter. Therefore, the surface treatments improved results in two ways. The organic blanket reduced evaporation, which could promote seed germination and consequently higher seedling density. On the other hand, organic matter improved growth and survival. This is not surprising, since organic matter benefits plant development and some authors have even demonstrated that a paucity of organic matter could limit species establishment during primary succession on gypsum outcrops

Table 3. Effects of surface treatments on each bedding material by species on survival and growth. Left, survival analysis: number of monitored seedlings (N), percentage mortality, and summary of the Wilcoxon test. Right, growth analysis: number of monitored seedlings alive (N), mean growth (cm) (±SE), and summary of the GLM. Species: Hsq (*Helianthemum squamatum*), Hsy (*Helianthemum syriacum*), Ls (*Lepidium subulatum*), Ot (*Ononis tridentata* subsp. *crassifolia*), Ro (*Rosmarinus officinalis*), St (*Stipa tenacissima*), Tz (*Thymus zygis* subsp. *gracilis*). Bedding material: GS (gypsum spoil), RG (raw gypsum), TA (topsoil addition), TR (topsoil removal). Surface Treatment: SB (sowing plus organic blanket), SO (sowing plus organic matter), S (sowing).

Species	Bedding material	Surface treatment	Survival				Growth			
			N	Mortality (%)	χ^2	*P*	*N*	Growth (cm)	χ^2	*P*
Hsq	TA	S	26	26.92	1.4655	0.4806	19	3.09 ± 0.29	0.1344	0.9350
		SO	12	9.09			10	3.15 ± 0.35		
		SB	34	20.59			27	2.94 ± 0.27		
	GS	S	34	2.94	1.8290	0.4007	33	3.23 ± 0.23	9.4795	0.0087
		SO	36	0.00			36	4.70 ± 0.37		
		SB	39	5.13			37	4.12 ± 0.29		
Ls	TA	S	24	29.17	5.6456	0.0594	17	1.83 ± 0.25	11.2422	0.0036
		SO	20	25.00			15	2.44 ± 0.57		
		SB	40	7.50			37	3.37 ± 0.39		
	GS	S	27	3.70	1.2401	0.5379	26	3.08 ± 0.63	54.3852	<0.001
		SO	37	0.00			37	7.20 ± 0.65		
		SB	39	2.56			38	6.48 ± 0.69		
Ot	TA	S	29	0.00	1.800	0.4066	29	9.77 ± 0.79	12.4515	0.0020
		SO	25	0.00			25	9.48 ± 0.98		
		SB	30	3.33			29	12.29 ± 0.98		
	GS	S	14	0.00	0.0000	0.0000	14	9.10 ± 1.49	27.4367	<0.001
		SO	14	0.00			14	16.08 ± 1.58		
		SB	17	0.00			17	12.58 ± 1.48		
	RG	S	14	0.00	2.1250	0.3456	14	13.01 ± 1.46	7.3635	0.0252
		SO	20	0.00			20	10.18 ± 1.00		
		SB	16	6.25			15	12.71 ± 1.72		
Ro	TA	S	40	17.50	1.8133	0.4039	33	5.24 ± 0.38	44.7246	<0.001
		SO	40	12.50			35	4.74 ± 0.38		
		SB	40	7.50			36	8.46 ± 0.69		
	GS	S	41	4.88	2.1398	0.3430	39	4.77 ± 0.65	44.6861	<0.001
		SO	40	2.50			39	8.61 ± 0.97		
		SB	40	10.00			36	6.16 ± 0.61		
	RG	S	40	2.50	2.1589	0.3398	39	1.79 ± 0.24	0.2455	0.8845
		SO	32	0.00			32	1.87 ± 0.26		
		SB	33	6.06			31	1.70 ± 0.21		
St	TA	S	17	0.00	3.8540	0.1456	17	5.94 ± 0.41	2.0308	0.3623
		SO	32	18.75			26	5.04 ± 0.40		
		SB	38	10.53			34	5.79 ± 0.35		
	GS	S	29	3.45	0.4375	0.8035	28	4.64 ± 0.39	1.3344	0.5131
		SO	20	5.00			18	4.67 ± 0.35		
		SB	27	7.41			25	5.29 ± 0.29		
	RG	S	26	30.77	1.6512	0.4380	18	4.89 ± 0.38	4.816	0.0900
		SO	10	10.00			9	4.51 ± 0.54		
		SB	25	28.00			18	6.29 ± 0.31		
Tz	TA	S	40	0.00	5.8139	0.0546	40	4.09 ± 0.32	11.9569	0.0025
		SO	41	12.20			37	3.79 ± 0.34		
		SB	46	2.17			45	5.30 ± 0.34		
	GS	S	40	0.00	10.3478	0.0057	40	4.67 ± 0.62	1.8611	0.3943
		SO	40	0.00			40	4.84 ± 0.44		
		SB	40	12.50			35	5.35 ± 0.54		
	TR	S	40	0.00	5.333	0.0695	40	6.82 ± 0.42	13.3402	0.0013
		SO	15	6.67			14	6.01 ± 0.59		
		SB	40	0.00			40	8.62 ± 0.62		

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(Dana & Mota 2006). Surface treatments can raise the recovery cost but provide some technical and ecological benefits (Muzzi et al. 1997), especially in semi-arid and arid environments (Bochet et al. 2010). Treatments such as the organic blanket promote good vegetative cover and reduce surface runoff (and consequently seed loss) and the erosion rate (Muzzi et al. 1997; Benik et al. 2003). However, if the long-term goal is to reestablish native vegetation, the use of some surface treatment such as large amounts of biosolids could be negative (Paschke et al. 2005). In fact, in an experiment to rehabilitate a gypsum quarry, the use of solid waste compost as organic amendment promoted good vegetation cover (Castillejo & Castello 2010), although this was not provided by gypsophile and gypsovag species.

It is therefore relevant to select optimal methods regarding bedding material, surface treatments and seed mixture, since we not only need a high plant density or cover, but also an appropriate composition to recover the target habitat. Species composition is clearly a key issue in judging restoration success (Henderson 1999; Lorite et al. 2010). This fact is particularly pertinent in habitats exclusive to specific substrates such as dolomite, serpentine or gypsum, since they are composed mainly of specialist plant species, frequently rare or even endemic species (Parsons 1976; Kazakou et al. 2008; Mota et al. 2008). In our experiment, all species selected for the sowing showed positive results regarding density, survival and growth in the most effective treatments. Plant density was especially high for *Lepidium subulatum, Helianthemum squamatum, Rosmarinus officinalis* and *Thymus zygis* subsp. *gracilis*. In considering the future recovery plan, the seed proportion should probably be adjusted. Therefore, we should assess our results over the long term in order to optimize the seed mixture composition.

After the summer, even higher values of plant density were recorded than earlier in the year (in all sowing plots on GS and TA bedding materials), and there was also a high survival rate. These results are relevant for ecological restoration, since establishment after germination is severely limited by summer drought in Mediterranean-type ecosystems (Herrera 1992). In addition, survival to the first summer is a key factor for the development of some gypsophiles. Escudero et al. (1999, 2000) found low survival percentages for *H. squamatum* and *L. subulatum* in natural habitats that were especially related to drought. However, they found that most *H. squamatum* seedlings surviving at the end of the first year were still alive at the end of the second year. In our sown plots, most of the marked plants not only survived but grew further during this season, probably due to the characteristics of the gypsum spoil. The gypsum properties may determine a significant increase in water availability during summer drought (Meyer 1986; Meyer et al. 1992), which would justify the active growth and the flowering phenology of most gypsophiles during the summer (Meyer 1986; Gómez et al. Gómez et al. 1996; Escudero et al. 2000). In addition, besides the positive results regarding plant density, survival and growth after the first summer, habitat recovery could be favoured since the target species are small and have a short life cycle, even able to produce flowers and fruits in the first year (author's unpublished data). Therefore, in spite of the short-term nature of our results, they point in the right direction to recover the target habitat. However, the sowing experiment should be monitored over the long term to confirm the ecological and economic viability of the restoration options planned.

In conclusion, the short-term results of this study highlight the importance of implementing measures to recover the target gypsum habitat. An appropriate seed mixture of gypsophiles and gypsovags sown on gypsum spoil is adequate to guarantee a high plant density of the key species. Some technical solutions, such as adding organic matter or laying organic blanket, can improve effectiveness of the sowing, whereas some common practices, such as topsoil addition, may disadvantage the early stages of the target species.

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