

Rethinking the management of mycorrhizal soil infectivity to restore Mediterranean and tropical forest ecosystems

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Introduction

Desertification, one of the main causes of climate change, generally results from a variety of factors, including climatic variations and human activities. Among the man-mediated degradative activities, deforestation is considered to have a major impact by causing extinction, changes to climatic condition, desertification and the displacement of local populations (Defries et al. 2007).

Forest cover is an important source of protection from soil degradation and deforestation which impacts population structure, successional patterns and species diversity, generally inducing degradations in the physico-chemical and biological soil properties (Requena et al. 2001). These changes can be recorded in microbial functional capacity (microbial metabolism, biomass and composition, enzymatic activities and soil organic matter flux) which is mainly involved in soil quality and function (Chaer et al. 2009). Many studies have also shown that deforestation and soil cultivation alter soil microbial community structure (Bossio et al. 2005) and may lead to reduction in microbial biodiversity (Chaer et al. 2009).

Among components of soil microbiota, mycorrhizal fungi are known to be essential key components of sustainable soil-plant systems, especially in arid ecosystems (Duponnois et al. 2011). The mycorrhizal symbiosis mobilizes and transports nutrients to roots (Smith & Read, 2008), reduces water stress (Augé, 2001) and improves soil aggregation in eroded soils (Caravaca et al. 2002). It has also been reported that arbuscular mycorrhizal (AM) fungi affect the diversity of plant communities (van der Heijden et al. 1998) and influence relationships between plants (van der Heijden et al. 1998).

Since trees are a primary source of protection from soil degradation, many afforestation programs have been undertaken but with generally low performance in terms of productivity and seedling survival after outplanting (Duponnois et al. 2005a). These deficiencies have usually been recorded in Mediterranean semi-arid areas known to have low bioavailable phosphate content and high phosphate retention capacities (Duponnois et al. 2011). This environmental context represents the most favourable conditions for AMF's potential to increase plant growth without any mineral fertilizers (Rodriguez & Sanders, 2015). Unfortunately, this microbial resource has been largely neglected despite numerous studies focused on this symbiosis.

The native inoculum potential of AM fungi in arid and semi-arid Mediterranean ecosystems is generally limited which, in turn, prevents plant establishment and growth (Smith & Read 2008). It is necessary to apply mycorrhizal inoculation technologies or to manage native AM fungus communities to replace or reinforce the mycorrhizal potential in these degraded areas (Duponnois et al. 2011).

Approaches to AM application in forestry practices

This chapter aims to describe different practical approaches to integrate the AM symbiosis in forestry practices through a “reductionist” approach (also named Controlled mycorrhization) (Inoculation of optimized AM fungal strains to improve the plant growth in unfriendly conditions) or a “holistic” approach (Suitable management of AM fungal diversity for ensuring AM fungi – dependent ecosystem services) (Rodriguez & Sanders, 2015). Each of these cultural practices will be illustrated by results from field experiments performed in Mediterranean and tropical areas.

The “reductionist” approach (controlled mycorrhization)

In recent decades, considerable research has been made by using specific mycorrhizal fungal strains to enhance outplanting performances with forest tree species (Caravaca et al. 2002). Hence, numerous studies have reported the beneficial effects on plant growth resulting from AM fungal inoculation during the nursery plantation. Among all the AM fungal strains tested in these experiments, *Rhizophagus irregularis* has attracted great interest because of (1) its world-wide distribution, (2) its high genetic variability and variation in effects on plant growth and (3) its ability to be produced in an *in vitro* system.

Some of its impacts on the growth of different tree species in controlled conditions are reported in table 1. Most of these experiments have been performed in controlled conditions and few studies have clearly demonstrated the benefits

Table 1
Impact of *R. irregularis* on the growth of tree species
in controlled conditions after different times of cultivation

Tree species	Time (months)	Impact of <i>R. irregularis</i> on plant growth		References
		On shoot biomass	On root biomass	
<i>Acacia holosericea</i>	4	+ 77.5% ⁽¹⁾	+ 122.7% ⁽²⁾	Duponnois et al. (2005b)
<i>Fraxinus uhdei</i>	3	+ 250%	+ 180%	Ambriz et al. (2010)
<i>Cupressus atlantica</i>	3	+ 48.7%	+ 155.2%	Ouahmane et al. (2007)
<i>Acacia mangium</i>	3	+ 20.2%	+ 50%	Weber et al. (2005)
<i>Citrus aurantium</i>	5	+ 273.3%	+ 66.3%	Nemec & Vu (1990)
<i>Acacia tortilis</i>	4	+ 499.2%	+ 78.3%	André et al. (2003)
<i>Parkia biglobosa</i>	2	+7.1%	+ 25.5%	Guissou et al. (1998)
<i>Tamarindus indica</i>	2	+6.7%	+ 36%	Guissou et al. (1998)
<i>Zizyphus mauritiana</i>	2	+ 130.3%	+ 152%	Guissou et al. (1998)
<i>Alnus cordata</i>	2	+ 441%	+ 1407%	Monzon & Azcon (2001)
<i>Alnus incana</i>	2	+ 644%	+ 1041.2%	Monzon & Azcon (2001)
<i>Alnus glutinosa</i>	2	+ 996.7 %	+ 1194%	Monzon & Azcon (2001)
<i>Acacia senegal</i>	3	+ 171.4%	+ 127.3%	Ndoye et al. (2013)
<i>Phoenix dactylifera</i>	5	+ 140.4%	+ 165.4%	Baslam et al. (2014)

⁽¹⁾ (Shoot biomass of mycorrhizal plants / Shoot biomass of non mycorrhizal plants) x 100. ⁽²⁾ (Root biomass of mycorrhizal plants / Root biomass of non mycorrhizal plants) x 100.

of fungal inoculation in the field. The degree of mycorrhizal responses on a reforestation site depends on the status of fungal colonization at planting, and the persistence of introduced fungi and other biotic and abiotic factors at the planting site (Duponnois et al. 2011).

Hence, the use of AM fungi and plants adapted to the local environmental conditions may be a prerequisite for the success of reforestation programmes (Duponnois et al. 2005a). The potential effect of mycorrhizal inoculation with native AM fungi on the survival rates and early growth performance in the field of Mediterranean tree species (i.e. cypress, carob) has been assessed in a few studies (Manaut et al. 2015). The results showed the high potential of this approach by sustainably improving the growth and nutrient status of both tree species and also by inducing a positive soil microbial environment for nutrient cycling and environmental stress resistance (figs. 1 & 2).

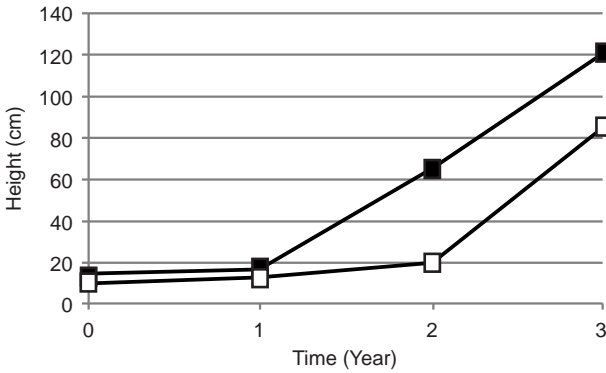
The “holistic” approach

It has been reported that certain shrubs react positively to the survival and growth of other neighboring plant species by creating a better environmental habitat with low stresses from high radiation and temperature as well as from soil nutrient and moisture deficiencies (Callaway & Walker, 1997) named “the nurse-plant syndrome” (Niering et al. 1963). The ecological facilitation between plant species results in the patchy distribution of the vegetation commonly observed in Mediterranean areas, especially in degraded ecosystems (Callaway & Walker, 1997).

Hence it has been suggested that the use of nurse plants as planting microhabitats in Mediterranean degraded ecosystems could promote the survival and development of native tree species and constitute an alternative reforestation technique compared to the standard practices (Duponnois et al. 2011). The “fertility islands” or “resource islands” (Schlesinger et al. 1996) resulting from the establishment of these nurse plants show a higher arbuscular mycorrhizal (AM) soil infectivity compared to the adjacent soil away from plant influence (Duponnois et al. 2011), which can improve plant growth and survival in arid conditions, by increasing the supply of nutrients to the plants (especially for soil P uptake) (Smith & Read, 2008), enhancing soil aggregation in eroded soils (Caravaca et al. 2002) and reducing water stress (Augé, 2001).

After three years’ plantation, it was reported that the association between *C. atlantica* and a nurse plant, *L. stoechas*, enhanced the growth of *C. atlantica* and provided better soil microbial characteristics compared to the control treatment (fig. 3) (Duponnois et al. 2011). AM mycelium network, total microbial activity, dehydrogenase activity, phosphate-solubilizing fluorescent pseudomonads and N, P nutrient uptake by *C. atlantica*, were significantly higher in the presence of *L. stoechas*. This pioneer shrub facilitated the early establishment of Cypress seedlings by improving soil microbial characteristics and AM fungus community development. Since the facilitative effect of one

A. HEIGHT



B. COLLAR DIAMETER

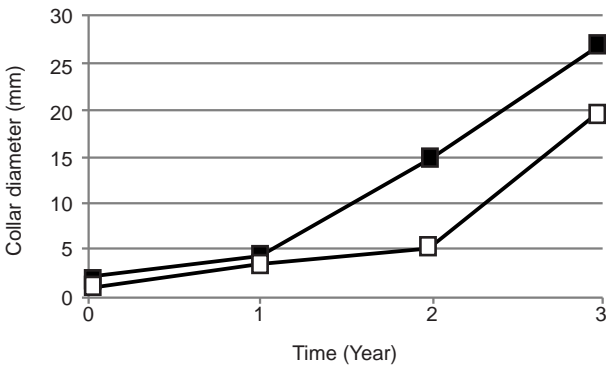


Figure 1

Height and collar diameter of carob outplants in the field, either inoculated with AM fungi (■) or non-inoculated (control □). An asterisk indicates a significant ($P < 0.05$) difference between the two treatments for a given year (From Manaut et al. 2015).

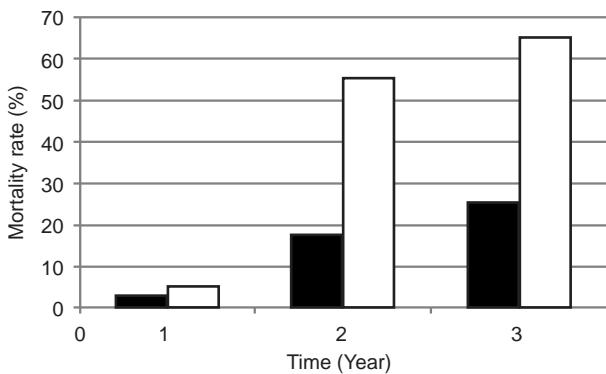


Figure 2

Cumulative mortality of carob outplants in the field, either inoculated with AM fungi (■) or non-inoculated (control □) during the three years of plantation (From Manaut et al. 2015).

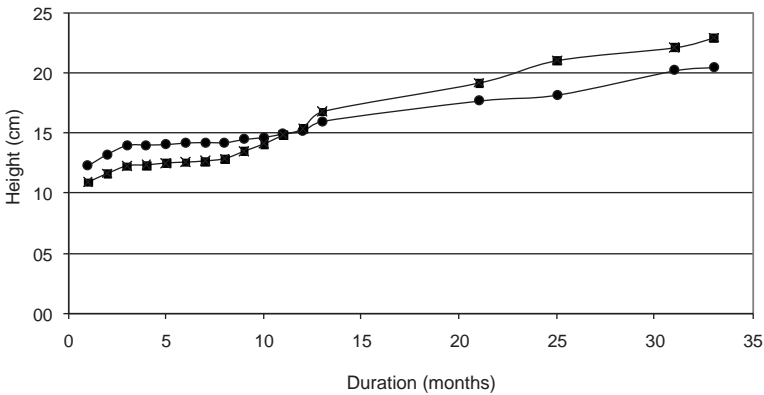


Figure 3

Time course changes in plant height (expressed in cm) of *C. atlantica* outplants growing under natural conditions in the High Atlas Mountains (Morocco), either non-inoculated (Control) (●) or associated with *L. stoechas* plants (■). Symbols represent means (\pm standard error of the mean). An asterisk indicates that the difference between the height of uninoculated *C. atlantica* and *C. atlantica* associated with *L. stoechas* is significant in the corresponding month according to the Newman Keul's test ($p < 0.05$).

plant species on another increases with abiotic stress (Callaway, 1995), the benefits of this technique would be useful in reforestation programs undertaken to rehabilitate degraded areas in the Mediterranean region (Duponnois et al. 2011). Other shrub species have been identified for their potential nursing effects on Mediterranean tree species (fig. 4).

Conclusion

These data show that the management of the mycorrhizal soil infectivity through different cultural approaches (reductionist or holistic approaches) has large potentialities to improve the performances of afforestation programmes, especially in Mediterranean and Tropical areas. This biological tool must be used according to the biological characteristics of the targeted areas (physico-chemical characteristics, biological characteristics) in order to reach sustainable objectives in forest ecosystem productivity and resistance. Hence ecological approaches at community and population scales must be encouraged with a view to better informed management of AM fungi in order to propose practical solutions to manage forest ecosystems in a sustainable manner.

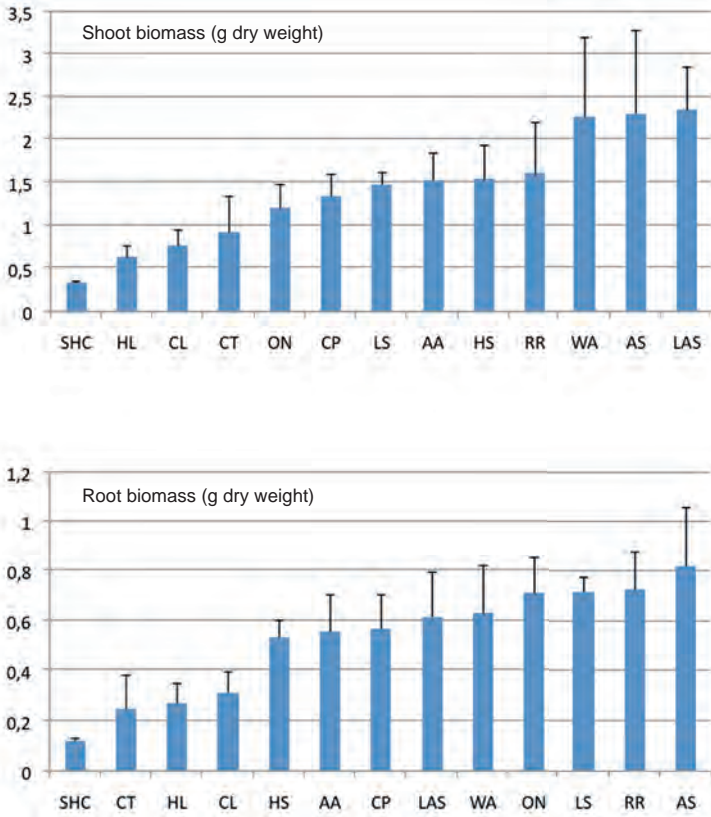


Figure 4

Growth responses of *Acacia raddiana* seedlings to the soil origins collected under shrub species native from Moroccan arid areas after 4 months' culture in glasshouse conditions (Unpublished data). HL: *Helianthemum lupii*; ON: *Ononis natrix*; HS: *Haloxylon scoparium*; RR: *Retama retama*; WA: *Withania adpressa*; LS: *Lavandula sp.*; LAS: *Launea sp.*; CL: *Cleome sp.*; CT: *Convolvulus trautianus*; AA: *Artemisia herba alba*; AS: *Astericus sp.*; SHC: Soil non influenced by plants.

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The Mediterranean Region under Climate Change

A Scientific Update

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