HYDROSEEDING FOR RESTORING DEGRADED SEMI-ARID MEDITERRANEAN ENVIRONMENTS: A REVIEW OF CHALLENGES

Houssam Shaiban [1], Carla Khater[2*], Johnny Fenianos[2, 3], Thierry Dutoit[1]
[1]Avignon University, Aix Marseille University, CNRS, IRD, IMBE, IUT site Agroparc, 337 Chemin des Meinajariés BP 61207, F-84911 Avignon cedex 09, France.
[2]Center for Remote Sensing- National Council for Scientific Research Lebanon. Bir Hassan- BP 11-8281 Riad El Solh, Beirut-Lebanon.
[3]University Paul Valéry, Laboratoire Epsylon, Montpellier, 34199- France.
Corresponding author: Dr. Carla Khater
Carla.khater@cnrs.edu.lb.com

(Received November 2019 – Accepted March 2021)

ABSTRACT

Shaiban, H., Khater, C., Fenianos, J. & Dutoit, Th. (2021). Hydroseeding for Restoring Degraded Semi-Arid Mediterranean Environments: A Review of Challenges. *Lebanese Science Journal,* 22(1), 38-67.

Hydroseeding is a restoration technique commonly used in varied restoration projects. This literature review, encompassing about 100 published research papers from 1990 to 2020, revealed numerous limitations in a semi-arid Mediterranean environment. Challenges facing hydroseeding as a restoration tool in semi-arid Mediterranean environments were evaluated by analyzing different factors affecting ecological and technical levels. This issue was approached by sorting variables under either biotic or abiotic factors, further sub-dividing them under either natural-environmental or human-influenced factors. The review highlighted several constraints when applying hydroseeding techniques in a semi-arid Mediterranean environment: Slope steepness, slope aspect, high water runoff, low presence of water, mixing solutions used, and high cost for applying this technique are some of those constraints facing its success. Other shortcomings are related to the low success rate of commercial seed mixtures under harsh conditions, and their tendency to compete with native species. Moreover, the review provided recommendations to increase hydroseeding success by using varied techniques such as topsoil spreading, using native seeds, Mycorrhizal, or Rhizobium inoculation, and the use of nurse plants. Furthermore, environmental psychology approach was suggested as means to convey a better message and increase acceptability towards improved innovative suggestions.

Keywords: abiotic, biotic Factors, Limitations, success, failures, restoration techniques

http://dx.doi.org/10.22453/LSJ-022.1.038-067

lsj.cnrs.edu.lb/vol-22-no-1-2021/

INTRODUCTION

Vegetation is a cornerstone of natural ecosystems. It is not only an essential habitat for different living species but also carries ecosystem services and functions such as nutrient cycling, soil protection, water purification, etc. (Hölzel *et al*., 2012). Numerous factors lead to ecosystem degradation and surface modifications with irreversible loss of soils via removal of upper soil, sedimentation, or salinization, etc. Whenever a certain threshold level is crossed, it cannot reverse back without interventional correction to alternate what led to that threshold being crossed (Aronson *et al*., 1993). This fact is especially valid for semi-arid Mediterranean ecosystems, where natural recovery after the disturbance has been recognized to be harder than other ecosystem types (Blondel *et al*., 2010). In such conditions, ecological restoration techniques are required to initiate, assist, and accelerate recovery of degraded ecosystems with respect to their structure, functional properties, and exchanges with surrounding landscapes (Society for Ecological Restoration [SER], 2004). Restoration is not easy and straightforward because of several factors restricting its success, such as abiotic and biotic constraints (Bakker and Berendse, 1999).

One important restoration technique applied to reintroduce vegetation is manual seeding, where seeds are hand spread with no specialized equipment. Such a manual method is suitable only for small areas (MacDonald *et al*., 2015). Drill seeding is another practice that involves seed application, utilizing conventional agricultural equipment below the soil surface. This practice is limited to relatively flat and well-groomed sites (MacDonald *et al*., 2015). Hydroseeding is another commonly used technique (Figure 1), especially on steep slopes and inaccessible regions (Davy, 2002). The process consists of mixing cellulose fiber, mulch, seeds, and later adding water into the tank and spraying the degraded area (Martin *et al*., 2002). Although used worldwide (more than 12 million km length of road networks in the United States, Europe, Japan, and Australia - http://www.piarc.org), hydroseeding has variable outcomes.

http://dx.doi.org/10.22453/LSJ-022.1.038-067

lsj.cnrs.edu.lb/vol-22-no-1-2021/

Figure 1. Utilizing hydroseeding technique as a restoration tool on a steep road cut slope.

The Mediterranean region (Figure 2) covers about 850 million hectares in 22 countries across Southern Europe, the Middle-East, and North Africa (Zdruli, 2014). In this vast region, hydroseeding as a restoration tool is increasingly applied (Andre's *et al*., 1996; Albaladejo *et al*., 2000; Matesanz *et al*., 2006; Tormo *et al*., 2007). A study from around the Mediterranean Basin, spanning over sixteen countries, surveyed 36 implemented restoration projects revealed that 17% of the total executed restoration projects were undertaken through hydroseeding practices and were carried out on post-industrial sites (mining), infrastructure development, deforestation, and drought sites (Nunes *et al*., 2016). In several cases, poor results in plant performance have been measured (Matesanz *et al*. 2006). Several direct and indirect variables determine the effectiveness of hydroseeding in semi-arid Mediterranean environments. This assessment should cover varied factors such as soil conditions, topography, season, climate, vegetation types, water availability, vulnerable or sensitive surrounding areas, and maintenance requirements. Once identified, those factors could be manipulated to improve restoration efforts (Tormo *et al*., 2008).

http://dx.doi.org/10.22453/LSJ-022.1.038-067

Figure 2. The Mediterranean Basin with its 22 bordering countries.

Successful restoration results from a combination of ecologically sound projects that are technically possible, financially feasible, and are socially acceptable (Khater, 2015). Hölzel *et al*. (2012) distinguished various factors affecting ecological restoration under three major headings: starting conditions, abiotic factors, and biotic factors. This paper presents a review of more than 100 research papers published between 1990 and 2020, reporting the success and failure of hydroseeding as a restoration technique for large-scale projects. It analyzes the reported cases in view of biotic and abiotic factors potentially affecting restoration success and differentiates between nature-based and human-related variables.

METHODS

The different variables affecting hydroseeding successes and failures in a semi-arid Mediterranean environment were assessed through exploiting diverse search engines (Google Scholars, Web of science, summon 2.0), searching in the title, abstract, and keywords of papers the following terms: “hydroseeding” plus “semi-arid Mediterranean environment” plus “cultural practices”, “microclimate”, “nurse plants”, “seed type/ competition/ inoculation”, “slope aspect/ steepness”, “soil addition/ mulching”, or “mixing solutions”(See Table 1).

Table 1. Primary and secondary keywords used to filter and select the papers used in the methodology.

Primary Search Key Words	Secondary Search Key Words	Author(s)	Title	Year of Publication
Hydroseeding Semi-arid	**History/procedures**	Albaladejo Montoro, J. Alvarez Rogel, J. Querejeta, J	Three hydro-seeding revegetation techniques	2000

http://dx.doi.org/10.22453/LSJ-022.1.038-067
National Council for Scientific Research – Lebanon 2018©
lsj.cnrs.edu.lb/vol-22-no-1-2021/

Mediterranean environment			for soil erosion control on anthropic steep slopes.	
		Andres, P. Zapater, V. Pamplona, M.	Stabilization of motorway slopes with herbaceous cover, Catalonia, Spain. Restoration Ecology 4:51- 60	1996
		Hölzel, N. Buisson, E. Dutoit, T.	Species introduction–a major topic in vegetation restoration.	2012
		Khater, C.	L’écologie appliquée : une responsabilité scientifique au carrefour de l’interdisciplinarité.	2015
		Matesanz, S. Valladares F. Tena D. Costa-Tenorio M. Bote D.	Early dynamics of plant communities on revegetated motorway slopes from Southern Spain: is hydroseeding always needed?	2006
		Mola, I. Jiménez, MD. López-Jiménez, N. Casado, MA. Balaguer, L.	Roadside reclamation outside the revegetation season: management options under schedule pressure.	2011
		Nunes, A. Oliveira, G. Mexia, T. Valdecantos, A. Zucca, C. Costantini, EA. Abraham, EM. Kyriazopoulos, AP. Salah, A. Prasse, R. Correia, O.	Ecological restoration across the Mediterranean Basin as viewed by practitioners.	2016
		Tormo, J. García-Fayos, P. Bochet, E.	Relative importance of plant traits and ecological filters in road embankment revegetation under semiarid Mediterranean conditions.	2008
		Zdruli, P.	Land resources of the Mediterranean: status, pressures, trends, and	2014

			impacts on future regional development.	
	Aftercare measures	Andres, P. Zapater, V. Pamplona, M.	Stabilization of motorway slopes with herbaceous cover, Catalonia, Spain.	1996
		Blondel, J., Aronson, J., Bodiou, J.Y. and Boeuf, G.	The Mediterranean region: biological diversity in space and time.	2010
	Nurse plants	Padilla, FM. and Pugnaire, FI.	The role of nurse plants in the restoration of degraded environments.	2006
		Skousen, JG. Zipper, CE.	Reclamation Guidelines for Surface-Mined Land: Revegetation Species and Practices.	2010
		Zelnik, I. Šilc, U. Čarni, A. Košir, P.	Revegetation of motorway slopes using different seed mixtures.	2010
	Water	Bochet, E. and García-Fayos, P.	Factors controlling vegetation establishment and water erosion on motorway slopes in Valencia. Spain.	2004
		Bochet, E. García-Fayos, P. Alborch, B. Tormo, J.	Soil water availability effects on seed germination account for species segregation in semiarid roadslopes.	2007a
		Bochet, E. García-Fayos, P. Poesen, J.	Topographic thresholds for plant colonization on semi-arid eroded slopes.	2009
		Bochet, E. García-Fayos, P. Tormo, J.	How can we control erosion of roadslopes in semiarid mediterranean areas? Soil improvement and native plant establishment.	2010a
		Cerdà, A.	Soil water erosion on road embankments in Eastern Spain.	2007

		Cerdà, A. and García-Fayos, P.	The influence of slope angle on sediment, water and seed losses on badland landscapes.	1997
		García-Fayos, P. García-Ventoso, B. Cerdà, A.	Limitations to plant establishment on eroded slopes in Southeastern Spain.	2000
		García-Palacios, P. Soliveres, S. Maestre, FT. Escudero, A. Castillo-Monroy, AP. Valladares, F.	Dominant plant species modulate responses to hydroseeding, irrigation, and fertilization during the restoration of semiarid motorway slopes.	2010
		Josa, R. Jorba, M. Vallejo, VR.	Opencast mine restoration in a Mediterranean semi-arid environment: failure of some common practices.	2012
		Tormo, J. Bochet, E. García-Fayo, P.	Is seed availability enough to ensure colonization success? An experimental study in road embankments.	2006
		Vallone, M. Pipitone, F. Alleri, M. Febo, P. Catania, P.	Hydroseeding Application on Degraded Slopes in the Southern Mediterranean Area (Sicily).	2013
		Wainwright, J.	Anthropogenic factors in the degradation of semiarid regions: a prehistoric case study in Southern France.	1994
	Soil addition	Albaladejo Montoro, J. Alvarez Rogel, J. Querejeta, J.	Three hydro-seeding revegetation techniques for soil erosion control on anthropic steep slopes.	2000
		Balaguer, L.	Las limitaciones de la restauración de la cubierta vegetal.	2002

http://dx.doi.org/10.22453/LSJ-022.1.038-067

		Bochet, E. and García-Fayos, P.	Factors controlling vegetation establishment and water erosion on motorway slopes in Valencia. Spain.	2004
		Brofas, G. Mantakas, G. Tsagari, K. Stefanakis, M. Varelides, C.	Effectiveness of cellulose, straw and binding materials for mining spoils revegetation by hydro-seeding, in Central Greece.	2007
		Gomez, JA. Rodríguez, A. Viedma, A. Contreras, V. Vanwalleghem, T. Taguas, EV. Giráldez, JV.	Evaluation of different techniques for erosion control on different roadcuts in its first year of implantation.	2014
		Hallock, BG. Power, A. Rein, S. Curto, M. Scharff, M.	Analysis of Compost Treatments to Establish Shrubs and Improve Water Quality.	2006
		Jimenez, MD. Ruiz-Capillas, P. Mola, I. Pérez-Corona, E. Casado, MA. Balaguer, L.	Soil development at the roadside: a case study of a novel ecosystem.	2013
		Merlin, G. Di Gioia, L. Goddon, C.	Comparative study of the capacity of germination and adhesion of various hydrocolloids used for revegetalization by hydroseeding.	1999
		Moreno de las Heras, M. Nicolau, JM. Espigares, T.	Vegetation succession in reclaimed coal-mining slopes in a Mediterranean-dry environment.	2008
		Rivera, D. Jáuregui, BM. Peco, B.	The fate of herbaceous seeds during topsoil stockpiling: restoration potential of seed banks.	2012

http://dx.doi.org/10.22453/LSJ-022.1.038-067

		Simón-Torres, M. del Moral-Torres, F. de Haro-Lozano, S. Gómez-Mercado, F.	Restoration of dump deposits from quarries in a Mediterranean climate using marble industry waste.	2014
		Tormo, J. Bochet, E. García-Fayos, P.	Roadfill Revegetation in Semiarid Mediterranean Environments. Part II: Topsoiling, Species Selection, and Hydroseeding.	2007
	Microenvironment	Elmarsdottir, A. Aradottir, AL. Trlica, MJ.	Microsite availability and establishment of native species on degraded and reclaimed sites.	2003
		Tormo, J. Bochet, E. García-Fayo, P.	Is seed availability enough to ensure colonization success? An experimental study in road embankments.	2006
	Seed type/competition/ inoculation/ aqueous solutions	Andres, P. and Jorba, M.	Mitigation strategies in some motorway embankments (Catalonia, Spain).	2000
		Begon, M., Harper, J.L. & Townsend, C.R.	Ecology: From Individuals to Ecosystems.	1996
		Bochet, E. Tormo, J. García-Fayos, P.	Native species for roadslope revegetation: selection. validation, and cost effectiveness.	2010b
		Boscutti, F. Vianello, A. Bozzato, F. Casolo, V.	Vegetation structure, species life span, and exotic status elucidate plant succession in a limestone quarry reclamation.	2016
		Bradshaw, A.D.	The reclamation of derelict land and the ecology of ecosystems.	1987

http://dx.doi.org/10.22453/LSJ-022.1.038-067

lsj.cnrs.edu.lb/vol-22-no-1-2021/

		Catania, P. Salvia, M. Vallone, M.	Hydroseeding for revegetation in a semiarid Mediterranean environment. In Structures and Environmental Technologies.	2012
		Clemente, AS. Moedas, AR. Oliveira, G. Martins-Loução, MA. Correia, O.	Effect of hydroseeding components on the germination of Mediterranean native plant species.	2016
		Engelbrecht, M. and García-Fayos, P.	Mucilage secretion by seeds doubles the chance to escape removal by ants.	2012
		Estaun, V. Vicente, S. Calvet, C. Camprubi, A. Busquets, M.	Integration of arbuscular mycorrhiza inoculation in hydroseeding technology: effects on plant growth and inter-species competition.	2007
		González-Alday, J. Marrs, RH. Martínez-Ruiz, C.	Soil seed bank formation during early revegetation after hydroseeding in reclaimed coal wastes.	2009
		Khater, C. and Martin, A.	Application of restoration ecology principles to the practice of limestone quarry rehabilitation in Lebanon.	2007
		Khater, C. Martin, A. Maillet, J.	Spontaneous vegetation dynamics and restoration prospects for limestone quarries in Lebanon.	2003
		Maestre, FT. Bowker, MA. Cantón, Y. Castillo-Monroy, AP. Cortina, J. Escolar, C. Escudero, A. Lázaro, R. Martínez, I.	Ecology and functional roles of biological soil crusts in semi-arid ecosystems of Spain.	2011

		Martin, A. Khater, C. Mineau, H. Puech, S.	Rehabilitation ecology by revegetation. Approach and results from two Mediterranean countries.	2002
		Martínez-Ruiz, C. Fernandez-Santos, B. Putwain, PD. Fernández-Gómez, MJ.	Natural and man-induced revegetation on mining wastes: changes in the floristic composition during early succession.	2007
		Matesanz, S. and Valladares, F.	Improving revegetation of gypsum slopes is not a simple matter of adding native species: Insights from a multispecies experiment.	2007
		Merlin, G. Di Gioia, L. Goddon, C.	Comparative study of the capacity of germination and adhesion of various hydrocolloids used for revegetalization by hydroseeding.	1999
		Miller, RM. and Jastrow, DJ.	The application of VA mycorrhizae to ecosystem restoration and reclamation.	1992
		Navas, M. and Moreau-Richard, J.	Can traits predict the competitive response of herbaceous Mediterranean species?	2005
		Oliveira, G. Clemente, A. Nunes, A. Correia, O.	Limitations to recruitment of native species in hydroseeding mixtures.	2013
		Oliveira, G. Clemente, A. Nunes, A. Correia, O.	Suitability and limitations of native species for seed mixtures to re-vegetate degraded areas.	2014
		Oliveira, G. Nunes, A. Clemente, A. Correia, O.	Testing Germination of Species for Hydroseeding Degraded Mediterranean Areas.	2012

http://dx.doi.org/10.22453/LSJ-022.1.038-067

		Peco, B. Ortega, M. Levassor, C.	Similarity between seed bank and vegetation in Mediterranean grassland: a predictive model.	1998
		Pywell, R.F., Bullock, J.M., Roy, D.B., Warman, L.I.Z., Walker, K.J. and Rothery, P	Plant traits as predictors of performance in ecological restoration.	2003
		Steinfeld, DE. Riley, SA. Wilkinson, K M. Landis, TD. Riley, LE.	Roadside revegetation: an integrated approach to establishing native plants.	2007
		Tormo, J. García-Fayos, P. Bochet, E.	Relative importance of plant traits and ecological filters in road embankment revegetation under semiarid Mediterranean conditions.	2008
	Slope aspect/steepness	Andres, P. Zapater, V. Pamplona, M.	Stabilization of motorway slopes with herbaceous cover, Catalonia, Spain. Restoration Ecology 4:51- 60	1996
		Ballesteros, M. Cañadas, EM. Marrs, RH. Foronda, A. Martín-Peinado, FJ. Lorite, J.	Restoration of gypsicolous vegetation on quarry slopes: guidance for hydroseeding under contrasting inclination and aspect.	2017
		Bochet, E. and García-Fayos, P.	Factors controlling vegetation establishment and water erosion on motorway slopes in Valencia. Spain.	2004
		Bochet, E. García-Fayos, P. Poesen, J.	Topographic thresholds for plant colonization on semi-arid eroded slopes.	2009
		Bochet, E. García-Fayos, P. Tormo, J.	Road slope revegetation in semiarid Mediterranean environments. Part I: seed	2007b

http://dx.doi.org/10.22453/LSJ-022.1.038-067

			dispersal and spontaneous colonization.	
		Cano, A. Navia, R. Amezaga, I. Montalvo, J.	Local topoclimate effect on short-term cutslope reclamation success.	2002
		Cerdà, A. and García-Fayos, P.	The influence of slope angle on sediment, water and seed losses on badland landscapes.	1997
		Dubayah, R.C.	Modeling a solar radiation topoclimatology for Rio Grande River Basin.	1994
		García-Fayos, P. and Cerdà, A.	Seed losses by surface wash in degraded Mediterranean environments.	1997
		González-Alday, J. Marrs, RH. Martínez-Ruiz, C.	The influence of aspect on the early growth dynamics of hydroseeded species in coal reclamation areas.	2008
	Socio-economic factors	Bochet, E. Tormo, J. García-Fayos, P.	Native species for roadslope revegetation: selection, validation, and cost effectiveness.	2010b
		Fenianos, J. Khater, C. Viglione, J. Brouillet, D.	Bridging nature and human priorities in ecological rehabilitation projects - a show case from Mediterranean environment - Qattine, Lebanon.	2017
		Martin, A. Khater, C. Mineau, H. Puech, S.	Rehabilitation ecology by revegetation. Approach and results from two Mediterranean countries.	2002

http://dx.doi.org/10.22453/LSJ-022.1.038-067

lsj.cnrs.edu.lb/vol-22-no-1-2021/

RESULTS

Hydroseeding techniques and their limitations

In semi-arid Mediterranean climates, hydroseeding has yielded poor results in plant performance (Matesanz *et al.*, 2006). These results could be due to a lack of sufficient knowledge about the success of hydroseeded species and the performance of native species (Bochet and García-Fayos, 2004). Understanding the response of those established species is critical for successful ecosystem restoration, and improving seed mixtures (González-Alday *et al.*, 2008).

Several factors affect hydroseeding successes or failures. Those factors can be grouped under abiotic factors or biotic factors (Table 2).

Table 2. Main factors extracted from the literature review that might be affecting the success or failure of the hydroseeding procedure in a semi-arid Mediterranean environment.

ABIOTIC FACTORS		BIOTIC FACTORS		OTHER FACTORS
Natural Environmental	**Human-Induced**	**Natural Environmental**	**Human-Induced**	
Site Topography and Properties: - Steepness & angle - Aspect	**Direct Hydroseeding Practices:** - Aqueous Hydroseeding type and properties - Intervention season	**Perils Affecting Seeds:** - Weed competition - Seed predation	**Seeds Used:** - Type - Availability & germination difficulties	**Starting Conditions** - Initial Status of Intervention Area
Soil Physical Characteristics: - Soil present/ absent - Microenvironment effect	**Varied Cultural Practices:** - Supplemental irrigation - Soil addition & amending - Mulching		**Seed Interaction:** - Interspecific seed competition - Nurse plants - Mycorrhizal inoculation	**Cost** **Social Factor**
Water Effect: - Water availability - Erosion				

http://dx.doi.org/10.22453/LSJ-022.1.038-067

Starting conditions are the existing conditions ranging from abandoned semi-natural environments to areas intensively used as cropland or heavily disturbed places such as quarries and mines (Hölzel *et al*., 2012). Although it is a very important aspect, this topic will not be covered in this review because it is out of scope when discussing hydroseeding pros and cons.

Abiotic factors affecting hydroseeding

Numerous abiotic factors might affect the hydroseeding end result those can either be natural-environmental factors or human-influenced factors (Table 2). Those factors do not act alone and often interact with one another or with different biotic factors.

Table 3. Factors affecting hydroseeding results in a semi-arid Mediterranean environment (NA - Natural Abiotic factors affecting hydroseeding; HA - Human-induced Abiotic factors affecting hydroseeding; HB - Human-induced Biotic factors affecting hydroseeding).

Variables	Successes	Failures
Slope Steepness	Slight to mild slope steepness - less than 45 degrees (NA) Terracing slopes above 45 degrees (HA)	Unmanaged steep slopes above 45 degrees (NA)
Aspect / Solar radiation	North facing - Low levels of solar radiation (NA)	South facing - High levels of solar radiation (NA)
Soil	Presence of topsoil (conservation of microorganisms, seeds, and nutrients) (NA/HA) Presence of microenvironment: increased soil surface roughness (small rocks, aggregates) (NA/HA) Addition of topsoil or amendments (HA) Mulching (synthetic or organic) (HA) Mycorrhizal soil inoculation (HB)	Absence of topsoil (loss of microorganisms, seeds, and nutrients) (NA/HA)
Water	Water abundancy conditions: regular rainfall (NA) or supplemental irrigation (HA) at germination/seedling phase	Water-stressed conditions: absence / irregular rainfall (NA) or lack of irrigation (HA) at germination/seedling stage
Weeds	Reduction of weed competition through appropriate selection of native seeds mixture (HB)	
Seed choice	Native (NB), competitive ability (NB), colonizing ability (NB), vegetative	Commercial seeds (HB), non-native seeds (HB/NB), seed predation (NB), inappropriate species (HB), lack of

http://dx.doi.org/10.22453/LSJ-022.1.038-067

	regeneration ability (NB), market availability (HB), easy to germinate (NB)	native seeds management: collection, handling, storage, etc.(HB)
"Nurse plant" seeds	Recommended for improving hydroseeding successes in harsh ecological circumstances: control erosion, suppress annual weeds, ultimately residues turned into nutrients (HA)	High percentages in seeds mixtures (HA)
Aqueous solution	Adhesive, fluid, free of hazardous material, enabling effective seed germination, limiting erosion (HA)	Might be species-specific (HA)
Cost-effectiveness		High cost per square meter compared to other methods (HA)
Social factors	Increased community awareness and acceptance	Cognitive residence to non-traditional techniques

Natural-environmental abiotic factors affecting hydroseeding

Natural-environmental abiotic factors are factors related to site topography, aspect, edaphic characteristics, and water availability. Topography and extreme environments can determine the success of a planting and restoration program (Bochet *et al*., 2009). Slope steepness, aspect, and type are all factors to consider in a harsh semi-arid Mediterranean climate. Because of low penetration and high runoff (Miyazaki *et al*., 1993), slopes with steep angles have intense water insufficiency, which leads to very low plant cover, accentuating the difficulty of re-vegetating them (Andre´s *et al*., 1996). Studies on motorway slopes in Catalonia-Spain concluded that hydroseeding was unsuitable for slope stabilization of road cuts near, or above, 45 degrees. The causes of failure include the probability of seeds moving downhill, with or without water (Cerdà and García-Fayos, 1997; García-Fayos and Cerdà, 1997). Even at lower steepness, on slope angles greater than 27–32 degrees, seed establishment is hindered by downward dragging (Bochet and García-Fayos, 2004). A study conducted in Malaga-Spain assessed whether hydroseeding techniques had any significance to contribute to species richness and vegetation cover by acting as starters or facilitators in the establishment of plants, and eventually checking their fate after the ecosystem has been restored. Results revealed that hydroseeding did not prove successful and the vegetation establishment on embankments was mainly from local seed bank and dispersal from the surrounding area (Bochet et al., 2007b). It concluded that hydroseeding is not needed in the presence of favorable conditions such as suitable climate and slope angle (Matesanz *et al*., 2005). To improve hydroseeding success in steep slopes efforts need to focus on increasing surface roughness, terracing at regular intervals, or excavating to produce slope angles below 45 degrees (Bochet and García-Fayos, 2004). Another factor affecting hydroseeding is the slope aspect. Different slope aspects (N, E, S, or W) have various exposures to solar radiation. Bochet *et al*. (2009) studied the correlation between slope angle thresholds and slope aspect with respect to plant colonization of highly eroded slopes in a semi-arid area.

They observed that plant colonization started at higher slope angles on North-facing than on South-facing slopes. This difference in the colonization capacity is due to water availability which is controlled by the solar radiation received. Another study in northwestern Spain evaluated the solar radiation effect on short-term herbaceous plant establishment on roadcut slopes after hydroseeding. Results showed a significant coincident trend of decrease in plant density, biomass, plant cover, and seedling development along the SE–SW–S gradient (Cano *et al*., 2002). Additional studies revealed that vegetation establishment was reduced considerably on South-facing slopes due to more severe conditions (Andre's *et al*., 1996; Cano *et al*., 2002). Aspect influence on early growth dynamics of hydroseeded species in a coal reclamation mine showed that grasses dominated both Northern and Southern slopes, except during the summer on the Southern slope, with grass cover always more on North-facing compared to South-facing slopes (González-Alday *et al*., 2008). A Contradicting study of almost three years involved hydroseeding gypsicolous vegetation on quarry spoil slopes. The two tested slopes (10-15% vs. 60-65%) and two contrasting aspects (North vs. South) revealed that shallow and Southern slopes were more suitable compared to Northern and steep slopes where non-target species developed readily outcompeting target species (Ballesteros *et al*., 2017).

A third natural-environmental abiotic factor affecting hydroseeding is the site edaphic characteristic. Soil presence or its absence, erosion, and microclimate are all factors affecting hydroseeding results. Initial soil conditions are the main factor leading to vegetation succession in reclaimed slopes in Mediterranean dry environment (Moreno de las Heras *et al*., 2008). Preservation of removed topsoil from construction sites is a valuable resource for ecological restoration. Removed soil contains high concentrations of micro-organisms, nutrients (Rivera *et al*., 2012), native seeds, and organic matter. All those factors could enhance plant establishment, increasing hydroseeding success rates (Merlin *et al*., 1999; Balaguer, 2002).

With the water running over bare and crusted soils leading to seed removal (Mitchley *et al*., 1996), the erosion process in Mediterranean climates is an important factor affecting hydroseeding, operating in a catastrophic mode (Wainwright, 1994). A major objective of hydroseeding is to generally control water erosion and the mechanical stabilization of barren slopes (Bochet *et al*., 2010a). A study in Spain on bare road embankments under construction revealed that the effect of erosion was 30 times more than the vegetated ones (Cerdà, 2007).

As for the microclimate effect, several degraded Mediterranean sites have adverse microclimatic conditions. Such inappropriate microsites, along with water stress, will affect the seedling establishment and plant growth, leading to poor performance of native species in hydroseeding (Tormo *et al*., 2006). The microclimate established between soil particles and adjacent aggregates will allow partial seed burial enabling a greater chance

http://dx.doi.org/10.22453/LSJ-022.1.038-067

lsj.cnrs.edu.lb/vol-22-no-1-2021/

for successful seedling establishment. The presence of small rocks will also provide shade and shelter, improving the establishment of seedlings (Elmarsdottir *et al*., 2003).

Water availability is yet another significant natural-environmental abiotic factor affecting hydroseeding success. In a Mediterranean semi-arid climate, water availability is a main ecological driver that shapes vegetation (Bochet *et al*., 2009). Low and irregular distribution of rainfall is a key factor limiting plant growth (Zohary, 1973). Seed arrival to road embankments under Mediterranean climate conditions is not enough to ensure successful plant colonization (Tormo *et al*., 2006). A study on regolith slopes in Southeast Spain concluded that short-lived water availability and high salinity of the regolith seem to be the key factors limiting vegetation colonization (García-Fayos *et al*., 2000). Furthermore, recurrent droughts cause not only high rates of plant mortality but also the inability of some species to expand their populations in dry conditions (Cerdà and García-Fayos, 1997, García-Fayos and Cerdà, 1997). Moreover, during the seedling establishment stage, the differences in water availability could explain the very-low plant colonization success, and the differential ability of plant species to establish in badland slopes (García-Fayos *et al*., 2000).

Human-influenced abiotic factors affecting hydroseeding

Human-influenced abiotic factors are factors introduced or modified by direct human interferences aiming to influence hydroseeding outcomes. Described under either direct-hydroseeding practices, varied cultural practices, cost of application, or social factors.

A factor that could directly affect hydroseeding practices is the type of aqueous solution utilized. One study (Merlin *et al*., 1999) assessed the effectiveness of a group of colloidal substances (of natural and synthetic origin) used in hydroseeding spraying with respect to adhesion, germination, seed growth, and erosion limitations. Results revealed that the desired colloids should have several characteristics: fluidity, adhesion to seeds, enable effective seed germination, be free of material hazardous to the environment, limit erosion, help in restoration or establishment of biological and ecological functions, and is of a low cost.

Alternation of the slurry component is another factor affecting the hydroseeding success. A comparative study (Clemente *et al*., 2016) using germination tests assessed the effects of different slurry components (bacteria-based fertilizing agent, bio-stimulant, dye, and surfactant) on the performance of a dozen native species used in hydroseeding of quarry slopes. The components affected the germination of 4 out of 12 native species, favoring germination in 2 species (*Thymus mastichia* & *Cistus albibus*) but delayed it in 2 other species (*Bituminaria bituminosa* & *Helichrysum stoechas*). The study concluded that the effect of slurry components on germination is species-specific; hence any used hydroseeding components should be adjusted to the sown species (Clemente *et al*., 2016).

Another study (Catania *et al*., 2012) evaluated commercially available seeds on a degraded artificial slope in a Southern Mediterranean area for the effectiveness of four different hydroseeding solutions. The study assessed total vegetation cover, hydroseeding vegetation cover, hydroseeding success index, and both the natural and hydroseeded vegetation height. In conclusion, the research revealed that success is conditioned by the type of the mixture components, with mixtures of equal terms earthworm humus and mulch providing the best results in terms of vegetation cover (Catania *et al*., 2012). The intervention season is another human-influenced abiotic factor affecting hydroseeding. Under semiarid Mediterranean conditions, hydroseeding timing appears to be a critical factor since climatic conditions following hydroseeding significantly affect species fate. Both climatic conditions and the selection of a suitable species capable to establish under water-stressed conditions should be considered since both factors are important in determining species performance in sowing (Tormo *et al*., 2008). If hydroseeding is to be performed out-of-season due to some strict schedule, efforts should focus on improving topsoil and microsite quality rather than increasing seed availability (Mola *et al*., 2011).

Various implemented cultural practices are other human-influenced abiotic factors affecting hydroseeding. Supplemental irrigation after hydroseeding is one such practice. In a semi-arid Mediterranean environment, the application of irrigation after hydroseeding is controversial, with some studies supporting it, whereas other studies highlight a negative role. Studies supporting supplemental irrigation reveal that water stress in a Mediterranean environment highly obstructs plant growth. Therefore, after hydroseeding, irrigation must be applied for a few months due to insufficient rain. This is especially essential since the brief durability of soil water availability largely determines germination successes (Bochet et *al*., 2007a; García-Fayos *et al*., 2000). Another study in Sicily showed that not only mulch and humus are needed, but also irrigation should be carried out during the dry period (Vallone *et al*., 2013). Other studies recommended the use of drought-tolerant plants along with a careful irrigation plan (Josa *et al*., 2012). However, other studies raised concerns about irrigation which might lead to the prevention of long-term vegetation establishment due to competition with spontaneous colonizers (García-Palacios *et al*., 2010). Another study targeting motorway slopes in Spain concluded that fast-growing species dominate the community, rendering irrigation and fertilization of little effect, indicating that hydroseeding neither had a strong impact on vegetation cover nor did it significantly decrease erosion rates of degraded sites in semi-arid Mediterranean environments (García-Palacios *et al*., 2010).

The addition of soil and/or amendments can also be another factor affecting hydroseeding outcomes. Topsoil spreading can improve soil texture, upsurges nutrient soil retention, decreases nutrient loss, reduce sediment runoff and facilitate quick development of dense vegetation cover (Jimenez *et al*., 2013). Topsoil addition prior to hydroseeding could be an important technique in roadfill revegetation in Mediterranean environments. This could be achieved through improving soil physical and chemical properties and also by providing a seed bank to assist spontaneous regeneration (Tormo *et*

http://dx.doi.org/10.22453/LSJ-022.1.038-067

lsj.cnrs.edu.lb/vol-22-no-1-2021/

al., 2007). A study showed that topsoiling followed by hydroseeding of a selected native seed mixture was the most effective treatment to control erosion on roadfills in terms of cost and benefit (Bochet *et al*., 2010b). Another study, assessing quarry restoration, evaluated the contribution of a 30 cm topsoil layer above marble sludge (a material with high water retaining capacity) before hydroseeding. The results indicated an increase in slope water storing capacity, significantly increasing biomass (Simón-Torres *et al*., 2014). Added topsoil low in organic matter, Fe and Mn, will limit vegetation establishment and development (Bochet and García-Fayos, 2004), therefore, mixing compost with the soil could improve germination of native seeds (Hallock *et al*., 2006).

Mulching is another implemented cultural practice. Mulches and organic amendments can promote seed burial, germination, and establishment, especially if dry soil conditions prevailed (Roberts and Bradshaw, 1985). A study conducted in the Giona Mountain-Greece examined the effectiveness of hydroseeding combined with varied materials. Results showed that hydroseeding alone leads to poor results, but when combined with tilling and mulching, it created satisfactory vegetation cover from the first year after application (Brofas *et al*., 2007). Mulching could also improve the odds of hydroseeding steep slopes. One study in Cordoba- Spain tested the effectiveness of different mulches (vegetal mulch, humic acids, vegetal mulch with humic acids, and control) on steep slopes. Hydroseeding with the combination of plant mulch and humic acids significantly reduced soil runoff up to 98.5 percent. This result may be attributed to the combined effect of the protection against raindrop impact and improvement to soil structure brought by organic amendments (Albaladejo *et al*., 2000). Even in some cases, the total replacement of hydroseeding by spreading of a thick compost blanket (pellet form) could enormously benefit seeds germination, because of matting effect, enabling them to withstand harsher and more intensive rainfalls compared to hydroseeding (Tyler, 2003). Gomez *et al*. (2014) evaluated the effect of three different mats paralleled with hydroseeding for controlling erosion under Mediterranean conditions. The mats used were: Organic mats (made of coconut or esparto grass fiber), synthetic net mats, and synthetic 3D-net mats. Significant erosion control was achieved using different erosion mats combined with hydroseeding, versus control, but showed no clear differences among the diverse matting materials during one year (Gomez *et al*., 2014).

Cost is yet another factor affecting the decision regarding whether to implement hydroseeding or not. A study compared the cost of different kinds of applications (broadcasting, drill, and hydroseeding). Results revealed that broadcasting cost ranged from $25 to $75 /hectare, drilling native seed cost range was $60 to $135 /hectare, and hydroseeding cost was $1,358 /hectare (Pawelek *et al*., 2015). A probable reason for the high cost of hydroseeding could be the market price of native seeds. Another study revealed that the prices of selected seed mixtures were 30 times more than that of commercial species, although the cost of relevant ecological advantages provided by the use of native species was only twice that of the commercial species based on cost-effectiveness assessment (Bochet *et al*., 2010b). Martin *et al*. (2002) compared the prices

http://dx.doi.org/10.22453/LSJ-022.1.038-067

lsj.cnrs.edu.lb/vol-22-no-1-2021/

(in USD/kg) amongst different kinds of seeds used for hydroseeding in the semi-arid Mediterranean environment. Results revealed a vast range in the price range. With prices varying from as low as 2 - 3.5 USD/ kg for industrially produced species, to 80- 120 USD/ Kg for native species (hand-harvested and collected near restoration area), 6- 25 USD/ kg for common cultivated wild species, and between 50- 850 USD/ kg for the difficult to collect and grow wild species. More demand for native species in restoration projects will probably encourage investing in native seed and plant production, ultimately leading to their abundance at more competitive prices (Bochet *et al*., 2010b).

Biotic factors affecting hydroseeding

Biotic factors could play a positive or negative role in the outcome of hydroseeding by affecting separately or collectively hydroseeding outcomes (Table 3). Also, both biotic and abiotic factors might interact altering the end result.

Human-influenced biotic factors affecting hydroseeding

Through the influence of the soil seed bank, seeds are considered one of the most important actors at the first stages of the restoration process, playing a fundamental role in the composition of future vegetation (Peco *et al*., 1998). Therefore, the choice of species in seed mixtures is vital when planning a restoration project. Possible guidelines for seed selecting could be, the ability of seeds to disperse, produce sufficient viable seeds, be competitive under local conditions, be of perennial nature, and have a high root/ shoot ratio (Khater *et al*., 2003). Three- groups of seed species are used for hydroseeding: Commercial species, native seed species collected near the intervention area, and native seeds obtained from cultivated wild species (Martin *et al*., 2002). Commercial species are those plant seed species produced in vast amounts following international norms. Although the use of commercial grasses and legume seeds are probably the most prevalent hydroseeding roadside re-vegetation method (Steinfeld *et al*., 2007), they frequently give poor results from the very beginning (Andre´s and Jorba, 2000; Martínez-Ruiz et al., 2007). Extremely competitive forage grasses and legumes (ex: *Lolium multiflorum*, *Vicia villosa*, *Festuca arundinacea*, *Medicago sativa*, *Onobrychis sativa*, *Agropyron cristatum*, *Melilotus officinalis*) (Bochet *et al*., 2010b) are in most locations non-native seeds used for agriculture practices or lawn establishment. Choosing seeds that are not adapted to harsh climatic constraints, like those prevailing in semi-arid Mediterranean environments, will lead to failure (Martin *et al*., 2002), especially with long periods of drought and erosive rains (Bochet and García-Fayos, 2004). A study in West-Central Spain evaluated the influence of using commercial seed mixtures in hydroseeding to restore uranium mine wastes under semi-arid Mediterranean climate. Results confirmed the non-suitability of commercial species mixture, suggesting instead to use local seeds (Martínez-Ruiz *et al*., 2007). Commercial seed mixtures also give poor results regarding species richness and overall biomass. As the dominance of certain used species eventually takes over other spreading or native spontaneous ones (Tormo *et al*., 2008). Therefore,

http://dx.doi.org/10.22453/LSJ-022.1.038-067

lsj.cnrs.edu.lb/vol-22-no-1-2021/

careful assessment of the competitive interactions among commercial and native species is imperative when both seed types are intended for use in a mixture, else it can dramatically affect the outcome of hydroseeding (Matesanz and Valladares, 2007). Using inappropriate species might potentially hinder the establishment of autochthonous species, lead to low diversity in communities, and can even become an integral part of the seed bank causing long-term problems (González-Alday *et al*., 2009). The importance of using native species is becoming widely acknowledged, and restoration projects are gradually considering native species for hydroseeding mixtures (Matesanz and Valladares., 2007). Unfortunately, several problems hinder the use of native seeds for hydroseeding in a Mediterranean environment. Concerns such as the scarce availability of information about proper seed collection methods, handling, storage, germination requirements, and seedling culture (Clewell and Rieger, 1997) leads to the narrowing down of choices of seeds used mainly to three main criteria's: ecological needs, agro-ecological constraints and economic feasibility (Khater and Martin, 2007). Odds could be enhanced through species selection, seeds pre-treatment, hydroseeding scheduling, and/or manipulation of seeding density and relative species proportion (Oliveira *et al*., 2012).

Interspecific seed competition is yet another human-influenced biotic factor affecting hydroseeding practices. The kind and percentage of different seeds in a mixture, proportions of native seed densities, varied morphological features, or growth rates are all factors that could affect the end result. Hence, co-seeded species that display more competitive growth traits should be added at a lower proportion (Oliveira *et al*., 2013). Native species cannot simply be included in re-vegetation 'recipes', since success depends on density and seedling characteristics of the other co-seeded species. Therefore, their early performances and morphology must be taken into account in the choice of seed mixtures used in restoration actions (Oliveira *et al*., 2014). Another factor highlighted in literature affecting hydroseeding is the "nurse plant syndrome", defined as the positive influence of the adult plants on seedlings (Niering *et al*., 1963). The harsher the ecological circumstances, the stronger the facilitative effect of nurse plants (Padilla and Pugnaire, 2006). Fast-growing annual species acting as nurse plants may be included with seed mixes of perennial grasses and forbs, providing protection for slower establishing perennial species by creating shade for a few months after seeds are applied (Skousen and Zipper, 2010). In the semi-arid Mediterranean environment, nurse plants will ultimately decline fast since they can hardly survive such harsh climatic conditions (Zelnik *et al*., 2010), their residues decomposed by soil microorganisms and nutrients released back to be used by perennial plant species (Skousen and Zipper, 2010). By rapidly re-establishing vegetation cover, nurse plants can also control erosion, consequently suppressing annual weeds (Mitchley *et al*., 1996). Zelnik *et al*. (2010) observed that seed mixtures with nurse species accelerate succession on slopes during the initial years but delay the establishment of late-successional species from the adjacent target vegetation. Hence, recommending that the proportion of nurse species in seed mixtures not exceed 20%.

http://dx.doi.org/10.22453/LSJ-022.1.038-067

lsj.cnrs.edu.lb/vol-22-no-1-2021/

Mycorrhizal inoculation is another human-influenced biotic factor affecting hydroseeding. Its use, among other inoculants, in restoration actions was recommended for the positive effect on plant establishment, nutrient cycling, ecosystem sustainability (Miller and Jastrow, 1992), and improvement of root enhancement and root branching density- a desirable quality in degraded soils (Stokes *et al*., 2009). They could also help to stabilize soil surface and create the assortment needed to increase plant production (Maestre *et al*., 2011). One of the few studies using inoculum for hydroseeding in semi-arid Mediterranean climate had the objective of selecting an adequate fungus combination (Arbuscular Mycorrhizal Fungi - AMF inoculum), along with legumes and grasses native to the Mediterranean region. The experiment evaluated the implications on severely disturbed areas as well under controlled conditions (greenhouse trial). Results revealed that the establishment of a symbiotic relationship improves aboveground plant growth and increases the legumes/grasses ratio (both in the greenhouse and in the field) (Estaun *et al*., 2007). Another study by Brown *et al*. (1983) measured rhizobium viability in hydroseeding slurries by testing variation in the pH due to fertilizer addition. They concluded that phosphorus fertilizer as triple-superphosphate significantly reduced the pH leading to the loss of Rhizobium viability. The study concluded that Phosphorous addition should be in the form of diammonium Phosphate rather than triple Superphosphate, ensuring Rhizobial survival, and inoculation of legume seeds (Brown *et al*., 1983).

Natural-influenced biotic factors affecting hydroseeding

Several perils could impact the fate of the hydroseeded seeds in their intended location, such as weed competition and seed predation. Weed competition was highlighted through a study in a limestone quarry in North-Eastern Italy evaluating the effect of technical reclamation on the plant community (Boscutti *et al*., 2016). It concluded that different practices favoring native perennial species (e.g. appropriate seed mixtures, mowing, tree and shrub planting) could limit weed-control efforts and limit invasive species spread (Boscutti *et al*. 2016). Another study measuring the basal area of herbaceous Mediterranean species revealed that plants with a large basal area were least suppressed by competition, concluding that plants basal area could be used to predict the competitive ability of species performance (Navas & Moreau-Richard, 2005). Seed predation is another natural-influenced biotic factor affecting hydroseeding, achieved through grazing by animals such as birds, mammals, ants (Chambers and MacMahon, 1994), or even pathogens (Hulme, 1998). A study that analyzed different types of seeds, actively collected, as food items by ants showed that more than 50% of the experimental seeds that were glued to the ground with their own mucilage survived, compared to only 0–20 % of the control of seed survival after the same exposure time (Engelbrecht and García-Fayos, 2012).

Whereas most studies in literature addressed technical issues as barriers in hindering hydroseeding processes, very few articles (Fenianos *et al.*, 2017; 2018)

http://dx.doi.org/10.22453/LSJ-022.1.038-067

highlighted social factors as issues affecting it. To successfully implement adapted environmental solutions, especially in ecological restoration projects, Fenianos *et al*. (2017, 2018) investigated possible contributions of cognitive resistance and the need to work on increasing acceptability for adopting new or non-traditional techniques. Using cognitive flexibility as a mixed approach with awareness-raising sessions positively increased the perception of test groups towards less traditional and more ecological rehabilitation concepts on quarries.

DISCUSSION

Initially developed for ski slopes and side road embankments in Northern European countries, hydroseeding as a restoration tool has shown considerable limitations in Mediterranean ecosystems. This review from the semi-arid Mediterranean context concludes that the practice of hydroseeding is faced with limited success. A review of the main biotic and abiotic factors as either natural or human-induced that might be affecting it revealed several limiting factors. Some of those factors are site topography and its properties (slope angle, aspect, and microclimates availability), edaphic factors and water availability, cultural practices, the types of seeds used and the interaction among them, and the different perils facing them. Better results can be achieved by incorporating various techniques, such as using nurse plants, ameliorating the soil and its microclimates, supplemental irrigation, the proper choice of seeds, regulating spraying medium, and seed inoculation. Environmental socio-cognitive psychology approaches might help to better convey and increase acceptability towards modified applications of Hydroseeding.

As a consequence, the limits of using hydroseeding as a restoration technique in a semi-arid Mediterranean environment calls for additional research efforts to sufficiently comprehend its pros and cons.

ACKNOWLEDGEMENTS

This research is part of a PhD thesis of first author and part of two projects “TREET” and “RESTORE” funded by Grant Research Program- CNRS, and CEDRE Program. This is an LIA O-LiFE contribution number SA 41-2018.

REFERENCES

Albaladejo Montoro, J. Alvarez Rogel, J. & Querejeta, J. (2000). Three hydro-seeding revegetation techniques for soil erosion control on anthropic steep slopes. *Land Degradation & Development*, 11(4), 315- 325.

Andre´s, P. & Jorba, M. (2000). Mitigation strategies in some motorway embankments (Catalonia, Spain). *Restoration Ecology*, 8, 268–275.

Andre´s, P. Zapater, V. & Pamplona, M. (1996). Stabilization of motorway slopes with herbaceous cover, Catalonia, Spain. *Restoration Ecology*, 4, 51- 60.

Aronson, J. Floret, C. Floc'h, E. Ovalle, C. & Pontanier, R. (1993). Restoration and Rehabilitation of Degraded Ecosystems in Arid and Semi-Arid Lands. I. A View from the South. *Restoration ecology*. 1(1), 8-17.

Bakker, J. P. & Berendse, F. (1999). Constraints in the restoration of ecological diversity in grassland and heathland communities. *Trends in Ecology and Evolution* 14:63–68.

Balaguer, L. (2002). Las limitaciones de la restauración de la cubierta vegetal. *Revista Ecosistemas.* 11(1),8.

Ballesteros, M., Cañadas, E. M., Marrs, R. H., Foronda, A., Martín-Peinado, F. J. & Lorite, J. (2017). Restoration of gypsicolous vegetation on quarry slopes: guidance for hydroseeding under contrasting inclination and aspect. *Land degradation & development*, *28*(7), 2146-2154.

Blondel, J., Aronson, J., Bodiou, J. Y. & Boeuf, G. (2010). The Mediterranean region: biological diversity in space and time. *Oxford University Press.*

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

Bochet, E. García-Fayos, P. Alborch, B. & Tormo, J. (2007a). Soil water availability effects on seed germination account for species segregation in semiarid roadslopes. *Plant and Soil,* 295(1-2), 179-191.

Bochet, E. García-Fayos, P. & Poesen, J. (2009). Topographic thresholds for plant colonization on semi-arid eroded slopes. *Earth Surface Processes and Landforms,* 34(13), 1758-1771.

Bochet, E. García-Fayos, P. & Tormo, J. (2007b). Road slope revegetation in semiarid Mediterranean environments. Part I: seed dispersal and spontaneous colonization. *Restoration Ecology,* 15(1), 88-96.

Bochet, E. García-Fayos, P. & Tormo, J. (2010a). How can we control erosion of roadslopes in semiarid mediterranean areas? Soil improvement and native plant establishment. *Land Degrad. Dev.*, 21, 110–121.

Bochet, E., Tormo, J. & García-Fayos, P. (2010b). Native species for roadslope revegetation: selection, validation, and cost effectiveness. *Restoration Ecology*, 18(5), 656-663.

Boscutti, F., Vianello, A., Bozzato, F. & Casolo, V. (2016). Vegetation structure, species life span, and exotic status elucidate plant succession in a limestone quarry reclamation. *Restoration Ecology* 25(4):595-604.

Brofas, G., Mantakas, G., Tsagari, K., Stefanakis, M. & Varelides, C. (2007). Effectiveness of cellulose, straw and binding materials for mining spoils revegetation by hydro-seeding, in Central Greece. *Ecological Engineering* 31(3):193-199.

Brown, M. R., Wolf, D. D., Morse, R. D. & Neal, J. L. (1983). Viability of Rhizobium in fertilizer slurries used for hydroseeding. *Journal of environmental quality* 12(3):388-390

http://dx.doi.org/10.22453/LSJ-022.1.038-067

Cano, A., Navia, R., Amezaga, I. & Montalvo, J. (2002). Local topoclimate effect on short-term cutslope reclamation success. *Ecological Engineering*, 18(4), 489-498.

Catania, P., Salvia, M. & Vallone, M. (2012). Hydroseeding for revegetation in a semiarid Mediterranean environment. In Structures and Environmental Technologies. International Conference of Agricultural Engineering-CIGR-AgEng 2012: agriculture and engineering for a healthier life, Valencia, Spain, 8-12 July 2012 (pp. C-1675). CIGR-EurAgEng.

Cerdà, A. (2007). Soil water erosion on road embankments in Eastern Spain. *Science of the Total Environment*, 378(1), 151-155.

Cerdà, A. & García-Fayos, P. (1997). The influence of slope angle on sediment, water and seed losses on badland landscapes. *Geomorphology*, 18, 77- 90.

Chambers, J. C. & MacMahon, J. A. (1994). A day in the life of a seed: movements and fates of seeds and their implications for natural and managed systems. *Annual Review of Ecology and Systematics*, 25(1), 263-292.

Clemente, A. S., Moedas, A. R., Oliveira, G., Martins-Loução, M. A. & Correia, O. (2016). Effect of hydroseeding components on the germination of Mediterranean native plant species. *Journal of Arid Environments*, 125, 68-72.

Clewell, A. & Rieger, J. P. (1997). What practitioners need from restoration ecologists *Restoration Ecology*, 5, 350-354.

Davy, J. (2002). Establishment and manipulation of plant populations and communities in terrestrial systems. In: Perrow M. & Davy J. (Ed.): Handbook of ecological restoration. Cambridge University Press. Cambridge, UK, pp. 223-241.

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

Engelbrecht, M. & García-Fayos, P. (2012). Mucilage secretion by seeds doubles the chance to escape removal by ants. *Plant Ecology*, 213(7), 1167-1175.

Estaun, V., Vicente, S., Calvet, C., Camprubi, A. & Busquets, M. (2007). Integration of arbuscular mycorrhiza inoculation in hydroseeding technology: effects on plant growth and inter-species competition. *Land Degradation & Development*, 18(6), 621-630.

Fenianos, J. Khater, C. Brouillet, D. (2018). When Psychology Meet Ecology: Cognitive Flexibility for Quarry Rehabilitation. *World Academy of Science, Engineering and Technology, International Journal of Psychological and Behavioral Sciences*, 12(5).

Fenianos J, Khater C, Viglione J, Brouillet D (2017) Bridging nature and human priorities in ecological rehabilitation projects - a show case from Mediterranean environment - Qattine, Lebanon. Plant Sociology 54 (l), 103-110.

García-Fayos, P. and Cerdà, A. 1997. Seed losses by surface wash in degraded Mediterranean environments. Catena 29:73- 83.

García-Fayos, P., García-Ventoso, B. & Cerdà, A. (2000). Limitations to plant establishment on eroded slopes in Southeastern Spain. *Journal of Vegetation Science*, 11(1), 77-86.

García-Palacios, P., Soliveres, S., Maestre, F. T. Escudero, A., Castillo-Monroy, A. P. & Valladares, F. (2010). Dominant plant species modulate responses to hydroseeding, irrigation, and fertilization during the restoration of semiarid motorway slopes. *Ecological Engineering*, 36(10), 1290-1298.

Gomez, J. A., Rodríguez, A., Viedma, A., Contreras, V., Vanwalleghem, T., Taguas, E. V. & Giráldez, J. V. (2014). Evaluation of different techniques for erosion control on different roadcuts in its first year of implantation. In EGU General Assembly Conference Abstracts, 16, 3362.

González-Alday, J., Marrs, R. H. & Martínez-Ruiz, C. (2008). The influence of aspect on the early growth dynamics of hydroseeded species in coal reclamation areas. *Applied Vegetation Science*, 11, 405–412.

González-Alday, J., Marrs, R. H. & Martínez-Ruiz, C. (2009). Soil seed bank formation during early revegetation after hydroseeding in reclaimed coal wastes. *Ecological Engineering*, 35(7), 1062-1069.

Hallock, B. G., Power, A., Rein, S., Curto, M. & Scharff, M. (2006). Analysis of Compost Treatments to Establish Shrubs and Improve Water Quality. *Digital commons*, 1, 79-90.

Hölzel, N., Buisson, E. & Dutoit, T. (2012). Species introduction–a major topic in vegetation restoration. *Applied Vegetation Science*, 15(2), 161-165.

Hulme, P. E. (1998). Post-dispersal seed predation: consequences for plant demography and evolution. *Perspect. Plant Ecol*., 1, 32–46.

Jimenez, M. D., Ruiz-Capillas, P., Mola, I., Pérez-Corona, E., Casado, M. A. & Balaguer, L. (2013). Soil development at the roadside: a case study of a novel ecosystem. *Land Degradation & Development*, 24(6), 564-574.

Josa, R., Jorba, M. & Vallejo, V. R. (2012). Opencast mine restoration in a Mediterranean semi-arid environment: failure of some common practices. *Ecological Engineering*, 42, 183-191.

Khater, C. (2015). L'écologie appliquée: une responsabilité scientifique au carrefour de l'interdisciplinarité. HDR. Université Aix-Marseille, 57pp.

Khater, C. & Martin, A. (2007). Application of restoration ecology principles to the practice of limestone quarry rehabilitation in Lebanon. *Lebanese Science Journal*, 8(1), 19-28.

Khater, C., Martin, A. & Maillet, J. (2003). Spontaneous vegetation dynamics and restoration prospects for limestone quarries in Lebanon. *Applied Vegetation Science*, 6(2), 199-204.

Macdonald, S. E., Landhäusser, S. M., Skousen, J., Franklin, J., Frouz, J., Hall, S., Jacobs, D. F. & Quideau, S. (2015). Forest restoration following surface mining disturbance: challenges and solutions. *New Forests*, 46(5-6), 703-732.

Maestre, F. T., Bowker, M. A., Cantón, Y., Castillo-Monroy, A. P., Cortina, J., Escolar, C., Escudero, A., Lázaro, R. & Martínez, I. (2011). Ecology and functional roles of biological soil crusts in semi-arid ecosystems of Spain. *Journal of arid environments*, 75(12), 1282-1291.

Martin, A., Khater, C., Mineau, H. & Puech, S. (2002). Rehabilitation ecology by revegetation. Approach and results from two Mediterranean countries. *Korean Journal of Ecology*, 25(1), 9-17.

Martínez-Ruiz, C., Fernandez-Santos, B., Putwain, P. D. & Fernández-Gómez, M. J. (2007). Natural and man-induced revegetation on mining wastes: changes in the floristic composition during early succession. *Ecological Engineering*, 30(3), 286-294.

Matesanz, S. & Valladares, F. (2007). Improving revegetation of gypsum slopes is not a simple matter of adding native species: Insights from a multispecies experiment. *Ecological engineering*, 30(1), 67-77.

Matesanz, S., Valladares, F., Tena, D. & Costa-Tenorio, M. (2005). Rasgos biogeográficos. florísticos y ecológicos de comunidades herbáceas en taludes de carretera en el sur de España. *Ecología*, 19, 97-112.

Matesanz, S., Valladares F., Tena, D., Costa-Tenorio, M. & Bote, D. (2006). Early dynamics of plant communities on revegetated motorway slopes from Southern Spain: is hydroseeding always needed? *Restoration Ecology*, 14(2), 297-307.

Merlin, G., Di Gioia, L. & Goddon, C. (1999). Comparative study of the capacity of germination and adhesion of various hydrocolloids used for revegetalization by hydroseeding. *Land Degradation & Development*, 10, 21–34.

Miller, R. M. & Jastrow, D. J. (1992). The application of VA mycorrhizae to ecosystem restoration and reclamation. *In Mycorrhizal Functioning. Allen MF (ed.). Chapman & Hall: New York, NY*, 438–467.

Mitchley, J., Buckley, G. P. & Helliwell, D. R. (1996). Vegetation establishment on chalk marl spoil: the role of nurse grass species and fertilizer application. *Journal of Vegetation Science*, 7, 543-548.

Miyazaki, T., Hasegawa, S., Kasubuchi, T., & Hopmans, J. W. (1994). Water flow in soils. *Soil Science*, *157*(4), 264.

Mola, I., Jiménez, M. D., López-Jiménez, N., Casado, M. A. & Balaguer, L. (2011). Roadside reclamation outside the revegetation season: management options under schedule pressure. *Restoration Ecology*, 19(1), 83-92.

Moreno de las Heras, M., Nicolau, J. M. & Espigares, T. (2008). Vegetation succession in reclaimed coal-mining slopes in a Mediterranean-dry environment. *Ecological Engineering*, 34, 168–178.

Navas, M. & Moreau-Richard, J. (2005). Can traits predict the competitive response of herbaceous Mediterranean species? *Acta Oecologica*, 27(2), 107-114.

Niering, W. A., Whittaker, R. H. & Lowe, C. H. (1963). The Saguaro: a population in relation to environment. *Science*, 142, 15–23.

Nunes, A., Oliveira, G., Mexia, T., Valdecantos, A., Zucca, C., Costantini, E. A., Abraham, E. M., Kyriazopoulos, A. P., Salah, A., Prasse, R. & Correia, O. (2016). Ecological restoration across the Mediterranean Basin as viewed by practitioners. *Science of the Total Environment*, 566, 722-732.

Oliveira, G., Clemente, A., Nunes, A. & Correia, O. (2013). Limitations to recruitment of native species in hydroseeding mixtures. *Ecological Engineering*, 57, 18-26.

Oliveira, G., Clemente, A., Nunes, A. & Correia, O. (2014). Suitability and limitations of native species for seed mixtures to re-vegetate degraded areas. *Appl. Veg. Sci.,* 17, 726–736.

Oliveira, G., Nunes, A., Clemente, A. & Correia, O. (2012). Testing Germination of Species for Hydroseeding Degraded Mediterranean Areas. *Restoration Ecology,* 20, 623–630.

Padilla, F. M. & Pugnaire, F. I. (2006). The role of nurse plants in the restoration of degraded environments. *Frontiers in Ecology and the Environment,* 4(4), 196-202.

Pawelek, K. A., Smith, F. S., Falk, A. D., Clayton, M. K., Haby, K. W. & Rankin, D. W. (2015). Comparing three common seeding techniques for pipeline vegetation restoration: A case study in South Texas. *Rangelands,* 37(3), 99-105.

Peco, B., Ortega, M. & Levassor, C. (1998). Similarity between seed bank and vegetation in Mediterranean grassland: a predictive model. *J. Veg. Sci.,* 9, 815–828.

Rivera, D., Jáuregui, B. M. & Peco, B. (2012). The fate of herbaceous seeds during topsoil stockpiling: restoration potential of seed banks. *Ecological Engineering,* 44, 94-101.

Roberts, R. D. & Bradshaw, A. D. (1985). The development of a hydraulic seeding technique for unstable sand slopes. II. Field evaluation. *Journal of Applied Ecology,* 979-994.

Society for Ecological Restoration. (2004). The SER international primer on ecological restoration. SER, Washington, DC, US.

Simón-Torres, M., del Moral-Torres, F., de Haro-Lozano, S. & Gómez-Mercado, F. (2014). Restoration of dump deposits from quarries in a Mediterranean climate using marble industry waste. *Ecological Engineering,* 71, 94-100.

Skousen, J. G. & Zipper, C. E. (2010). Reclamation Guidelines for Surface-Mined Land: Revegetation Species and Practices, 460(122), 1-18.

Steinfeld, D. E., Riley, S. A., Wilkinson, K. M., Landis, T. D. & Riley, L. E. (2007). Roadside revegetation: an integrated approach to establishing native plants. (available from HTTP://www.wfl.fhwa.gov/td/publications/managersguide.htm).

Stokes, A., Atger, C., Bengough, A. G., Fourcaud, T. & Sidle, R. C. (2009). Desirable plant root traits for protecting natural and engineered slopes against landslides. *Plant and soil,* 324(1-2), 1-30.

Tormo, J., García-Fayos, P. & Bochet, E. (2008). Relative importance of plant traits and ecological filters in road embankment revegetation under semiarid Mediterranean conditions. *Ecological Engineering*, 33(3), 258-264.

Tormo, J., Bochet, E. & García-Fayo, P. (2006). Is seed availability enough to ensure colonization success? An experimental study in road embankments. *Ecological Engineering,* 26(3), 224-230.

Tormo, J., Bochet, E. & García-Fayos, P. (2007). Roadfill Revegetation in Semiarid Mediterranean Environments. Part II: Topsoiling, Species Selection, and

Hydroseeding. *Restoration Ecology,* 15, 97–102. doi:10.1111/j.1526-100X.2006.00194.

Tyler, R. W. (2003). The soil and water quality link–using composted products for effective stormwater management. *In* Proceeding of the First Interagency Conference on Research in the Watersheds. US Department of Agriculture, Agricultural Research Service, Benson, AZ,107-116

Vallone, M., Pipitone, F., Alleri, M., Febo, P. & Catania, P. (2013). Hydroseeding Application on Degraded Slopes in the Southern Mediterranean Area (Sicily). *Applied engineering in agriculture*, 29(3), 309-319.

Wainwright, J. (1994). Anthropogenic factors in the degradation of semiarid regions: a prehistoric case study in Southern France. *In:* Millington, A.C. &Pye, K. (eds.) Environmental change in drylands: Biogeographical and geomorphological perspectives, pp. 305-320. J. Wiley & Sons, Chichester.

Zdruli, P. (2014). Land resources of the Mediterranean: status, pressures, trends, and impacts on future regional development. *Land Degradation & Development*, 25(4), 373-384.

Zelnik, I., Šilc, U., Čarni, A. & Košir, P. (2010). Revegetation of motorway slopes using different seed mixtures. *Restoration Ecology*, 18(4), 449-456.

Zohary, M. (1973). Geobotanical foundations of the Middle East, Gustav Fischer Verlag, Stuttgart, Germany, 2738pp.

http://dx.doi.org/10.22453/LSJ-022.1.038-067