Chapter 12
Monitoring the Development of Nurse Plant Species to Improve the Performances of Reforestation Programs in Mediterranean Areas

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Abstract In the Mediterranean basin, a millenarian history of overexploitation has lead to the loss of most primeval forests and an increase of the surface area covered by shrublands that represent stages of degradation of mature forests. In this situation, and since environmental characteristics act as barriers to succession, human intervention is usually necessary to improve recovery of woodlands. Reafforestation is a common practice in Mediterranean areas to achieve this aim but its performances are very low with high rates of early mortality making this practice unprofitable in ecological as well as in economic terms.

In degraded semiarid ecosystems, shrub and tall-grass species grow following a patchy distribution. Traditionally, shrubs growing near to newly planted trees are considered heavy competitors, and are consequently removed before planting. However, the vegetation patches usually constitute "fertility islands" or "resource islands" which could promote the tree species development. It has previously been assessed that some native plant species could act as "nurse plants" through their positive impacts on soil abiotic characteristics (i.e., soil nutrient contents), but they also exhibit a positive influence on soil microbiota, especially on symbiotic

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microorganisms including rhizobia and mycorrhizal fungi. In this chapter, an attempt is made to assess the beneficial effects of plant nurses on the growth of Mediterranean tree species like *Cupressus* species, and on the bio-functioning of soils. Furthermore, the potential benefits of native plant species in the rehabilitation of degraded areas especially in stressful conditions is reviewed and discussed.

12.1 Introduction

Shrub and tall-grass species growth following a patchy distribution are characteristic of the plant communities in semiarid ecosystems and more particularly in Mediterranean areas. The vegetation patches usually form "fertility islands" (Garner and Steinberger 1989) or "resource islands" (Schlesinger et al. 1996) that could be involved in the development of native plant species (Callaway 1995, 1997). It has been previously reported that some native plants species improve their own environment by self-promoting changes in water infiltration, organic matter, etc. (Bochet et al. 1999; Valladares and Pugnaire 1999), and could act as "nurse plants" through their positive impacts on the survival of other native plant species (Carrillo-Garcia et al. 2000). It is now well accepted that the spatial proximity among plants could be beneficial in environments such as Mediterranean-type ecosystems that are characterized by abiotic stress (Boucher et al. 1982; Callaway and Walker 1997; Gomez-Aparicio et al. 2004).

In semiarid Mediterranean ecosystems, desertification processes result from scarce and irregular rainfall, long dry and hot summers, and man-mediated degradative activities like deforestation, overgrazing, non-regulated cultivation techniques, etc. (Francis and Thornes 1990). Desertification generally alters natural plant communities including population structure, succession pattern, and species diversity (Barea and Jeffries 1995). In addition, these disturbances are often accompanied by degradation of physico-chemical and biological soil properties, such as nutrient availability, microbial activity, soil structure, etc., that largely determine soil quality and fertility (Garcia et al. 1997a, b; Albaladejo et al. 1998; Requena et al. 2001). For instance, it is well known that land degradation is usually linked with reductions in the belowground microbial diversity and/or activity (Kennedy and Smith 1995).

Among components of soil microbiota, arbuscular mycorrhizal (AM) fungi are known to be key components of natural systems in semiarid ecosystems and particularly important in counteracting desertification of Mediterranean ecosystems (Carpenter and Allen 1998; Brundrett 1991). The mycorrhizal symbiosis mobilizes and transports nutrients to roots (Smith and Read 1997), reduces water stress (Augé 2001), and improves soil aggregation in eroded soils (Caravaca et al. 2002). AM fungal symbiosis also changes root functions (e.g., root exudation) (Graham et al. 1981; Marshner et al. 1997), modifies carbohydrate metabolism of the host plant (Shachar-Hill et al. 1995), and synergistically interacts with rhizosphere populations (Andrade et al. 1997; 1998). The structure and functionalities of these microbial communities surrounding AM roots differ from those of the rhizosphere

(Duponnois et al. 2005), and this microbial compartment has been named “mycorrhizosphere” (Linderman 1988). It has also been reported that AM fungi affect the diversity of plant communities (van der Hejden et al. 1998; Klironomos et al. 2000; O’Connor et al. 2002) and influence competitive relationships between plants (West 1996; Marler et al. 1999; van der Heijden et al. 2003).

It is well known that the AM fungal activity is generally low in degraded semiarid Mediterranean ecosystems (Maremammani et al. 2003). However, an increased activity of fungal inoculum is needed in both natural and artificial processes of re-vegetation. It has already been shown that AM inoculation of plants is very effective in establishing plants on disturbed soils (Estaun et al. 1997). In order to increase and maintain high populations of infective AM propagules in soil, two main cultural practices can be considered: (1) screening of AM fungal isolates (native or exotic isolates) for their effect on the plant growth under controlled conditions and a cultural substrate inoculation with the most efficient AM strains, and (2) adoption of field practices to manage and improve the inoculum potential of indigenous AM fungi. The inoculation practice is generally used in tree nurseries to help tree establishment in field conditions (Plenchette 2000; Franson and Bethlenfalvay 1989). However, previous studies have reported that, although AM inoculation improved plant growth, it could also strongly modify soil microbial activities (Dabire et al. 2007). In some conditions, to overcome the negative influences of AM inoculation on soil microbiota, it is possible to increase AM soil potential through the management of highly mycotrophic plants (Azcon and Barea 1997). In the following section, focus is placed on highlighting the impacts of some Mediterranean shrubs on microbial functionalities and AM potential and evaluating their significant use in forestry practices to enhance the performance of afforestation program. In this context, most of the reported results will be directed to *Cupressus* spp. and *Lavendula* species. In Morocco, the area of natural and introduced cypress stands, one natural species, *Cupressus atlantica*, and two introduced species, *Cupressus sempervirens* and *C. arizonica*, has declined, and numerous reports indicate a complete absence of natural regeneration. Although attempts have been made to replant these species, the rate of success has been very low. *Lavandula* species are representative plant species in Mediterranean shrublands and belong to the natural succession in semiarid Mediterranean ecosystems (Barea et al. 1992). They have been classified as “obligatory mycorrhizal” (Brundrett 1991) or as “highly dependent on mycorrhiza” (Habte and Manjunath 1991).

12.2 Impacts of “Nurse Plant Species” on Soil Microbial Functionalities and AM Fungus Communities

A study has been conducted in the N’Fis valley (Haut Atlas mountains, Morocco) at the Idni station (8°17′02″ W, 31°54′34″N, 1,700 m above sea level) in a natural stand of *C. atlantica* (Ouahmane et al. 2006). This area was covered by a sparse and degraded vegetation mainly composed of grasses (i.e., *Stipa nitens* Ball.) and various shrub species, such as *Cistus salviifolus* L., *Lavandula dentata* L., *L. stoechas* L., *Thymus pallidus* Coss., *Polygala balansae* Coss., *Globularia alypum* L. and *Thymus satureioides* Coss. Soil samples were collected from the rhizosphere of *L. dentata*, *L. stoechas*, and *T. satureioides* (abundant shrub species and always recorded in the vicinity of *C. atlantica* adult trees) and of *C. atlantica*. Control samples were collected from bare soil sites, away from plant influence. The soil carbon and nitrogen contents were higher under *C. arizonica* than under the other sampling areas due to the leaf litter formation and the fact that, in forest ecosystems, most of the soil nitrogen is in organic form (Kaye and Hart 1997) (Table 12.1), while soluble phosphorus contents were significantly lower under the targeted plant species than in the bare soil (Table 12.1). Therefore, the shrub species did not demonstrate greater effects on soil chemical characteristics and, in contrast, decreased soil P content. The main impacts of these shrub species were recorded on soil functionalities and AM soil potential.

Microbial functional diversity in rhizosphere and in bare soil was assessed by measuring the patterns of in situ catabolic potential (ISCP) of microbial communities (Degens and Harris 1997). Organic compounds comprising of a range of amino acids, carbohydrates, organic acids, and amides were screened for differences in substrate-induced respiration (SIR) between soil treatments. The results show that microbial communities are very different according to the soil origin (Fig. 12.1). In particular, SIR responses to carboxylic acids were significantly higher in the *C. atlantica* and *T. satureioides* rhizosphere soils than in the soils of other origins (Fig. 12.1). Soluble organic acids are involved in plant nutrient acquisition and they particularly act as biological weathering agents of minerals in soils. They could be of high molecular weight (HMW) (i.e., humic substances) or low molecular weight (LMW) produced by plant roots and soil microorganisms (Ochs 1996). In the process of P acquisition from minerals, among the identified carboxylic acids, dicarboxylic (oxalic, tartaric, malic, fumaric, malonic acids) and tricarboxylic acids (citric acid) have been found very effective in P mobilization (Ryan et al. 2001). Since the highest SIR responses with most of these organic acids have been measured under *C. atlantica* and one of the targeted shrub species (*T. satureioides*), it suggests that these plant species and their associated microflora

Table 12.1 Chemical characteristics of the rhizosphere soils collected from *Lavandula dentata*, *L. stoechas*, *Thymus satureioides*, *Cupressus atlantica* and the bare soil (control) in the *C. atlantica* stand located in the N'Fis valley (Haut Atlas mountains, Morocco)

	Control	Plant species			
		L. dentata	*L. stoechas*	*T. satureioides*	*C. atlantica*
pH	7.5 a	7.0 a	7.5 a	7.4 a	7.7 a
Total carbon (%)	1.58 a	1.60 a	1.73 a	1.80 a	3.15 b
Total nitrogen (%)	0.09 a	0.10 ab	0.12 ab	0.10 a	0.14 b
C/N	17.2 a	15.7 a	14.7 a	18.8 a	22.9 a
Soluble P (mg kg^{-1})	19.7 d	7.9 a	9.8 ab	11.8 bc	13.1 c

Data in the same line followed by the same letter are not significantly different ($p < 0.05$) according to one-way analysis of variance. Adapted from Ouahmane et al. (2006)

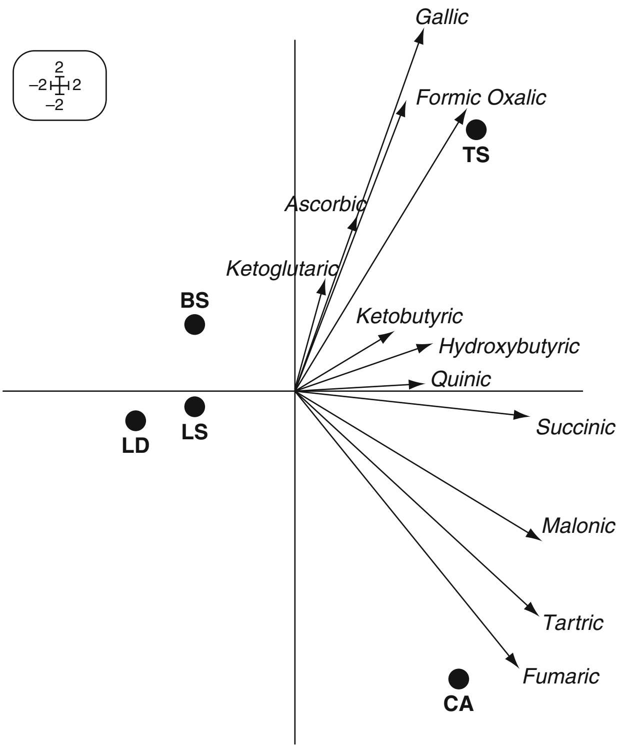

Fig. 12.1 Between-group analysis (BGA) of the substrate-induced respiration (SIR) responses with respect to the rhizosphere and the bare soils. *LS*, *LD*, *TS*, *CA* and *BS* represent *Lavandula stoechas, L. dentata*, *Thymus satureioides*, *Cupressus atlantica* and bare soils, respectively (Ouahmane et al. 2006)

(AM fungi and mycorrhizosphere microbiota) excreted higher amounts of such organic acids which could exert a selective influence on soil microbial communities through a multiplication of microorganisms that catabolize organic acids.

Beside the positive effects of "nurse" plant species on soil microbial functionalities, they also increase the mycorrhizal soil infectivity. Three *Lavandula* species (*L. multifida*, *L. dentata*, *L. stoechas*) have been studied for their AM dependencies (Ouahmane et al. 2007). After inoculating with the AM fungus, *Glomus intraradices*, the mycorrhizal dependency of *L. stoechas* was 33% whereas those recorded for *L. dentata* and *L. multifida* were 63 and 58%, respectively (Ouahmane et al. 2007). These results confirmed the high mycorrhizal dependency of these plant species (Azcon and Barea 1997). Lavender plants are very mycotrophic and enrich their cultural soil in AM fungal propagules. The *L. multifida* have been found to increase the mycorrhizal soil infectivity (Table 12.2) in six different soils as determined by MPN (most probable number) method (Ouahmane et al. 2007). In addition, this positive contribution is linked with the total soil P contents since the highest increases were recorded in soils with the lowest soil total P contents. Hence,

Table 12.2 Responses of soil mycorrhizal infectivity to *Lavandula multifida* plantation in six sandy soils after 5 months culturing

Soils	pH (H_2O)	Total C (g C kg^{-1})	Organic matter (%)	Total N (g kg^{-1})	Total P (g kg^{-1})	MSI[a]
1	5.8	3.99	0.7	0.26	68.5	533.3
2	4.9	2.85	0.5	0.19	78.7	1121.9
3	5.4	6.62	1.1	0.46	119.2	144.9
4	5.7	3.17	0.5	0.12	48.4	443.0
5	6.1	7.29	1.3	0.60	200.7	87.2
6	5.7	3.09	0.5	0.47	90.0	131.3

[a] (MSI of soil planted with *L. multifida*) – (MSI of soil unplanted with *L. multifida*) after 5 months culture in each soil. Adapted from Ouahmane et al. (2007)

as lavender plants have a patchy distribution in *Cupressus* stands in Haut Atlas Mountains in Morocco, this *Lavandula* species could act as a "nurse plant" for natural regeneration of *Cupressus* young seedlings by (1) enhancing soil microbial activities (in particular those involved in P mobilization), and (2) enhancing the mycorrhizal soil infectivity.

12.3 Response of *Cupressus* sp. Growth to the "Nurse" Plant Effects

Recognizing the benefits recorded for lavender plants on soil diversity and functioning, several studies have been undertaken to determine their potential impacts on the early growth of *Cupressus* sp. To test the potential benefits from the association between *Cupressus* sp. and "nurse plant" on the growth of each plant partner, Ouahmane et al. (2007) conducted an experiment in controlled conditions combining the following treatments: *C. arizonica*+*L. multifida*, *L. multifida* alone and *C. arizonica* alone in 20-l pots filled with non-disinfected sandy soil. The results show that the height of plant species was increased in the dual cultivation treatment (Fig. 12.2). In addition, after 4 months culturing, the growth of *L. multifida* and *C. arizonica* was generally higher when they were cultured together than those recorded for singly cultured treatment (Fig. 12.2). A similar effect was observed for the mycorrhizal colonization of the plants (Table 12.3). Other studies have also been conducted to evaluate the capacity of the "fertility islands" created by the nurse plants to facilitate the early growth of *Cupressus* spp.. Soil samples were collected under *L. dentata*, *L. stoechas* and *T. satureioides* rhizosphere and from an area free of cover plant (control). Soils were then packed in 1-dm^3 pots and one *C. arizonica* seedling was planted per pot. After 6 months of culturing, the height, stem diameter, N and P foliar contents, AM colonization, and shoot and root biomass were significantly higher in the soils originating from the nurse plants than in the bare soil (Table 12.4). These results suggest that *C. atlantica* has to be mycorrhizal in order to reach its optimal growth and that this Mediterranean tree species is "highly dependent on mycorrhizas" (Habte and Manjunath 1991). These

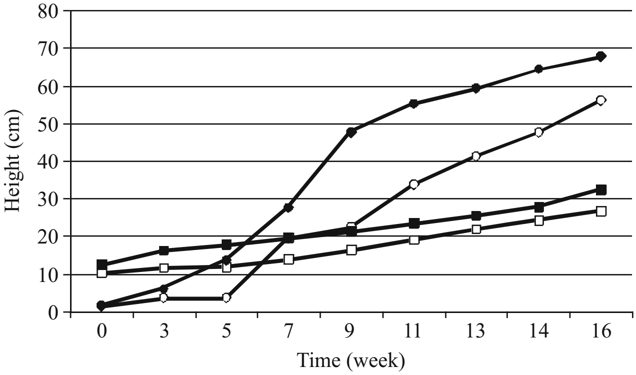

Fig. 12.2 Time course changes in plant height (in cm) of *Cupressus arizonica* and *Lavandula multifida* seedlings in the mono and dual cultivation treatments. Height growth of *C. arizonica* seedlings: *empty square C. arizonica* alone; *filled square C. arizonica*+*L. multifida* – height growth of *L. multifida* seedlings; *empty circle L. multifida* alone; *filled circle L. multifida*+ *C. arizonica* (adapted from Ouahmane et al. 2007)

Table 12.3 Growth and mycorrhizal colonization of *Cupressus arizonica* and *Lavandula multifida* after 4 months culturing in a non-disinfected sandy soil

Plant species	Treatment	Shoot biomass (mg dry weight/plant)	Root biomass (mg dry weight/plant)	Mycorrhizal colonization (%)
C. arizonica	Alone	3,393 a	735 a	4 a
	+ *L. Multifida*	3,456 b	1,499 b	92 b
L. multifida	Alone	1,020 a	1,102 a	10 a
	+ *C. arizonica*	1,032 a	2,120 b	50 b

For each plant species, data in the same column followed by the same letter are not significantly different ($p < 0.05$) according to one-way analysis of variance. Adapted from Ouahmane et al. (2007)

Table 12.4 Growth and mycorrhizal colonization of *Cupressus atlantica* seedlings planted in the rhizosphere soils collected from *Lavandula dentata*, *L. stoechas*, *Thymus satureioides*, *C. atlantica* and the bare soil (control) after 6 months culturing in greenhouse conditions

	Control	Soil origin			
		L. dentata	*L. stoechas*	*T. satureioides*	*C. atlantica*
Height (cm)	14.2 a	18.6 b	21.0 cd	23.0 d	19.4 bc
Stem diameter (mm)	2.02 a	2.72 bc	2.72 bc	2.94 c	2.54 b
Shoot biomass (mg dry weight/plant)	330 a	634 bc	738 c	666 bc	486 ab
Root biomass (mg dry weight/plant)	76 a	176 c	157 bc	115 abc	104 ab
N (mg/plant)	0.79 a	1.56 b	1.82 c	2.03 d	1.48 b
P (mg/ plant)	0.033 a	0.107 c	0.115 c	0.147 d	0.090 b
AM colonization (%)	35 b	48 b	50 b	75 c	54 b

Data in the same line followed by the same letter are not significantly different ($p < 0.05$) according to one-way analysis of variance. Adapted from Ouahmane et al. (2007)

studies confirmed that plant nurses mainly act on *Cupressus* seedling growth through their impact on AM fungus communities. AM fungi are important agents in promoting plant co-existence (Allen and Allen 1990). Moreover, the abundance and diversity of AM fungi are known to have a strong effect on the direction of succession (Medve 1984). This AM fungal effect is mainly important in early successional ecosystems where plant and soil have been severely disturbed and where AM fungi are absent or are in low abundance and patchily distributed (Hart et al. 2003). Hence, the use of plant nurses as promoting agent of mycorrhizal soil infectivity could be of great interest in restoring a self-sustaining vegetation cover in order to act against desertification.

12.4 Conclusion

The use of nurse shrubs facilitates seedling establishment in many different ecological settings in Mediterranean mountains (Gomez-Aparicio et al. 2004) suggesting that the removal of shrubs is not an appropriate practice for reforestation in Mediterranean mountains. Therefore, a new paradigm for the science of restoration of Mediterranean forests emerges from all these ecological studies (Maestre et al. 2001, 2002; Gomez-Aparicio et al. 2004). It is based on the natural spatial patterns of regeneration of woody vegetation with shrubs as micro-sites for recruitment. Furthermore, since the benefits of positive interactions between plant species is widely recognized (Callaway et al. 2002), this innovative forestry practice might be more relevant under the predicted rise in temperatures, dryness, and rainfall variability for the Mediterranean region under global warming (IPCC 2001). Since the primary limitation of plant fitness is generally represented by the severity of the physical environment, the enhancement of environmental conditions by nurse shrubs can be of crucial importance in many stressful environments.

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