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Native Species for Roadslope Revegetation: Selection, Validation, and Cost Effectiveness

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Abstract

Native species arise as an alternative to improve the poor success of traditional hydroseeding with commercial species in degraded areas. The objectives of this study were to (1) establish a procedure to select suitable native species for roadslope revegetation, (2) validate the procedure by means of field sowing experiments, and (3) assess cost effectiveness of the use of native species in hydroseeding as regards commercial ones. Vegetation surveys were performed in semiarid roadslopes of East Spain and species success evaluated according to abundance and frequency. A list of potentially suitable species for revegetation was produced and a subset of species selected and hydroseeded to check their suitability in hydroseeding. Cost effectiveness of the use of native species was estimated. Results support the suitability of the procedure for the selection of native species. Vegetation cover produced by the hydroseeded mixture of native species was high (between 43 and 70% throughout the 4 years) and was 4–20 times higher than the cover produced by a standard commercial seed mixture. The price of the selected seed mixture was 30 times that of the commercial one, but the cost of relevant ecological advantages provided by the use of native species was only twice that of the commercial species on the basis of cost effectiveness assessment. Practical consequences for restorers, policymakers, and practitioners are discussed, and the use of native species is encouraged to improve revegetation success of roadslopes and similar slope types especially in semiarid and arid environments.

Key words: autochthonous, erosion, hydroseeding, restoration, roadside, semiarid, vegetation.

Introduction

Increasing worldwide road construction due to increasing population density, road transportation, and road traffic has resulted in an increasing ecological importance of roadside vegetation (Forman 2000; Rivas et al. 2006). In order to minimize the ecological and geomorphological impacts of road construction on plant communities and soil stability, revegetation of newly created roadside slopes is often envisaged. Hydroseeding has been the most widespread method used for roadslope revegetation in the past few decades (Enríquez et al. 2004). The main objective of hydroseeding is generally short term and consists of mechanical stabilization of barren slopes and control of water erosion. The prevalence of this geomorphological objective as regards to other more long-term ecological ones related to the characteristics of the plant community has led to the use of fast-growing commercial species in hydroseeding (Matesanz et al. 2006). These latter commercial species are mainly grass and leguminous species that enhance a fast and dense vegetation cover able to prevent erosion in the very first months after road construction. Under dry and semiarid conditions, however, the use of commercial species recommended on the basis of published standards (NTJ 08H 1996) has produced very unconvincing results on roadslopes. In many cases, most of the sowed commercial species disappear after the first growing season (Andrés & Jorba 2000; Martínez-Ruiz 2000), and the total vegetation cover achieved is usually too low to ensure erosion control, except in the most favorable conditions like north-facing roadfills and/or gentle slopes (Bochet & García-Fayos 2004). Thus, autochthonous species may arise as an attractive alternative to improve hydroseeding success in semiarid roadslopes as they provide moreover relevant ecological advantages such as the conservation of local diversity, the existence of ecotypes adapted to specific environmental conditions, the provision of compatible habitats for other native plants and animals, and the enhancement of natural colonization (i.e., Nóvak & Prach 2003; Petersen et al. 2004).

Some studies have already reported the successful use of indigenous (locally collected) species in roadslope revegetation and the higher establishment rates of these species as compared to commercial ones in a wide range of conditions (i.e., Paschke et al. 2000; Tinsley et al. 2006; and Tormo et al. 2007 for semiarid roadslopes). However, the terms "indigenous," "autochthonous," or "native" are often misleadingly used in the context of roadside restoration, where they usually refer to taxa that occur naturally in a particular country or region without direct or indirect

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human actions (Harper-Lore 1996). This biogeographical meaning is often confused with ecological insights about habitat requirements, and there is a general erroneous belief that “autochthonous” species are adapted to the local conditions of a specific area within this country or region (Brown 1997). However, specific local conditions of the area to be restored may hinder plant colonization of some native species and the use of “autochthonous” species at a national, regional, or even local scale is therefore not necessarily a guarantee of restoration success. To this respect, Bochet et al. (2007) reported that the harsh environmental conditions of semiarid roadslopes, mainly due to water stress, act as ecological filter for the establishment success of native species that grow in the adjacent areas to the roadslopes. The same authors stated moreover that, among other possible processes, the ability to germinate in semiarid roadslopes under water stress could be an indicator of a species’ potential for success under semiarid conditions.

A major challenge of restoration is therefore the selection of “native” species from the local flora that are moreover able to overcome the specific limitations of the disturbed area to be restored. In the present study, we propose an efficient procedure to select suitable native species for roadslope revegetation that are adapted to the local conditions of the degraded area that has to be restored. This procedure is based on the identification of the spontaneous colonizing vegetation of roadslopes and on the hypothesis that successful spontaneous colonizers are the most suitable species for roadslope revegetation. We also aim at evaluating the costs of ecological and geomorphological advantages provided by the use of native species in hydroseeding.

The specific objectives of this study are:

(1) to establish a species selection procedure that will help practitioners to choose suitable native species for roadslope revegetation in order to improve revegetation success;
(2) to validate the species selection procedure by testing the performance of the selected species in field sowing experiments and to compare their performance with that of commercial ones; and
(3) to assess the cost effectiveness of the use of native species in hydroseeding as regards commercial ones.

Methods

Study Area

The area selected is representative of large areas of inner Spain with semiarid climatic conditions. The study area is located in the Region of Utiel-Requena, a plateau at 500 m above sea level in East Spain (lat 39°29′N, long 1°06′W). Two different roadslope systems were selected, one between 267 and 307 km of the A3 highway (Requena Site) and the other between 189 and 190 km of the N330 road (Utiel Site).

Lithology and climate are homogeneous in the two roadslope systems. Soils are derived from calcareous marls and clays of Tertiary age. Mean annual precipitation and temperature range between 418 mm and 14.2°C at Requena and 399 mm and 12°C at Utiel. Precipitation is very variable among and within years with two peaks, one in May and the other in October. Frost in winter and droughts in summer are common (Pérez 1994). Requena roadslopes were built between 1992 and 1994 and hydroseeded just after road building, and Utiel roadslopes were built in 2003. Land use in the area is dominated by vineyards and dry farming, but small patches of Mediterranean shrubland remain in the adjacent areas to the roadslopes.

Species Selection

The whole process of species selection consisted of two different steps: species selection and validation.

Species Selection. Flora surveys were performed in the roadslopes of the Requena Site from March to June 2000 in order to produce a list of species able to grow on roadslopes. Forty-six roadslopes were surveyed, all more than 20 m long, 5 m high, and 25° steep and with less than 5% cover of rock outcrops. Sampling accounted for the slope type and aspect with 21 roadcuts and 25 roadfills, both including north- and south-facing slopes.

Flora surveys were performed by two people who walked the roadslopes in two transect lines parallel to the road, one in the upper part and the other in the lower part of the roadslope, and noted all species found in their respective fields of vision. Two groups of species were considered in the surveys: the group of native species that colonized spontaneously the roadslopes since the end of road building and the group of species included in the hydroseeded mixtures used by the public administration in 1992–1994. After each roadslope survey, the two surveyors assigned together a single value of relative abundance to each species according to the following classes: 0, species absent; 1, less than 10 individuals scattered along the slope; 2, individuals present either regularly or in local monospecific patches; and 3, species present abundantly along the slope. Species establishment success was then assessed by taking into consideration the frequency and abundance of the species. Frequency was defined as the percentage of roadslopes in which a species was present and abundance as the relative abundance of each species in each roadslope. A species was considered successful if it was present in more than 50% of the roadslopes surveyed and if it had abundances equal or greater than class “2” in at least one-third of the roadslopes where the species was present. When a species did not fulfill both requirements, it was considered unsuccessful. Assessment of species success accounted for the slope type and aspect.

Validation. A subset of successful species was chosen (SelMix), submitted to a hydroseeding experiment, and its performance was compared with that of a standard commercial seed mixture (ComMix). The experiment was carried out in November 2003 at the Utiel Site. Bare roadfills, homogeneous in slope length (from 12 to 15 m), angle (28°), and age (September 2003) were chosen. No hydroseeding was performed on roadcuts because seed removal by gravity is a major problem on these steep slopes, and revegetation success is more a matter of seed trapping than of species selection (Bochet & García-Fayos 2004). Twelve 4 × 4–m plots were randomly located in the middle part of the roadfills and randomly assigned to the treatments (six plots of ComMix vs. six plots of SelMix). The ComMix consisted of a standard seed mixture widely used in the region (NTJ 08H 1996) and provided by a local seed supplier (Intersemillas S.A, Valencia, Spain). The SelMix consisted of a subset of successful species on roadfills (see Table 1). This selection was based on the existence of dense populations of these species in the study area in order to reach high efficiency in seed harvesting and cleaning. Although *Medicago sativa* and *Dactylis glomerata* were in the list of species used in the 1992–1994 revegetation tasks, they are also native species in the study area (García 1996) and then we decided to include them in the SelMix. Moreover, *M. sativa* was included in both mixtures because it is the most widely used species in hydroseeding for revegetation in Mediterranean roadslopes (NTJ 08H 1996). Seeds of SelMix species were collected from local populations during the growing season prior to the experiment and stored in paper bags in dark conditions at room temperature, but seeds of *M. sativa* and *D. glomerata* were supplied by a local seed supplier (Intersemillas S.A). Germination rates were 60 to 81% for selected species (Tormo et al. 2006) and greater than 85% for all commercial species (data from Intersemilla S.A.). Both mixtures consisted of 25 g/m^2 seeds, 15 g/m^2 short fiber wood mulch, 15 cm^3/m^2 humic acids, and 50 g/m^2 organic fertilizers. A company was contracted for the hydroseeding experiment, and the authors supervised the experiment in the field. Containers (16.5 × 16.5 × 12.0 cm) placed in the four corners of each 4 × 4–m plot allowed the checking of the spatial homogeneity of the hydroseeding procedure (no significant differences in the weight of collected seeds in the containers between treatments: $t = -0.947; df = 10; p = 0.366$).

The response variables were vegetation cover provided by the whole set of sowed species included in the mixture and specific vegetation cover produced by each single sowed species. Weeds that appeared in the plots after hydroseeding were not included in the vegetation cover measured. Plots were visited yearly in June 2004, 2005, 2006, and 2007. Vegetation cover estimations were recorded by two observers in the central 2 × 2–m area of the plots in four 1 × 1–m subplots to avoid edge effects. The maximum acceptable difference between both observers was 10%; otherwise, the estimate was repeated.

Because one of the plots was damaged by road construction activities after hydroseeding, only 11 plots were taken into account in the analyses (five ComMix and six SelMix plots).

Cost Effectiveness

Total costs derived from the use of ComMix and SelMix species in hydroseeding—once species have been selected—were estimated. ComMix cost was calculated on the basis of the available list of seed prices provided by local seed suppliers. Contribution of each species to the mixture in percentage of seed weight was taken into account for this calculation. Because most of the selected species included in the SelMix were not available by local seed suppliers, we roughly estimated their seed prices mainly on the basis of seed harvesting and cleaning efforts. Estimations were based on a worker's salary of 110 €/day and journeys' charges to the plant populations of 0.21 €/km (2007 tariffs of a local seed supplier). When existing standard mechanized techniques were considered useful for seed harvesting, then the seed price was adjusted. This was the case for *Bromus rubens*, *Avena barbata*, and *Plantago albicans* with final estimated seed prices 4, 8, and 22 times lower when mechanical standard seed harvesting was taken into account. Because the prostrate growing form of *M. minima* makes seed harvesting extremely laborious and time consuming, seed price was not estimated for this species as it would be unfeasible.

Table 1. Species composition (% seed weight) of the ComMix and SelMix mixtures used in the experimental hydroseeding at Utiel.

ComMix	%	*SelMix*	%
Festuca arundinacea (Poaceae)	20.0	*Avena barbata* (Poaceae)	21.2
Agropyron cristatum (Poaceae)	20.0	*Dactylis glomerata* (Poaceae)	20.0
Lolium multiflorum (Poaceae)	15.0	*Diplotaxis erucoides* (Brassicaceae)	18.4
Melilotus officinalis (Fabaceae)	15.0	*Bromus rubens* (Poaceae)	13.8
Onobrychis sativa (Fabaceae)	10.0	*Medicago sativa* (Fabaceae)	10.0
Vicia villosa (Fabaceae)	10.0	*Anacyclus clavatus* (Asteraceae)	6.3
Medicago sativa (Fabaceae)	10.0	*Plantago albicans* (Plantaginaceae)	5.2
		Medicago minima (Fabaceae)	5.1

ComMix, standard commercial seed mixture; SelMix, seed mixture that includes the selected successful species.

A cost effectiveness index was calculated and compared between both seed mixtures. It was defined as the ratio between the vegetation cover produced by the hydroseeded species (%) and the cost resulting from the use of these latter in hydroseeding (€/seeded m^2).

Statistical Analyses

Prior to analysis, the data were checked for normality and homogeneity of variances. Repeated-measure analysis of variance was used to determine changes over time in the cover produced by the two seed mixtures in the cover of annuals and perennials and in the cover of *M. sativa* (the only species common to both mixtures). Nonparametric correlations were used to determine the relationship between annual and perennial species within the seed mixtures. Statistical analyses were performed using R v.2.5 software (R Development Core Team 2007).

Results

Species Selection

A total of 324 species were recorded in the studied slopes of Requena (310 native and 14 hydroseeded in 1992–1994). Four of the hydroseeded species in 1992–1994 were not found on the slopes 6–8 years later (*Eragrostis curvula*, *Puccinelia distans*, *Trifolium campestre*, *Vicia villosa*). From the 324 species surveyed, 17 were evaluated as successful in all types of slopes and 49 at least in one of the four roadslope categories studied, following the proposed criteria (Table 2). We selected a subset of eight species that were successful at least on roadfills and potentially suitable to be used in roadfill revegetation (Tables 1 & 2).

Procedure Validation

In the SelMix plots, vegetation cover produced by the selected species was significantly higher than the cover produced by the ComMix species in the ComMix plots ($F_{[1,9]} = 170.93$, $p < 0.001$). It was 4, 20, 12, and 15 times higher than that of ComMix species in 2004, 2005, 2006, and 2007, respectively (Fig. 1). Significant changes in the vegetation cover occurred through time ($F_{[3,27]} = 12.37$, $p < 0.001$) in a similar way for both seed mixtures (no interaction between factors, $F_{[3,27]} = 2.33$, $p = 0.096$, Fig. 1).

Individuals of all species included in the SelMix mixture remained in the plots throughout the study, although *Diplotaxis erucoides* and *Dactylis glomerata* reached very low vegetation cover. Only four of the seven sowed species were recorded in the ComMix plots in the third visit, and only three remained after the last visit (Table 3). The specific cover of the ComMix species did not reach in any case 5%, but *Lolium multiflorum* in June 2004 (Table 3). The specific cover of the SelMix species varied

Table 2. Successful plant species living in roadslopes of the Requena Site obtained from flora surveys according to slope type and aspect.

	SRc	*NRc*	*SRf*	*NRf*
a. Hydroseeded species sown in 1992–1994 just after road building				
Bromus inermis	+	+	+	+
Onobrychis viciifolia	+	+	+	+
Sanguisorba minor	+	+	+	+
Medicago sativa	+	+	+	+
Dactylis glomerata	+	+	+	+
Festuca arundinaceae	+	+		+
Lolium rigidum	+	+		
Cynodon dactylon			+	
b. Native colonizers				
Alyssum simplex	+	+	+	+
Anacyclus clavatus	+	+	+	+
Avena barbata	+	+	+	+
Bromus rubens	+	+	+	+
Centaurea aspera	+	+	+	+
Cichorium intybus	+	+	+	+
Convolvulus arvensis	+	+	+	+
Diplotaxis erucoides	+	+	+	+
Euphorbia serrata	+	+	+	+
Hordeum murinum subsp. *leporinum*	+	+	+	+
Sonchus oleraceus	+	+	+	+
Scabiosa simplex	+	+	+	+
Bromus tectorum		+	+	+
Crepis vesicaria		+	+	+
Erodium cicutarium		+	+	+
Calendula arvensis			+	+
Carduus pycnocephalus			+	+
Filago pyramidata			+	+
Medicago minima			+	+
Plantago albicans			+	+
Scorzonera laciniata		+		+
Silene nocturna		+		+
Reseda phyteuma	+		+	
Pallenis spinosa	+		+	
Eryngium campestre	+	+		
Carthamus lanatus				+
Crepis foetida				+
Foeniculum vulgare subsp. *piperitum*				+
Linaria simplex				+
Papaver rhoeas				+
Senecio gallicus				+
Senecio vulgaris				+
Avena sterilis			+	
Erodium ciconium			+	
Erodium malacoides			+	
Hirschfeldia incana			+	
Reseda undata			+	
Aegilops geniculata		+		
Aegilops triuncialis		+		
Genista scorpius	+			
Santolina chamaecyparissus subsp. *squarrosa*	+			

NRc, north-facing roadcut; SRc, south-facing roadcut; NRf, north-facing roadfill; SRf, south-facing roadfill.

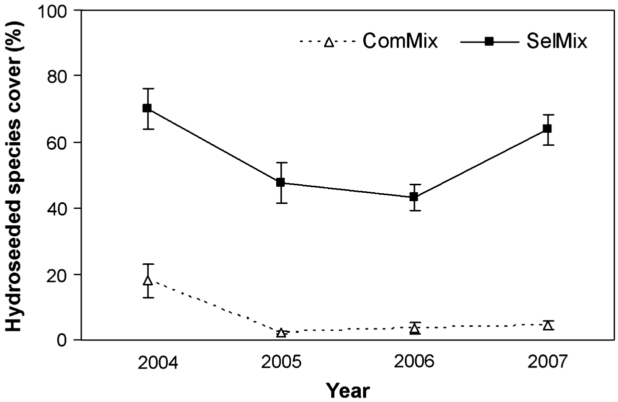

Figure 1. Variation over time in the cover (% $\bar{X}$ ± SE) of hydroseeded species in ComMix (standard commercial mixture) and SelMix plots (seed mixture of selected species).

considerably with time but was higher than 5% at least in one of the visits (except *D. erucoides* and *D. glomerata*). In some visits, the specific covers of *Avena barbata*, *Plantago albicans*, and *Medicago sativa* were higher than 15%. *Medicago sativa* reached a higher vegetation cover over time in SelMix than in ComMix plots ($F_{[1,9]} = 8.64$, $p = 0.016$, Table 3), although the sowing density was the same in both cases (10% of total seed mixture weight, Table 1). The magnitude of this difference increased over time (significant interaction between factors "mixture × time," $F_{[3,27]} = 9.54$, $p < 0.001$) because the cover of *M. sativa* increased highly from the first to the last visit in the SelMix plots and remained almost constant and extremely low in the ComMix ones (Table 3). A general inverted trend in the vegetation cover of annuals and perennials was observed throughout the study period in the SelMix plots ($r = -0.779$, $n = 24$, $p < 0.001$ and Table 3), indicating that the cover of annuals decreased at the same time as the cover of perennials increased from the first to the last visit. In the ComMix, no correlation was found between covers of annuals and perennials ($r = -0.024$, $n = 20$, $p = 0.919$ and Table 3). Moreover, changes in covers of annual and perennial species over time were less pronounced in the ComMix than in the SelMix plots (significant interaction between factors "mixture × time," $F_{[3,27]} = 3.89$; $p = 0.020$ for annuals and $F_{[3,27]} = 15.20$, $p < 0.001$ for perennials, Table 3).

Cost Effectiveness

Large differences in total price existed between the two seed mixtures used. The price of SelMix was 30 times that of the same weight of ComMix, only on the basis of seed harvesting and cleaning efforts (1.861 vs. 0.063 €/seeded m^2, Table 4). This difference is explained by differences of one or even two orders of magnitude between the seed price of SelMix and ComMix species (Table 4). Whereas the price of 1 kg of seeds of a SelMix species ranged between 3 and 350 €, it was in all cases less than 5 € for the ComMix species.

When taking into consideration the vegetation cover reached by the hydroseeded species at the end of the study period, the percent cover produced per euro and seeded square meter by the ComMix species was twice that produced by the SelMix species (cost-effectiveness index was 68.25 and 34.2%·$€^{-1}$·seeded m^{-2}, respectively).

Discussion

The present study provides evidence that the selection of appropriate species prior to revegetation is crucial to ensure the success of roadslope restoration in areas

Table 3. Vegetation cover (% $\bar{X}$ ± SE) produced by each individual species included in the seed mixtures.

	June 2004	*June 2005*	*June 2006*	*June 2007*
ComMix				
*Lolium multiflorum**	17.35 ± 5.53	1.60 ± 0.35	1.30 ± 0.80	0 ± 0
*Vicia villosa**	0 ± 0	0.30 ± 0.18	0 ± 0	0 ± 0
*Festuca arundinacea***	0.30 ± 0.18	0.30 ± 0.30	1.70 ± 1.13	1.90 ± 1.31
*Medicago sativa***	0.30 ± 0.18	0.15 ± 0.15	0.30 ± 0.30	1.15 ± 0.87
*Onobrychis sativa***	0 ± 0	0 ± 0	0.25 ± 0.25	1.25 ± 1.25
*Agropyron cristatum***	0 ± 0	0 ± 0	0 ± 0	0 ± 0
*Melilotus officinalis***	0 ± 0	0 ± 0	0 ± 0	0 ± 0
SelMix				
*Avena barbata**	22.17 ± 7.52	19.73 ± 7.68	9.27 ± 3.04	10.85 ± 4.94
*Bromus rubens**	18.76 ± 2.75	8.88 ± 2.31	4.31 ± 0.93	2.38 ± 0.41
*Anacyclus clavatus**	17.76 ± 4.40	10.67 ± 4.69	7.18 ± 1.51	6.06 ± 1.40
*Medicago minima**	4.50 ± 0.21	2.33 ± 0.76	4.21 ± 0.86	2.67 ± 0.43
*Diplotaxis erucoides**	4.41 ± 0.63	0.25 ± 0.16	0.54 ± 0.54	1.21 ± 0.53
*Plantago albicans***	1.00 ± 0.37	2.63 ± 0.60	7.27 ± 2.55	16.71 ± 4.25
*Medicago sativa***	0.83 ± 0.59	2.71 ± 0.85	10.42 ± 3.63	23.81 ± 6.44
*Dactylis glomerata***	0.75 ± 0.75	0.46 ± 0.22	0.13 ± 0.13	0 ± 0

ComMix, standard commercial seed mixture; SelMix, seed mixture that includes the selected successful native species that spontaneously colonize the roadslopes. Plant longevity: annual (*) and perennial (**).

Table 4. Seed prices of the sowed species used in the hydroseeding experiment.

SelMix	*PK (€/kg)*	*PCM (€/seeded m^2)*	*ComMix*	*PK (€/kg)*	*PCM (€/seeded m^2)*
Anacyclus clavatus	350.00*	0.553*	*Medicago sativa*	4.33	0.011
Diplotaxis erucoides	133.90	0.616	*Agropyron cristatum*	2.90	0.015
Bromus rubens	125.00*	0.431*	*Festuca arundinacea*	2.70	0.014
Avena barbata	40.00*	0.212*	*Melilotus officinalis*	2.05	0.008
Plantago albicans	18.00*	0.023*	*Vicia villosa*	1.90	0.005
Medicago sativa	4.33	0.011	*Onobrychis sativa*	1.75	0.004
Dactylis glomerata	3.00	0.015	*Lolium multiflorum*	1.65	0.006
Medicago minima	+	+			

PK, price of 1 kg of seeds of a given species (in €/kg); PCM, price of the species contribution to the seed mixture (in €/seeded m^2). Prices were provided by a local seed supplier or estimated (SelMix with *). + denotes price of *Medicago minima* could not be estimated due to the unfeasibility to harvest seeds from this prostrate species.

with unfavorable climatic conditions. Because plant performance on roadslopes is mainly dependent on the ability of species to overcome the local limitations (Tormo et al. 2006; Bochet et al. 2007), the selection of species able to thrive in areas with similar characteristics to the area that has to be restored is a required condition for restoration success.

The procedure described and tested in this study allows the selection of native species that fulfill this requirement. As a result, a list of potential species suitable for roadslope revegetation was proposed, which is specific, however, to the type of habitat and ecological conditions considered. Our data indicate that this suitability accounts for the type and aspect of the roadslopes because the limiting factors that act as filters for plant establishment can be of a different magnitude in the various types of roadslopes (water stress, erosion, and competition; Bochet et al. 2007). As a consequence, species selection should consider different lists of species for roadfill and roadcut revegetation or, better, a common list of species able to colonize successfully both roadslope types. However, in the case of roadcuts, species selection for revegetation by hydroseeding should be considered after solving problems related to the slope steepness such as seed removal by gravity (Matesanz et al. 2006).

The dense cover produced by the selected native species throughout the study period seems to be able to reduce erosion rates from 50 to more than 90% with respect to a bare soil (Gyssels et al. 2005). These species achieved therefore successfully the crucial geomorphological objective of erosion control, which is usually assigned to the fast-growing commercial grass and leguminous species included in the standard commercial mixtures used in revegetation. These latter species are supposed to give rise to a dense vegetation cover and facilitate the initial establishment of native plants in the first months after hydroseeding before they disappear rapidly (Merlin et al. 1999; Matesanz et al. 2006). However, our results confirm the low performance of the species in these standard commercial mixtures, already reported in other revegetation projects of semiarid roadslopes (Andrés et al. 1996; Albaladejo et al. 2000). Species of the ComMix mixture did not seem to act as nurse species because the vegetation cover they provided was too low in the first year after hydroseeding to efficiently control erosion (Gyssels et al. 2005). Although cover was at its highest 7 months after hydroseeding, the facilitation role of nurse species was not confirmed because no single commercial fast-growing annual was recorded in the plots in the first 5 months. *Lolium multiflorum* was the first commercial annual species that appeared in the plots in June 2004 with a 17.4% cover, when germination of native species was not expected to occur in the study area.

Competitive interactions with other species included in the ComMix could explain the unexpected lower cover of *Medicago sativa* recorded in the ComMix as regards the SelMix plots. To this respect, Hoffman and Isselstein (2004) report the highly competitive potential of several species of the genus *Lolium* (*L. multiflorum* was included in the ComMix) and San Emeterio et al. (2004) describe an allelopathic potential of *L. rigidum* on the growth of other commercial species, including *M. sativa.*

For both seed mixtures, the vegetation cover varied greatly over time, with the highest one recorded in 2004 and the lowest in 2005 and 2006. The yearly variation in vegetation cover could be largely attributed to the precipitation variation between years. Spain suffered in 2005 and 2006 a severe drought, and the spring precipitation in the area was much lower than the average calculated on the basis of a 29-year period (72.0 and 66.6 mm in 2005 and 2006, respectively, and an average of 104.3 mm for the period 1961–1990, Pérez 1994). On the contrary, springs were much wetter than the average in 2004 and 2007 (235.5 and 183.5 mm, respectively). The relatively high vegetation cover recorded in 2004 could be partly due to the influence of fertilizers and mulch supplied to the soil during the hydroseeding process carried out 7 months earlier (Albaladejo et al. 2000; Holmes 2001; Elmarsdottir et al. 2003).

Our cost estimations reveal, as expected, large differences (30 times) between both seed mixtures mainly due to differential seed harvesting costs. These differences may partly explain why commercial species are still preferred to native ones for restoration projects and why we are facing the following vicious circle: because native species are not available by seed suppliers, no one recommends their use in public works; as a consequence, road builders do not demand these species, and seed suppliers do not invest in improving seed production of native species; as a result, seeds of native species are still not available by seed suppliers and have no competitive price.

From an ecological and restoration management point of view, however, the use of native species is always to be encouraged, no matter what the price, because native species present relevant ecological and geomorphological advantages such as the preservation of genetic integrity and conservation of local diversity, compatibility with other native species, provision of habitats for native plant and animals and landscape integration, and an efficient prevention of erosion (Petersen et al. 2004; Tinsley et al. 2006).

In conclusion, (1) the seed mixture that included selected native species produced higher vegetation cover than a standard commercial seed mixture usually used in roadslope revegetation in semiarid Spain, dense enough to significantly reduce erosion risk and (2) the ecological and geomorphological advantages provided by the use of selected native species resulted in the reduction of their establishment cost to only twice that of using commercial species. These results should therefore encourage the application of the procedure proposed and the use of native species in revegetation projects of roadslopes as well as in other disturbed areas.

Implications for Practice

- Selection of suitable native species for restoration of roadslopes can be achieved in two steps: (1) identification and selection of spontaneous colonizers by means of flora surveys in an area with similar characteristics to the area that has to be restored and (2) experimental validation of the selected species at a small spatial scale with the technique that has to be used at a larger scale.
- An increased use of native species in restoration projects will increase their demand by road builders encouraging the investment in native plant cultivation by seed suppliers who will be in charge of seed collection and distribution. As a consequence, the price of seeds of native species will become more competitive.
- The common practice in roadslope revegetation to include in the commercial seed mixtures a small proportion of misleadingly called "native" species as an added environmental value is not a guarantee of restoration success. In this context, these species are usually called "native" because they belong to the national or regional flora, but they may not be adapted to the local limiting conditions of the area that has to be restored.

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