Roadfill Revegetation in Semiarid Mediterranean Environments. Part II: Topsoiling, Species Selection, and Hydroseeding

Jaume Tormo,[1,2] Esther Bochet,[1] and Patricio García-Fayos[1]

Abstract

Erosion is one of the main problems in roadfill restoration. Revegetation is widely used as a method to reduce erosion rates, and it is often carried out through hydroseeding. In semiarid Mediterranean conditions, this approach to revegetation often produces poor results due to climatic limitations. We evaluated whether (1) spreading topsoil and (2) hydroseeding with local rather than commercial species mixtures could improve the vegetative cover of roadfills. The study was carried out in 24 plots over a 20-month period. At the end of the study, vegetation cover was higher in topsoiled plots (38.8%) than in nontopsoiled plots (21.5%). Locally selected species produced higher vegetative cover (61.1%) than did standard commercial species (52.2%). After 20 months, the erosion index was not different among any treatment probably due to the low sensitivity of this variable. These results suggest that amendment of soils through the addition of topsoil is an important technique in roadfill revegetation in Mediterranean environments. Additionally, hydroseeding with local species will produce better vegetative cover on roadfills than does hydroseeding with available commercial species.

Key words: embankment, local species, public works, restoration, roadfill, seed bank, soil amendment.

Introduction

Road and railway construction significantly impacts soil and vegetation by moving large amounts of soil and underlying materials. Resulting roadfills that are built by accumulating and compacting materials from an adjacent area often present steep slopes and poorly consolidated soils that are very vulnerable to erosion (Arnáez & Larrea 1994; Navarro & Jonte 1996; Nicolau 2002). Erosion not only negatively affects roadfills but also has important consequences for associated infrastructure, including loss of structural support, sedimentation of adjacent areas, filling of roadbeds and dams, and initiation of landslides (Andrés & Jorba 2000; Navarro 2002).

Some authors have promoted passive restoration on the basis that spontaneous plant colonization through seed dispersal from nearby areas might produce high vegetation cover and good soil protection (Prach & Pysek 2001). However, under semiarid climate conditions, roadfills become less hospitable for plant colonization (Bochet & García-Fayos 2004). In these situations, spontaneous colonization is too slow to provide an effective vegetation cover to control soil erosion (Nicolau 1996), even though seed arrival to the slopes is not limited (Bochet et al. 2006).

[1]Centro de Investigaciones sobre Desertificación-CIDE (CSIC, UV, GV), Camí de la Marjal s/n, Apdo Oficial 46 470 Albal, Valencia, Spain.
[2] Address correspondence to J. Tormo, email jaume.tormo@uv.es

The success of spontaneous plant colonization in semiarid regions could potentially be improved through soil amendment techniques. The addition of topsoil, which has been previously stockpiled, facilitates vegetation establishment by improving physical or chemical soil properties (Cotts et al. 1991; Harwood et al. 1999; Balaguer 2002). At the same time, it provides a seed bank that can enhance spontaneous revegetation (Ward et al. 1996; Rokich et al. 2000; Holmes 2001).

Many more active restoration techniques, such as the use of geotextiles, blankets, and plants, have also been proposed for use in revegetation (Benik et al. 2003), but these techniques are too expensive to be used extensively in roadfills (Muzzi et al. 1997). More often, the revegetation of large and steep areas of soil is carried out by means of hydroseeding (Enríquez et al. 2004), which consists of projecting a seed mixture together with water, fertilizers, and other substances that improve soil properties to enhance the establishment of vegetation.

Hydroseeding has been widely used for the revegetation of roadfills in Spain for the past few decades. However, in semiarid Mediterranean conditions, this technique does not produce sufficiently dense vegetation cover (Muzzi et al 1997; Bochet & García-Fayos 2004). The species used in these sowings are generally not selected for local climatic conditions and are rarely adapted to Mediterranean semiarid environments with long periods of drought and erosive rains (Bochet & García-Fayos 2004). These environmental conditions become more pronounced in roadfills where soils have low fertility,

Table 1. Species compositions (% seed weight) of the commercial and the local seed mixtures applied used in the experimental hydroseeding.

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

superficial stoniness, and lack of structure (Jim 2001). In similar circumstances, some authors have highlighted the importance of using local species to ensure success of revegetation (Estarlich et al. 1995; Jusaitis & Pillman 1997; Kirmer & Mahn 2001; Montalvo et al. 2002).

In our study, we compare the relative effectiveness of topsoil spreading, hydroseeding with commercial species, and hydroseeding with selected local species on the revegetation of roadfills under semiarid conditions.

Study Area

The study area is located along the N-330 road in Utiel (eastern Spain, lat 39°29′N, long 1°06′W). The climate is semiarid Mediterranean, with mean annual temperature and precipitation of 12°C and 399 mm, respectively (Pérez 1994). Rainfall distribution is highly variable among and within years, generally with annual peaks in May and October. Calcareous marls and clays of tertiary origin are characteristic of the study area. Land use is dominated by vineyards and dry (nonirrigated) farming. Native vegetation is typical Mediterranean shrubland, but no large patches of intact native vegetation occur within at least 3 km of the study area.

Methods

Twenty-four plots (4 × 4 m each) were located on roadfills within a 1-km stretch of the same road to ensure similar lithologic and climatic conditions. Roadfill construction was completed in September 2003. All the roadfills were relatively homogeneous in slope length (between 12 and 15 m), and slope angle was 29°. Plots were all located in the middle part of the slope, approximately 4–5 m from the top of the slope. Plots were marked with iron nails and red ribbons in October 2003.

Six of the plots were randomly established in roadfills with no topsoil spreading. The rest of the plots were established in roadfills with topsoil spreading and randomly assigned to the following treatments (six plots per treatment): (1) hydroseeding with commercial species mixture (TS + ComMix); (2) hydroseeding with locally selected species (TS + SelMix); and (3) topsoiling with no hydroseeding (OnlyTS).

Selected plots included zones with and without spread topsoil. Spread topsoil came from vineyards near the road construction sites. As topsoil was stockpiled for less than 3 months and did not receive any treatment, we considered it to be "fresh."

The commercial species mixture consisted of a standard seed mixture widely used in the region and was provided by a local seed supplier (Intersemillas S.A., Quart de Poblet, Valencia, Spain) (Table 1). The locally selected seed mixture consisted of species identified in previous research (Tormo, unpublished data), which evaluated the colonization success of local species in the roadfills in the study area. Seeds of these 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. All species had germination rates higher than 80%, except *Agropyron cristatum* and *Onobrychis sativa* with more than 70% rate and *Diplotaxis erucoides* with more than 60% (data provided by the seed supplier and in Tormo et al. 2006). Both the commercial and the locally selected seed mixtures included 25 g/m^2 of seeds (i.e., the usual sowing application rate for roadfills in Spain), with 15 g/m^2 of short fiber wood mulch, 15 cm^3/m^2 of humic acids, and 50 g/m^2 of organic fertilizers. Experimental hydroseeding was carried out in November 2003 using conventional public works machinery to ensure the practical applicability of results.

To test the homogeneity of seed distribution during hydroseeding, four plastic containers (20 × 20 × 20 cm, open on the top) were placed in each plot to collect a sample of the sowed mixture. After hydroseeding, the contents of the containers were dried and seeds separated and weighed to determine the relative quantity of seeds that were sown in each plot.

Four soil samples, randomly taken from each plot with the topsoil treatment, were mixed and analyzed for aggregate stability, electrical conductivity, plant-available phosphorous, total organic matter, and total nitrogen. Chemical property analyses were carried out using the procedures published by Page et al. (1982), with the exception of electrical conductivity, which was measured according to the method proposed by Richards (1964). Aggregate stability was analyzed using the method described by Primo and Carrasco (1973).

To avoid edge effects, vegetation cover and soil erosion measurements were recorded only in the central 2 × 2–m area of the plots. Total vegetation cover for each species was calculated as the mean cover from a grid of four 1 × 1–m subplots. Visual cover estimates were made by two

Table 2. Mean ± SE of the soil properties in the NoTS and onlyTS plots.*

Soil Properties	*NoTS (n = 6)*	*OnlyTS (n = 4)*	*p value*
Organic matter (%)	1.21 ± 0.35	1.37 ± 0.25	0.157
Total nitrogen content (mg/g)	0.06 ± 0.00	0.10 ± 0.01	0.020
Available phosphorous content (mg P_2O_5/ 100 g soil)	0.54 ± 0.10	3.03 ± 0.83	0.057
Electrical conductivity (1:5) (μS/cm)	79.27 ± 2.87	113.28 ± 18.19	0.158
Aggregate stability (%)	4.63 ±0.20	6.88 ± 0.95	0.095

OnlyTS, only topsoiled plots; NoTS, nontopsoiled plots.
*The *p* values are for the *t* test between the two treatments.

observers; the maximum acceptable difference between the observers was 10%, otherwise the estimate was repeated. Partial vegetation covers attributable only to the sowed species were estimated during the study in the hydroseeded plots using the same method.

Soil erosion was estimated using a qualitative erosion index based on the proportion of the plot area affected by rills. This index varied between 0 and 4, where 0, no rills; 1, less than one-fourth of the subplot affected by rills; 2, between one-fourth and one-third of the subplot affected by rills; 3, between one-third and one-half of the subplot affected by rills; and 4, more than one-half of the subplot affected by rills (modified from González 1993). Estimates were made by two observers, as in the vegetation cover survey. An erosion index, ranging from 0 to 16, was calculated for each plot by summing the estimates for the four 1 × 1–m subplots.

Six surveys were carried out to assess the development of vegetation in the plots throughout the study. The erosion index was estimated only in the first and sixth survey. We first surveyed the plots 3 months after hydroseeding (16 Februrary 2004), when erosion risk was highest, to evaluate the capacity of the vegetation to quickly cover the roadfill and to protect the soil surface (Estarlich et al. 1995). Second and third surveys were carried out on 22 April 2004 and 26 June 2004, respectively. The fourth survey was carried out on 30 September 2004 to evaluate vegetative cover remaining after summer drought, which plays a crucial role in the protection of the soil against upcoming erosive autumn rains. Fifth (09 March 2005) and sixth (13 June 2005) surveys were aimed at evaluating the capacity of the plants to maintain their populations on the roadfills. The contribution of hydroseeded species to the total vegetative cover was evaluated only in the third and sixth surveys (26 June 2004 and 13 June 2005, respectively). Before the first survey, one of the TS + ComMix plots was damaged by road construction activities, which caused all statistical analyses (except hydroseeding homogeneity) to be unbalanced.

Because the treatments were not fully crossed, we analyzed the effect of topsoil spreading and hydroseeded mixtures separately. The comparisons were performed independently for each survey.

All the comparisons were performed using generalized linear models with a quasipoisson error distribution. The Fisher statistic was used for the deviance comparison. Comparisons between hydroseeding treatments and topsoiled plots were carried out using the estimated standard errors for *t* tests (Crawley 1993). All statistical analyses were performed using R v.1.8.1 software (R Development Core Team 2005).

Results

Soil Properties

The properties of added topsoil were not clearly different from those of the parent material. Only the soil nitrogen content was different between the soils of plots with topsoil addition without seeding and those without topsoil addition (Table 2).

Sowing Homogeneity

Mean seed densities of sowed species in the plastic containers were 23.48 ± 8.00 g of seeds/m^2 for the commercial mixture and 30.85 ± 17.30 g of seeds/m^2 for the locally selected species mixture. These results were not significantly different ($t = 0.947$, $df = 10$, $p = 0.366$). Moreover, there was no correlation between the density of seeds sowed and the vegetative cover in the plots at the first survey ($r^2 = 0.123$, $df = 9$ $p = 0.291$), regardless of hydroseeding mixture. This indicates that possible differences in plant cover between hydroseeding treatments should be only attributed to the species composition of the seed mixtures.

Vegetation Cover

Topsoil spreading had a direct influence on the cover of vegetation. Plots with topsoil addition had greater vegetative cover than nontopsoiled plots during all surveys, with significant differences ($p < 0.05$) occurring in all, except the fourth survey. In this survey, although the data followed the same trend as in other surveys, vegetative cover of nontopsoiled plots increased slightly because of the presence of big but ephemeral forbs during the summer (Fig. 1). These forbs were not present during subsequent surveys.

Hydroseeded plots, regardless of the seed mixture used, reached more than 50% vegetative cover 5 months after treatment and continued to support significantly greater cover throughout the study than the plots without additional seeding (Fig. 2).

Only in the first survey did the use of locally selected seed mix produced (Fig. 2) more total vegetative cover than did the use of a commercial seed mixture; otherwise the cover of vegetation was the same, regardless of the seed source. However, the partial cover provided by the hydroseeded species included in the locally selected seed mixture was more than the cover of the hydroseeded species in the commercial seed mix (Table 3).

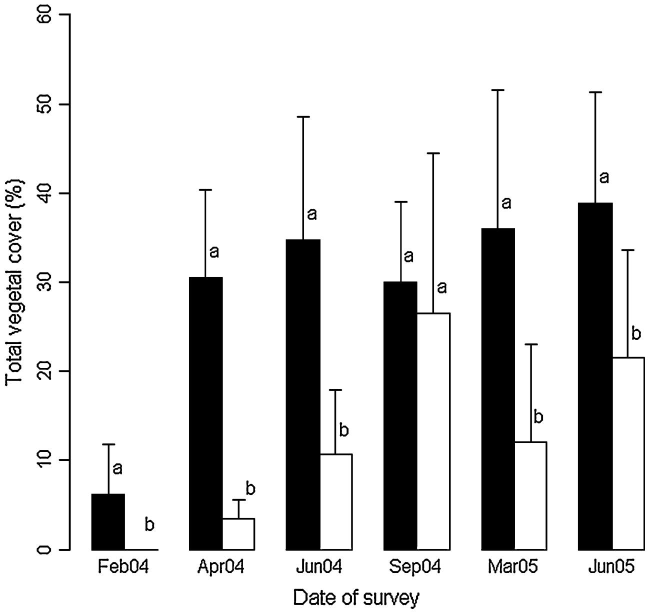

Figure 1. Mean ± SE of total vegetation cover (%) in only topsoiled plots (black bars) and nontopsoiled plots (white bars). Bars with different letters are significantly different within surveys, $p < 0.05$.

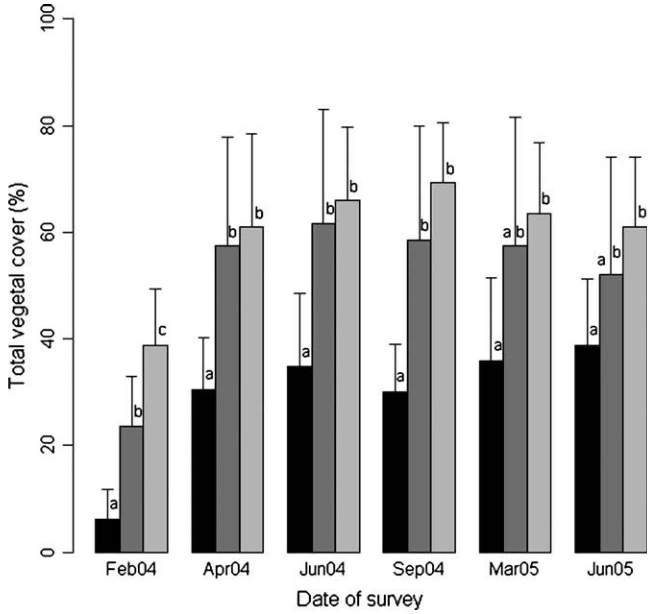

Figure 2. Mean ± SE of total vegetation cover (%) in only topsoiled plots (black bars), also shown for topsoiled plus commercial seed mix (dark gray bars) and topsoiled plus selected seed mix (light gray bars). Bars with different letters are significantly different within surveys, $p < 0.05$.

Erosion

Plots with only topsoil spreading became less prone to erosion between the first and the last survey than did the nontopsoiled plots (Fig. 3); however, these differences were not significant ($F_{[1,10]} = 3.199$, $p = 0.104$).

The increase in value of the erosion index in the plots hydroseeded with a selection of local species was the lowest of the studied plots, but the differences were not statistically significant in any case.

Discussion

Hydroseeding produced higher vegetative cover than did just the use of topsoil; however, the use of topsoil resulted in higher vegetative cover than no site treatment. The low vegetative cover in the untreated plots indicates that without restoration measures, natural colonization in semiarid roadfills takes place slowly (Bochet et al. 2006). Consequently, active restoration seems to be essential for enhancement of the establishment of vegetation in these environments.

Some studies have found that the time period immediately after roadfill construction is critical for restoration success (Estarlich et al. 1995). In our study, although precipitation during the germination period (from November 2003 to February 2004) was less than half of the mean value (59 vs. 135 mm; Pérez 1994), hydroseeded plots quickly reached more than 50% vegetative cover. This is higher than that necessary for slope stabilization in the soil erosion or vegetation cover curves described for highly erosion-sensitive slopes in the region (Calvo et al. 1992). Whereas the cover provided by vegetation in the treated plots (only topsoiled or topsoiled and hydroseeded) was relatively stable, vegetative cover of untreated plots was highly variable over time, with ephemeral plants providing protection to the soil only occasionally.

In Mediterranean habitats, the summer drought preceding the autumn erosive rainfalls is a critical time for revegetation projects. Our study showed no significant decrease in vegetative cover after the summer season, in either the hydroseeded plots or the plots with only topsoil spreading. Both approaches seem to be successful in providing vegetative cover in the most critical period.

In previous studies, topsoil spreading improved vegetation cover in two ways: by improving soil properties (Cotts et al. 1991; Harwood et al. 1999; Balaguer 2002) and by providing a soil seed bank (Ward et al. 1996; Rokich et al. 2000; Holmes 2001). In our study, the differences in soil properties (except nitrogen content) between the topsoiled and the nontopsoiled plots were low and not significant. We can then conclude that the main contribution of the topsoil was the soil seed bank.

Table 3. Mean ± SE of the vegetative cover (%) found on plots sowed with the commercial and the local seed mixtures in the third and six surveys.

	Seed Mixture			
Survey Date	*Commercial*	*Local*	*F values*	*p values*
26 June 2004	17.95 ± 12.84	**2.35 ± 0.99**	31.330	0.001
13 June 2005	**69.95 ± 13.87**	47.64 ± 13.71	111.920	0.001

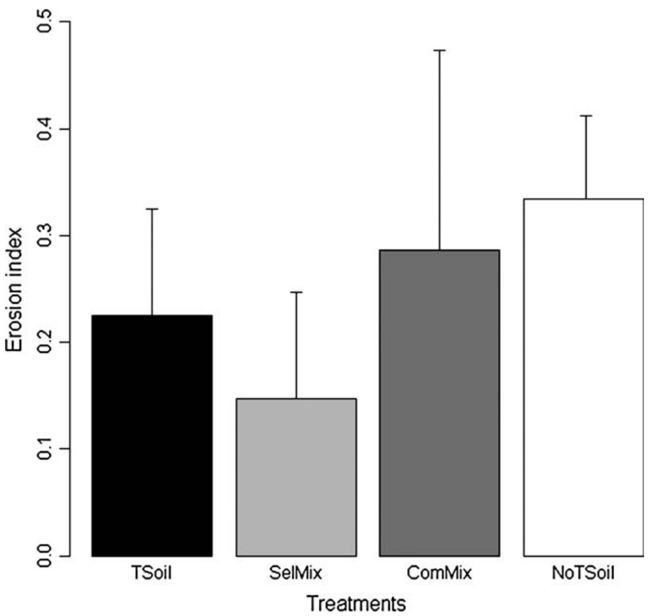

Figure 3. Mean ± SE of the erosion index change in the four treatments between the first and the last survey (20 months). OnlyTS, only topsoiled plots; TS + SelMix, topsoiled plots sown with commercial seed mixture; TS + ComMix, topsoiled plots sown with local selected seed mixture; and NoTS, plots without treatment.

Plots hydroseeded with commercial seed mixture reached total vegetative cover similar to those sowed with the locally selected species mixture. However, this similarity disappeared when cover of the sowed species was examined instead of total cover. In this case, vegetative cover of the locally selected species mixture was as much as three times (in third survey) and 20 times (in sixth survey) higher than that of the commercial species mixture. Total vegetative cover of the hydroseeded plots decreased with time, but cover of the locally selected species remained above 45%, whereas that of the commercial species almost disappeared at the end of the study period. These results indicate that species selection is an important step in revegetation planning in semiarid or other stressful habitats (Siniscalco et al. 1998).

Our results support the conclusions of Elmarsdottir et al. (2003), who proposed the use of fertilization as a simple reclamation approach for native plant communities. At the end of the season, plots hydroseeded with a commercial seed mixture had greater vegetative cover than did those with only an addition of topsoil, despite the fact that most commercial species were providing no cover at this point in the study. This suggests that amendments included in the hydroseeding play an important role in revegetation. Hydroseeding mixtures provide fertilizers and mulch that improve soil properties (Albaladejo et al. 2000; Holmes 2001) and consequently enhance plant establishment and growth for the species contained in the topsoil seed bank (Sheldon & Bradshaw 1977) and for those whose seeds arrived from adjacent areas (Bochet et al. 2006).

In our study case, hydroseeding was spread over a layer of fresh topsoil previously stockpiled for less than 3 months, which contained an important seed bank (as shown by the relatively high vegetative cover obtained in the plots with only topsoil addition). However, when topsoil is stockpiled for longer periods, the seed bank could be depleted and seed supplementation could be necessary (Rokich et al. 2000).

Erosion could have occurred before or during hydroseeding, which would have influenced erosion estimations. To control for this effect, we only used the increase in erosion index from the first to the last control surveys.

No significant differences were found among treatments in relation to the increase in erosion index. This lack of difference could be due to the low sensitivity of the index, which was originally developed for larger plots at the hillslope scale.

Implications for Practice

In semiarid environments, our work has the following implications for the restoration of roadfills:

- No sowing of seed is necessary if the topsoil with a rich seed bank is available.
- However, the addition of fertilizers and other amendments will improve revegetation success by improving the soil properties and by enhancing germination from the topsoil seed bank.
- If no topsoil is available, or its seed bank has been depleted, then addition of seed by means of hydroseeding or other techniques will improve the results.
- Vegetative cover will be improved if the seeds used in revegetation projects are those that establish well in the local conditions and are collected from local populations.

Acknowledgments

We thank the Spanish “Plan Nacional I+D+I del Ministerio de Ciencia y Tecnología” (project REN2001-2313), “Consejo superior de Investigaciones Científicas,” and “Fundación Bancaja” for their funding. We also thank José Antonio Bellido for his assistance in hydroseeding; the staff of the laboratories of the Centro de Investigaciones sobre Desertificación for soil analyses; two anonymous referees for their considerable help in improving the article; and Cynthia Jones and Jenny Brown for language editing.

LITERATURE CITED

Albaladejo, J., J. Alvarez, J. Querejeta, E. Díaz, and V. Castillo. 2000. Three hydro-seeding revegetation techniques for soil erosion control on anthropic steep slopes. Land Degradation & Development **11:**315–325.

Andrés, P., and M. Jorba. 2000. Mitigation strategies in some motorway embankments (Catalonia, Spain). Restoration Ecology **8:**268–275.

Arnáez, J., and V. Larrea. 1994. Erosion models and hydrogeomorphological functioning on hill-roads (Iberian System, La-Rioja, Spain). Zeitschrift Fur Geomorphologie **38:**343–354.

Balaguer, L. 2002. Las limitaciones de la restauración de la cubierta vegetal. Ecosistemas XI:1 (available from http://www.revistaecosistemas.net).

Benik, S. R., B. N. Wilson, D. D. Biesboer, B. Hansen, and D. Stenlund. 2003. Performance of erosion control products on a highway embankment. Transactions of the American Society of Agricultural Engineers **46:**1113–1119.

Bochet, E., and P. García-Fayos. 2004. Factors controlling vegetation establishment and water erosion on motorway slopes in Valencia, Spain. Restoration Ecology **12:**166–174.

Bochet, E., J. Tormo, and P. García-Fayos. 2007. Road slope revegetation in semiarid Mediterranean environments. Part I: seed dispersal and spontaneous colonization. Restoration Ecology **15:**88–96.

Calvo, A., A. M. Harvey, J. Payá, and R. W. Alexander. 1992. Response of badland surfaces in southeast Spain to simulated rainfall. Quaternary Geomorphology **5:**3–14.

Cotts, N. R., E. F. Redente, and R. Schiller. 1991. Restoration methods for abandoned roads at lower elevations in Grand-Teton National-Park, Wyoming. Arid Soil Research and Rehabilitation **5:**235–249.

Crawley, M. J. 1993. GLIM for ecologists. Blackwell, Oxford, United Kingdom.

Elmarsdottir, A., A. L. Aradóttir, and M. J. Trlica. 2003. Microsite availability and establishment of native species on degraded and reclaimed sites. Journal of Applied Ecology **40:**815–823.

Enríquez, A., M. J. Carrasco, and J. M. Varela. 2004. Seguimiento de la eficacia de la restauración vegetal de los taludes de autovías. Ingeniería Civil **134:**27–35.

Estarlich, E., A. J. Hernandez, L. Aranda, and J. Pastor. 1995. Estudio de los factores edáficos relacionados con la erosión y escorrentía en taludes de fuerte pendiente; ensayos de revegetación. Boletín de la Sociedad Española de la Ciencia del Suelo **2:**161–167.

González, M. 1993. Erosión real y potencial. Principales métodos para su estimación. Montes **34:**31–40.

Harwood, M. R., J. B. Hacker, and J. J. Mott. 1999. Field evaluation of seven grasses for use in the revegetation of lands disturbed by coal mining in Central Queensland. Australian Journal of Experimental Agriculture **39:**307–316.

Holmes, P. M. 2001. Shrubland restoration following woody alien invasion and mining: Effects of topsoil depth, seed source, and fertilizer addition. Restoration Ecology **9:**71–84.

Jim, C. Y. 2001. Ecological and landscape rehabilitation of a quarry site in Hong Kong. Restoration Ecology **9:**85–94.

Jusaitis, M., and A. Pillman. 1997. Revegetation of waste fly ash lagoons. 1. Plant selection and surface amelioration. Waste Management & Research **15:**307–321.

Kirmer, A., and E. Mahn. 2001. Spontaneous and initiated succession on unvegetated slopes in the abandoned lignite-mining area of Goitsche, Germany. Applied Vegetation Science **4:**19–27.

Montalvo, A. M., P. A. McMillan, and E. B. Allen. 2002. The relative importance of seeding method, soil ripping, and soil variables on seeding success. Restoration Ecology **10:**52–67.

Muzzi, E., F. Roffi, M. Sirotti, and U. Bagnaresi. 1997. Revegetation techniques on clay soil slopes in northern Italy. Land Degradation & Development **8:**127–137.

Navarro, J. 2002. Control de la erosión en desmontes originados por obras de infraestructura viaria: aplicación al entorno de Palencia capital. Ph.D. dissertation. Universidad Politécnica de Madrid, Escuela Técnica Superior de Ingenieros de Montes, Madrid, Spain.

Navarro, J., and M. A. Jonte. 1996. La erosión hídrica en los desmontes de la N-610 y N-611 en la circunvalación de la ciudad de Palencia. Rutas **54:**35–42.

Nicolau, J. M. 1996. Rainfall erosion on surface coal mine spoil banks in Mediterranean environment. European Conference & Trade Exposition on Erosion Control. Barcelona, Spain, 29–31 May 1996. International Erosion Control Association.

Nicolau, J. M. 2002. Runoff generation and routing on artificial slopes in a Mediterranean-continental environment: the Teruel coalfield, Spain. Hydrological Processes **16:**631–647.

Page, A. L., R. H. Mille, and D. R. Keeney. 1982. Methods of soil analysis. Part 2. Chemical and microbiological properties. American Society of Agronomy—Soil Science Society of America, Madison, Wisconsin.

Pérez, A. 1994. Atlas Climatic De La Comunitat Valenciana. 345. Conselleria d'obres publiques urbanisme i transports, Valencia, Spain.

Prach, K., and P. Pysek. 2001. Using spontaneous succession for restoration of human-disturbed habitats: experience from Central Europe. Ecological Engineering **17:**55–62.

Primo, E., and M. J. Carrasco. 1973. Química agrícola I: Suelos y fertilizantes. Alambra, Madrid, Spain.

R Development Core Team. 2005. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3–900051–07–0 (available from http://www.R-project.org).

Richards, L. A. 1964. Diagnosis and improvement of saline and alkali soils. Agricultural Handbook 60, USDA, Washington, D.C.

Rokich, D. P., K. W. Dixon, K. Sivasithamparam, and K. A. Meney. 2000. Topsoil handling and storage effects on woodland restoration in Western Australia. Restoration Ecology **8:**196–208.

Sheldon, J. C., and A. D. Bradshaw. 1977. Development of a hydraulic heeding technique for unstable sand slopes 1. Effects of fertilizers, mulches and stabilizers. Journal of Applied Ecology **14:**905–918.

Siniscalco, C., A. Reyneri, A. Ciotti, A. Peyron, and S. Pala. 1998. Use of wild plant herbaceous species for revegetation. Acta Horticulturae **457:**371–378.

Tormo, J., E. Bochet, P. García-Fayos. 2006. Is seed availability enough to ensure colonization success? An experimental study in road embankments. Ecological Engineering **26:**224–230.

Ward, S. C., J. M. Koch, and G. L. Ainsworth. 1996. The effect of timing of rehabilitation procedures on the establishment of a jarrah forest after bauxite mining. Restoration Ecology **4:**19–24.