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Plant soil symbioses, role in Terga (West of Algeria) sandpit rehabilitation

Benelhadj Djelloul Saadia[1], Ighilhariz Zohra[*1], Boukhatem Zineb Faiza[1], Robin Duponnois[2], Philippe de Lajudie[2], Bekki Abdelkader[1]

[1]*Laboratory of Biotechnology of Rhizobia and Plant Breeding, Faculty of Nature and Life Sciences, Oran 1 Ahmed Ben Bella University, Oran, Algeria*

[2]*IRD-UMR LSTM, Campus de Baillarguet, Montpellier, France*

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Abstract

Intensive exploitation of Terga sandpit situated in west of Algeria had led to degraded ecosystem. The objective of this work consists in a strategy of site revegetating by introducing native species *Schinus terebinthifolius* associated or not to two nitrogen fixing species *Retama monosperma* and *Lotus creticus*. Physico-chemical soil analysis and mycorrhyzal soil infectivity determination were performed on bare soil and after 24 months of planting. Endomycorrhizal structures presence or absence was recorded for each treatment. Compared to naked soil, the obtained analysis showed soil fertility evolution after two years of plants introduction. Thus, for the various plant associations, the mycorrhizal soil infectivity was significantly improved and increased more than four times. Control area mycorhization frequency was 60 % and more than 80 % for *Schinus terebinthifolius* associated with legumes. Hence, this association had a positive effect on *Schinus terebinthifolius* growth, phosphorus and nitrogen sheets content, in particular when this species was associated with *Lotus creticus*.

* **Corresponding Author: Ighilhariz Zohra** ✉ zoraighil@yahoo.fr

Introduction

Terga sandpit is a Mediterranean natural ecosystem weakened by natural and anthropological constraints, especially deteriorated by an anarchistic and excessive sand exploitation (Ghodbani *et al.*, 2008). This influences the plant place setting and the physical, chemical and biological characteristics of soil (Garcia *et al.*, 1997; Requena *et al.*, 2001; Hamel, 2004; Perevolotsky *et al.*, 2005). Among the microbial components, particularly sensitive to these erosion phenomena, the symbiotic microorganisms (rhizobia and mycorrhizal fungi), known to be key elements in the main telluric biogeochemical cycles (C, N and P) functioning (Duponnois, 2013) and so favor the plants growth. Mycorrhizal fungi were a ubiquitous world ecosystems component and were generally considered as a key factor for sustainable soil-vegetation system (Brundrett, 2002).

They improve the plants mineral nutrition (Hopkins, 2003; Grimoldi *et al.*, 2005; Smith and Read, 2008) in particular the minerals with low mobility as phosphorus and nitrogen (Plenchette and Burden, 1988; Provorov *et al.*, 2002; Fortin *et al.*, 2008). Furthermore, arbuscular mycorrhizal fungi (AMF) hyphea also play a role in the soil aggregates formation and stability (Hamel *et al.*, 1997; Wright and Upadhyaya, 1998) and so limit the erosion risks (Le Roux, 2002). They play a major role in forest management programs and in degraded sites rehabilitation (Duponnois *et al.*, 2010).

The objective of this work consists in finalizing a sandpit revegetation strategy after exploitation in Terga (Ain Temouchent, Algeria) based on the symbioses plants/mycorrhizal fungi and legume/nitrogen fixing bacteria.

Their effect on soil composition and structure, nourishing elements bioavailability and the microbial activity, on the basis of Mycorrhizal Soil Infectivity assessment.

It aims to evaluate the associative impact between a non-legume native botanical species *Schinus terebinthifolius* associated or not with nitrogen fixing species (*Retama monosperma* and *Lotus creticus*).

Materials and methods

Experimental site localization

The experiment was realized on an exploited sandpit land plot in Terga-Ain Temouchent (Algeria) situated at 90 km in the West of Oran, at 35°26' 33.03 North latitude and 1°13' 33.48 West longitude. The annual average temperature is 17.5°C; the recorded pluviometric accumulation is 300 to 400 mm per year. *Schinus terebinthifolius* is considered as an endemic species in this region.

Experimental plan

Two years old *Schinus terebinthifolius* plants obtained from a tree nursery were introduced into a 120m² land plot. This ligneous species was associated or not with two legumes, *Lotus creticus* and/or *Retama monosperma*. The experimental plan was totally randomized with 10 repetitions for each of the 4 treatments (Table1). The watering was assured by a drip system (Fig. 1).

Table 1. Treatments realized with *Schinus terebinthifolius* and legumes association for the sandpit of Terga rehabilitation.

Treatment 1 (10 plants)	Treatment 2 (10 plants)	Treatment 3 (10 plants)	Treatment 4 (10 plants)
SL	SR	SM	So (control)
Schinus terebinthifolius + *Lotus creticus*	*Schinus terebinthifolius* + *Retama monosperma*	*Schinus terebinthifolius* + Mix (*Retama monosperma* + *Lotus creticus*)	*Schinus terebinthifolius* non associated

Fig. 1. Site of the sandpit of Terga the day of plants introduction on April, 2012.

Physical and chemical analysis of soil

Physico-chemical characteristics evolution was studied by analyzing soil samples collected at 20-30 cm of depth from the studied site.

Five soil sub-samples were collected diagonally from plot land for forming composite by April, 2012 before the planting, and the second soil sampling was performed in April 2014 after two years of plant species introduction. For the latter, soil sampling was performed randomly around plants.

Soil Mycorrhizal Infectivity (MSI)

The microbiological characteristics evolution was effectuated on a soil homogenate taken at 20 cm distance around the introduced plant species with three repetitions for each treatment, a sample from naked soil served as control.

The used method was described by Plenchette *et al.* (1989). It consisted in mixing the soil samples which were sterilized twice (at 140 °C for 1 hour) with the same soil which was not sterilized at different rates (100, 48, 24, 12, 6 and 3%) and filled in 150 ml/pots.

Ten sorghum seeds were sown by pot with five repetitions for each ratio. After 15 days of growth, the roots were colored by Phillips and Hayman (1970) method which revealed the presence of mycorrhizal structures in the roots. The observation was carried out by light microscopy "OPTIKA".

Parameters of plant growth

The growth of *Schinus terebinthifolius* was estimated by the height measure from the snare to the end of the main stem and by the branching out number. The follow-up was made monthly for 24 months.

Estimation of the degree of roots' natural colonization

Schinus terebinthifolius roots sampling were made after 24 months of its introduction. Three samples for each treatment were randomly chosen and colored as described by Phillips and Hayman (1970).

The roots were washed with water, cut in about 1 cm fragments, cleared in 10 % KOH solution for 45min at 90 °C then placed for 10 min in lactic acid at room temperature to eliminate the KOH and then colored during 20 min at 90°C in Trypan Blue. The excess of the coloring agent was eliminated by the addition of glycerin. The frequency and the intensity of colonization were calculated according to Trouvelot *et al.* (1986) method.

Plant aerial part nitrogen and phosphorus content determination

Chemical analyses were made for mineral elements content determination in aerial parts of plant to evaluate the effect of different plants associations on their nitrogen and phosphorus contents. *Schinus terebinthifolius* aerial parts were dried at 60°C during 3 days then powdered for total nitrogen analysis according to Kjeldahl (1883) method and the phosphorus according to Joret-Hebert (1955).

Statistical analysis

The results were subjected to a one way variance analysis (ANOVA) with SPSS 17 software; means were compared by Tukey test. Correlation coefficients were calculated between all variables.

Using the same software, a principal component analysis (PCA) was carried out for grouping the treatments with physical and chemical analysis and soil MSI.

A correlation analysis was carried out to test the covariance among dependant variables (MSI, pH, organic matter, nitrogen and phosphorus rates) by means of the Pearson coefficient using the same software.

Results and discussion

A degraded site rehabilitation experience in Terga region was made using native *Schinus terebinthifolius* associated with legumes *Lotus creticus* and *Retama monosperma*.

Physical and chemical soil analysis of the studied soil

Granulometric analysis (Table2) showed that soil presented a sandy texture of more than 90% sand with very few clays and silt. The naked soil before plantation presented an alkaline pH (8,8), and after 24 months, it decreased slightly with values close to the neutrality for the different plant associations (pH 7,5-6,5). The rate of naked soil active limestone was 4,90%, it increased in the soils of the different treatments and varied between 13,50 and 18,36%. It was about soils moderately calcareous. The studied soils presented EC<1 mS/cm and were considered as no saline for all the samples.

The organic matter rate (MB > 0,01%) and nitrogen content (> 0,05%) were very low but increased slightly under the different treatments compared with the naked soil (Table 2). The same phenomenon was observed for the phosphorus which didn't exceed 12 ppm for all samples while it was only 6,3 ppm for the naked soil. The C/N ratio was very low and varied between 0,15 and 0,20. It was an indicator reflecting organic matter evolution degree and its decomposition capacity more or less quickly in the soil.

Table 2. Physical-chemical analysis of soil taken from the degraded site of Terga.

		Bare soil	SL	SR	SM	So (control areas)
Granulometry %	Clay	$2^{a}\pm0$	$3^{a}\pm0$	$5^{a}\pm0,8$	$3^{b}\pm0$	$2^{a}\pm0$
	Silt	$4^{a}\pm0$	$3^{a}\pm1$	$2^{b}\pm0$	$2^{b}\pm0$	$4^{a}\pm0$
	Sand	$94^{a}\pm0$	$94^{a}\pm1,7$	$93^{a}\pm0$	$95^{a}\pm1,7$	$94^{a}\pm0$
EC (1/5 mS/cm)		$0,18^{a}\pm0,02$	$0,207^{bc}\pm0,03$	$0,252^{be}\pm0,02$	$0,214^{b}\pm0,02$	$0,178^{ce}\pm0,02$
pH		$7,5^{a}\pm0,2$	$6,8^{b}\pm0,1$	$6,5^{d}\pm0,05$	$7,2^{c}\pm0,1$	$7,5^{d}\pm0,2$
Carbon/ Nitrogen(C/N)		$0,15^{a}\pm0,04$	$0,2^{a}\pm0,005$	$0,17^{a}\pm0,02$	$0,15^{a}\pm0,009$	$0,15^{a}\pm0,0015$
Carbon %		$0,0044^{a}\pm0,0003$	$0,01^{a}\pm0,0005$	$0,0069^{a}\pm0,001$	$0,0054^{a}\pm0,0009$	$0,0044^{a}\pm0,0003$
Totallimestone%		$50,5^{a}\pm2,17$	$45,5^{b}\pm0,7$	$50,5^{d}\pm1,3$	$38^{c}\pm1,7$	$50,5^{c}\pm2,1$
Active limestone%		$13,5^{a}\pm0,5$	$16,3^{be}\pm0,5$	$18,36^{ced}\pm0,1$	$14,3^{b}\pm1,6$	$13,5^{c}\pm0,5$
Organic Matter %		$0,007^{a}\pm0$	$0,017^{a}\pm0,0008$	$0,011^{a}\pm0,001$	$0,0092^{a}\pm0,0015$	$0,0075^{a}\pm0,0005$
Total Nitrogen %		$0,028^{a}\pm0,007$	$0,05^{b}\pm0,001$	$0,040^{bd}\pm0,005$	$0,036^{cde}\pm0,0005$	$0,028^{ae}\pm0,0007$
Phosphorus (ppm)		$7,16^{a}\pm0,76$	$11,67^{b}\pm0,5$	10,33 b ±0,5	$11,66^{b}\pm0,2$	$7,2^{a}\pm0,7$

Values followed by the same letter were not significantly different according to the test of Tukey ($p \leq 0.05$).

All the obtained results showed that the soil was characterized by a low chemical fertility regarding to low contents in major assimilable nutritional elements (nitrogen, phosphorus). However, a various physico-chemical soil parameters evolution was observed under introduced plants influence more marked when *S. terebinthifolius* was associated with *L. creticus* followed by the mix and finally *R. monosperma* compared with the control in particular in the case of phosphorus, nitrogen and organic matter. Phosphorus and nitrogen rate evolution under introduced species influence was also observed by Mouffak *et al.* (2014) under *Acacia saligna*-rhizobial-FMA associations influence. Callaway *et al.* (1995) showed that the soils fertility was improved by shrubs pioneers' presence which facilitated other plants development. Koske and Halvorson (1981), Brundrett (1991) and Hatimi and Tahrouche (2007) indicated that the sandy soils were generally poor in phosphorus and nitrogen and with their fungal symbionts, legumes were considered as soil fertility key elements. The fungal symbionts were not only used for their impact on the plant, but also for their capacity to persist in the soil (Duponnois *et al.*, 2013). The phosphorus rate was generally low in the alkaline and calcareous soils, it tends to be insolubilized by the calcium (phosphate of calcium and magnesium) and it was possible that the phosphoric anions precipitated in active limestone contact (Baize, 2000).

Some microorganisms such as *Pseudomonas*, *Bacillus* and rhizobia were able to solubilize phosphorus (Rodriguez and Fraga, 1999). Furthermore, Xiao Lin *et al.* (1997) reported that more than 80 % of the phosphorus consumed by the plant was absorbed by AMF extra-roots hyphae by enzymes excretion (phosphatases) degrading organic phosphates, or by diverse implementation mechanisms modifying the rhizospheric physico-chemical conditions (excretion of H^+ or HCO_3-and of acids or organic anions having complexing properties) (Mousain *et al.*, 1997).Indeed, the phosphatases activities measured in the infected roots or on the surface of mycorhizae were very superior to those of not infected (Williamson and Alexander, 1975). The nitrogen rate increase was probably due to the beneficial biological nitrogen fixation effect made by the introduced legumes in association with rhizobia. This improvement resulted from nitrogen and rich organic matter contribution by roots and leaves renewal and mainly by the litter decomposition (Bernhard-Reversat *et al.*, 1998). Besides, Hodge *et al.* (2001) suggested that the AMF improved the organic nitrogen decomposition.

Mycorrhizal Soil Infectivity (MSI)

A soil MSI characterized not only mycorrhizal fungi population present in the soil in spores mycelium and root mycorrhizal fragments form, but also the fact that this population was able to forming mycorrhizae in poor soil conditions. Microscopic observation showed the presence of different fungal structures (hyphae, vesicles and arbuscules) (Fig.2).

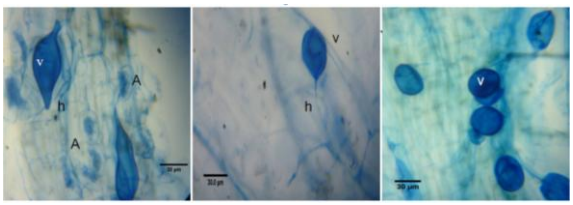

Fig. 2. Microscopic observation of the Arbuscular Mycorrhizal Fungi structures in the roots of trapping plant *Sorghum bicolor* from the rehabilitated soil of Terga site.

v: vesicle, h: hyphae, A: Arbuscule Experimental plot soil MSI_{50} was calculated then compared with the different treatments.

It was 17,46 at To before the plantation (Table3), this value indicated the quantity of soil necessary to mycorhize 50% of plants. After 24 months of planting, *S. terebinthifolius* MSI_{50} non associated with legumes (So) was 13,87 (Table3). The effect of legumes associated with *S. terebinthifolius* was more visible on the MSI_{50}.It was significantly ($p < 0.05$) lower when associated with *L. creticus* (SL=3, 94), followed by the mix (SM=4,02) and with *R. monosperma* (SR=5,25) (Table3). Root colonization establishment in the case of SL and SM required three times less of inoculum and two fold with *R. monosperma* compared with control (So).

Table 3. Determination of the SMI_{50} soils collected after 24 months of plants introduction in the rehabilitated Terga site.

Soil	y=Ax+B	R^2	MSI_{50}
T_o	Y=0,19x-0,007	0,824	17,46[a]
SL	Y=0,52x-0,21	0,983	3,94[b]
SR	Y=0,47x-0,29	0,963	5,25[b]
SM	Y=0,54x-0,26	0,971	4,02[b]
So(control areas)	Y=0,24x-0,15	0,932	13,87[c]

Y: linear regression to calculate the percentage of mycorrhizal plants according to the logarithm of the quantity of non sterilized soil. MSI_{50}: Mycorrhizal Soil Infectivity. R2: the coefficient of correlation. Values followed by the same letter were not significantly different according to the test of Tukey ($p \leq 0.05$).

The soil MSI_{50} before the plantation (17,46) indicated that legumes play a role in the soil mycorrhizal propagules enrichment. This beneficial effect was in agreement with Sanon *et al.* (2005) results who noted a clear soil mycorhizal potential improvement under *Zornia glochidiata* and mycorrhizal propagules soil enrichment under the influence of *R. monosperma, Acacia saligna, L. creticus* and *Pistacia lentiscus* observed by Bouazza Marouf *et al.* (2015).

MSI_{50} values decrease showed the strongly mycotrophic species effect, on legumes (*L. creticus* and *R. monosperma*) soil. Indeed, plants with high mycorrhizal dependency promote the fungi development which had a direct incidence on soil infectious mycorrhizal infectivity increase (Duponnois *et al.*, 2001).

Legumes were generally classified in the hyper mycotrophic species group (Habt *et al.*, 1991) which has, consequently, the capacity to promote the fungal symbionts multiplication and improve soil MSI (Plenchette *et al.*, 1983; Johnson *et al.*, 1992; Duponnois *et al.*, 2013).

In the arid and semi-arid areas, legumes were generally considered as nurse plants which can facilitate the survival and certain forest essences development by improving the soils nitrogen content, but also, because of their high mycotrophy, by contributing to the preservation of the MSI (Duponnois *et al.*, 2001). The association nurse plant/forest species would improve, not only the soil MSI, but also the ground microbial characteristics and the forest species growth (Duponnois *et al.*, 2012).

This effect "nurse plant or facilitator" was a quite particular importance in Mediterranean environment where the desertification processes worsening leads to soil microbial activities dysfunctions (Garcia *et al.,* 1997). Duponnois *et al.* (2011) showed that at the top Moroccan Atlas, *Lavandula stoechas* associated with *Cupressus atlantica* stimulated cypress young plants development, improved the MSI and microbial soil characteristics compared with non-associated *Cupressus atlantica,* showing the *Lavandula stoechas* plant nurse effect.

Studies led also on the lavender and the thyme showed that these species improved significantly the fungal propagules multiplication in the soil (Ouahmane *et al.*, 2006a). Compared with a naked soil, without plant place setting, the mycorhizal potential (number of propagules by 100 g of soil) was multiplied by 17 when this soil was colonized by *Lavandula dentata*, by 23 when the soil was influenced by *L. stoechas* and by *Thymus satureioides* (Ouahmane *et al.*, 2006a).

Plants development monitoring

For Terga site rehabilitation, *R. monosperma* and *L. creticus* were used as facilitator or nurse plant to promote *Schinus terebinthifolius* development.

The scientific hypothesis of this cultural practice was to find the best associations between the nitrogen fixing and non fixing species for the site rehabilitation.

After 24 months (Fig.3, 4), *S. terebinthifolius* growth in the presence of legumes *R. monosperma* and\or *L. creticus* was improved compared to control. Introduced plants aerial part height and branches number were recorded in the Fig. 5 A and B.

Fig. 3. Overview of the site of the sandpit of Terga after 24 months of the introduction of plants.

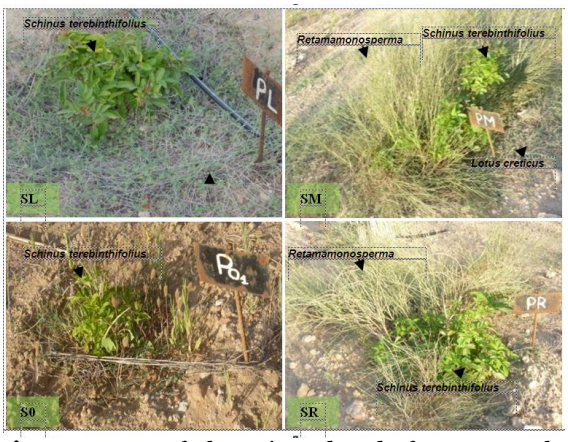

Fig. 4. Aspect of plants introduced after 24 months of growth in the rehabilitated Terga site.

So (control): *Schinus terebinthifolius* non associated, SR: *Schinus terebinthifolius* + *Retama monosperma*, SL: *Schinus terebinthifolius* + *Lotus creticus*, SM: *Schinus terebinthifolius* + Mix (*Retama monosperma* + *Lotus creticus)*

The Fig. 5A shows *S. terebinthifolius* growth evolution during 24 months. In first six months no changes were observed; this corresponded to post planting adaptation period.

After 24 months, various associations showed a significant effect ($p < 0.05$) on *S. terebinthifolius* growth. Indeed, the main stem height was significantly superior when associated with *L. creticus* (47,70 ± 0,87 cm) and in the mix (46,90 ±0,87 cm) compared to the control (40,90 ±0,65cm).

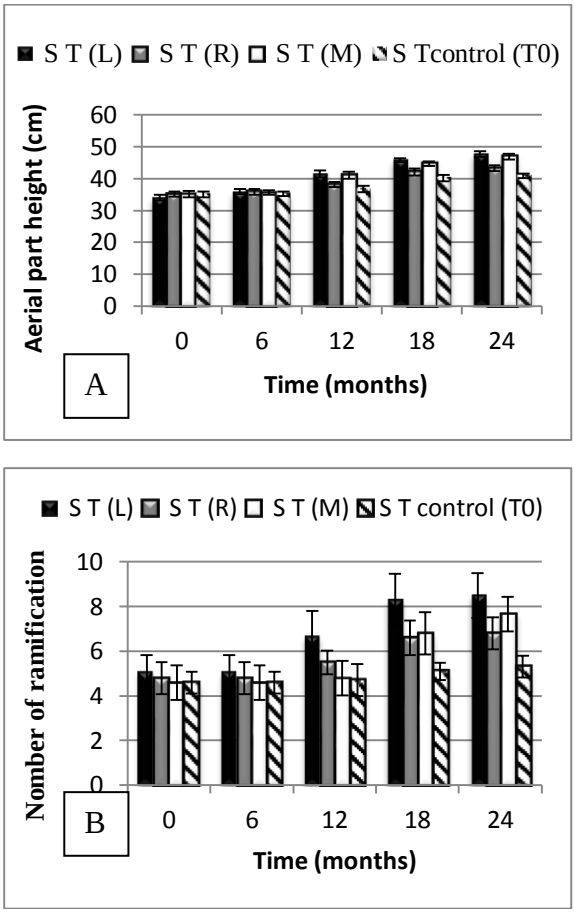

Fig. 5. Follow-up of the growth of *Schinus terebinthifolius* under the influence of the various associations after 24 months on the site of plantation. a) height of the air part, b) number of ramification.

So (control): *Schinus terebinthifolius* not associated, SR: *Schinus terebinthifolius* + *Retama monosperma*, SL: *Schinus terebinthifolius* + *Lotus creticus*, SM: *Schinus terebinthifolius* + Mix (*Retama monosperma* + *Lotus creticus*).

The two legumes associative effect was also observed on *S. terebinthifolius* ramification number (Fig. 5B). Compared with the control (3,50±0,49), this effect was notice able after 24 months on *S. terebinthifolius* associated with *L. creticus* (8,5±1,0) growth, followed by the mix (*R.monosperma* + *L.creticus*) (7,66±0,77) and *R. monosperma* (6,80±0,71).The three associations significantly improved the branching number compared to the control($p < 0.05$). Results showed that *S. terebinthifolius* growth when associated with legumes was more important than control. In a wide range of conditions, Bertness *et al.* (1997) and Stachowic *et al.* (2001) indicated that this type of positive association plays a role in the dynamics of plant communities, on the structure of epigeal stratum and facilitated certain forest essences growth (Bellingham *et al.* 2001, Holl*et al.*, 2002, Duponnois *et al.*, 2013). Franco and Nobel (1989) and Tewksbury and Lloyd (2001) named this type of interaction 'plant nurse effect'. Indeed legumes developed better on the little fertile soils (Cruz and Garcia, 1992), because of the symbiotic microorganisms which colonized their root system such as rhizobia and mycorhizals fungals. They would have the capacity to favor fungal propagules (hyphae, spores) development in their rhizosphere which facilitates the growth of other botanical species (Cruz and Garcia, 1992). Several works showed the mycorhizal fungi positive influence aspects on plants survival and development (Smith, 1980; Manjunath and Habte, 1988; Bago *et al.*, 1999; Smith and Read, 2008), in particular in marginalized soils (Dommergues and Mangenot, 1970; Strullu, 1991).

AM root colonization detection and rate evaluation

The microscopic study of treated *S. terebinthifolius* roots taken from Terga site and colored with Trypan Blue revealed the presence of different endomycorrhizal structures (hyphae, vesicles and arbuscules) (Fig. 6). Vesicles were abundantly observed compared to the arbuscular structures.

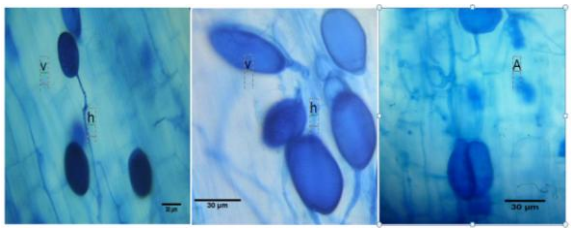

Fig. 6. Observation of the Arbuscular Mycorrhizal Fungi structures in the roots of the plant *Schinus terebinthifolius* after 24 months v: vesicle, h: hyphae, A: Arbuscule.

Rate Estimation of root colonization AM

Most of *S. terebinthifolius* roots were colonized by AM fungi (Fig.6). Roots mycorrhization results were recorded in the Table. 4.

After 24 months, we observed an evolution for all associations; where mycorrhizal frequency was more than 80% compared to the control (60%).

Table 4. Mycorhizal frequency and mycorhizal Intensity colonization in the root system of *Schinus terebinthifolius* after 24 months of the growth in the rehabilitated Terga site.

Treatments	SL	SR	SM	So (control)
Mycorhizal Frequency (F %)	87^{a}±2,64	$81,33^{a}$±2,3	$83,33^{a}$±3,05	60^{b}±0
Mycorhizal Intensity colonization in the root system (M%)	81^{a}±1,73	70^{a}±0	76^{b}±5,29	53^{c}±6,08

So: *Schinus terebinthifolius* not associated, SR: *Schinus terebinthifolius* + *Retama monosperma*, SL: *Schinus terebinthifolius* + *Lotus creticus*, SM: *Schinus terebinthifolius* + Mix (*Retama monosperma* + *Lotus creticus)*. Values followed by the same letter were not significantly different according to the test of Tukey ($p \leq 0.05$).

These results indicated the impact of legumes on the soil propagules richness after 2 years of planting. The same pattern was observed for the mycorrhization intensity which was superior to 70% for all the associations compared to the control (M=53%). *S. terebinthifolius* associated with legumes presented a mycorrhizal frequency and mycorrhizal intensity significantly improved, compared to the control ($p < 0.05$).

The AM structures observed in *S. terebinthifolius* roots reflected an important diversity of the AMF in the studied soil. Several authors indicated the occurrence and the diversity of the AMF in sandy soils (Read, 1989; Hatimi and Tahrouch, 2007). Due to their deficit in phosphorus, the dune soils were convenient for the development of the AMF and their association with plants (Koske and Halvorson, 1981). Growth improvement and arbuscules observation means that the introduced species *S. terebinthifolius* established a functional symbiosis with the presence of arbuscular structures considered as the nutriments exchange site (Abbott, 1982, Gianinazzi-Pearson, 1996, Ramos *et al.*, 2011).

This improvement was bound to the mineral nutrition, in particular the phosphorus, nitrogenous and hydric nutrition which were improved (Augé, 2001, Smith and Smith, 2012, Liu *et al.*, 2015, Habibzadeh, 2015).

This mycorhization was clearly improved under the both legumes influence in particular when *Schinus terebinthifolius* was associated with *Lotus creticus*.

Aerial parts P and N Content

Aerial part total nitrogen rates for all treatments were represented in the Table 5. Total nitrogen rate was 3,68±0,15% for control followed by 3,97±0,02% and 3,97±0,023% for *S. terebinthifolius* associated with *R. monosperma* and the mix and 4,20±0,23% with *L. creticus*. Compared to control, the nitrogen amount in various *S. terebinthifolius* associations was statistically similar ($p < 0,05$).

Concerning *S. terebinthifolius* aerial parts phosphorus content, it was 4,25±0,22 ppm for control, 5±0,244 ppm when associated with *R. monosperma* (SR). Significantly higher Values ($p < 0.05$) were observed in SL treatment (6,25±0,22 ppm) case and (7±0,44 ppm) for the mix (SM).

Relationship between soil physico-chemical characteristics and MSI Data were presented by projection on a factorial plan (F1xF2) in Fig.7. The principal component analysis (PCA) allowed representing graphically the relation between the various physico-chemical parameters and the MSI of the studied soils. The two axes describe 89,9 % total variation. The first axis expressed the most important percentage variation (70,17%). It gathered pH, silt and MSI.

They were positively correlated, with significant coefficients, 0,57 to 0,83 and negatively correlated to total limestone, active limestone, clay, phosphorus, carbon, conductivity and total nitrogen, with significant coefficients varying from -0,46 to -0,94. The second axis represents 16,34% variation. There was a very significant positive correlation between soil nitrogen and phosphorus with a coefficient of correlation 0.91. The nitrogen (0.89) and phosphorus (0,79) also presented a positive correlation with carbon. However these two parameters nitrogen and phosphorus; were negatively correlated to the MSI with coefficients of correlations -0,84 and -0,94 respectively. There was a very significant negative correlation between active limestone and electric conductivity (Fig. 7). So, the MSI level was important when pH and soil silt were high, at the opposite the MSI rate was weak when soil was rich in nitrogen and phosphorus.

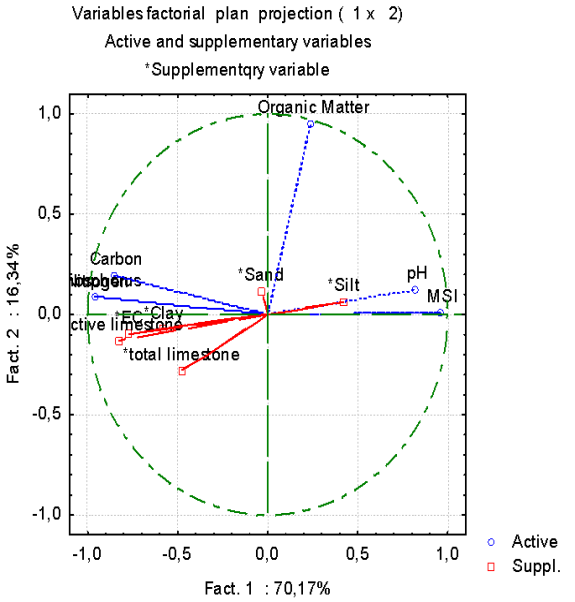

Fig. 7. Principal component analysis between physico-chemical and microbiological parameters of the soil.

The effect of the various associations on nitrogen and phosphorus *S. terebinthifolius* aerial parts content were more observed when it was associated with *L. creticus* and the mix followed by *R. monosperma* and control. In the degraded soils rehabilitation programs, Duponnois *et al.* (2001) showed that legumes associated with forest essences increased the nitrogen and phosphorus soil content. Indeed, legumes improved soil microbial communities which have a beneficial effect on nodulation and rhizobium-leguminous symbiosis by nitrogen biological fixation enhancement (Jayasinghearachchi and Seneviratne, 2004a).

Duponnois *et al.* (2013) observed an increase of the sheets nitrogen and phosphorus contents of young people cypress associated to the very mycotrophic lavender species which were superior to the control area.

Hypha colonized the roots of the non-leguminous plants and improved their growth (Seneviratne *et al.*, 2009), increased the nitrogen and phosphorus availability in soil (Jayasinghearachchi and Seneviratne, 2004b), bio-solubilized the rock phosphate (Jayasinghearachchi and Seneviratne, 2006) and produced hormones favoring the growth of plants (Bandara *et al.*, 2006). Legumes promoted the AMF multiplication and influenced positively their mineral absorption capacity essentially the phosphorus (Holevas, 1966; Grimoldi *et al.*, 2005), which stimulated the plants growth (Garbaye, 1991). Mycorrhizal fungi took the phosphorus, as not mycorrhizal plants, of the pool of soluble phosphorus (Masson, 1987) and played a very important role in the little or no soluble phosphorus forms solubilization by their enzymatic equipment as phytases and phosphatases (Gianinazzi-Pearson, 1982) and soil nitrogen plant absorption, mainly in the form of ammonium and from the atmosphere by increasing the efficiency of biological nitrogen fixation by leguminous and actinorhizal plants (Barea *et al.*, 1987, Marschner and Dell, 1994; Smith and Read, 2008). The main mycorrhizal fungi effect on the plant growth would be bound to phosphorus absorption increase, particularly in the soils where it was limiting (Smith, 1980; Clark and Zeto, 2000; Smith and Read, 2008). This symbiotic plant/fungi association mobilized and forwarded nitrogen and phosphor nutriments up to the plant and improved the soil aggregation (Querejeta *et al.*, 1998, Caravaca *et al.*, 2002).

Conclusion

This comparative study was carried out on a degraded site in the region of Terga Wilaya of Ain Temouchent. It concerned soil physical, chemical and biological characteristics before and after two years of native *Schinus terebinthifolius* introduction associated or not with legumes (*Retama monosperma* and *Lotus creticus*). If very low modifications were observed in the case of soil chemical properties (in particular the pH decrease, the N and P contents increase), the mycorhizal status of various studied soils was changed. Indeed, the mycorhizal soil infectivity (MSI_{50}) was decreased at least 3 times in MSI_{50} of the naked soil before the plantation. The associative effect also improved the growth and the nitrogenous and phosphate nutrition by *Schinus terebinthifolius*. These various parameters were improved when *Schinus terebinthifolius* was associated with *Lotus creticus*. These results show that the soil MSI can be improved by this type of plant community (forest trees/plants nurses). This property must be considered in the context of sustainable rehabilitation of degraded ecosystems.

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References

Abbott LK, Robson D. 1982. The role of vesicular-arbuscular mycorrhizal fungi and the selection of fungi for inoculation, Australian Journal of Agricultural Research **33**, 389-408.
http://dx. doi. org/10. 1080/00288233.1988.10423423

Augé RM. 2001. Water relations, drought and vesicular-arbuscular mycorrhizal symbiosis. Mycor-rhiza. **11**, 3-42.
http://dx.doi. org/10.100/ s005720-100097.

Bago B, Pfeffer PE, Douds Jr DD, Brouillette J, Bécard G &Shachar-Hill Y. 1999. Carbon metabolism in spores of the arbuscular mycorrhizal fungus *Glomus intraradices* as revealed by nuclear magnetic resonance spectroscopy. Plant Physiology **121**, 263-271.

Baize, D. 2000. Guide des analyses en pédologie (2nd Ed.). Paris, INRA 266.

Bandara WMMS, Seneviratne G, Kulasooriya SA. 2006. Interactions among endophytic bacteria and fungi: Effects and potentials. Journal of Biosciences **31,** 645-650.

Barea JM, Azcon C, Azcon R. 1987. Vesicular-arbuscular mycorrhizae improve both symbiotic N2 fixation and N uptake from soil as assessed with a 15N technique under field conditions. New Phytologist **106**, 717-725.
http//dx.di.org/10.1111/j.1469-8137.1 987. tb00172.x

Bellingham PJ, Walker LR, Wardle DA. 2001. Differential facilitation by a nitrogen-fixing shrub during primary succession influences relative performance of canopy tree species. Journal of ecology **89,** 861–875.
http://dx.doi.org/. 10;1046/ j.0022-0477.2001.00604.x

Bernhard-Reversat F, Harmand JM, Uguen K. 1998. Les litières et la dynamique de l'azote dans divers biotopes à Acacia d' Afrique occidentale et centrale. In: L' acacia au Sénégal. Campa Claudine (Ed.), Grignon C. (Ed.), Gueye M. (Ed.), Hamon Serge (Ed.). ORSTOM, ISRA. Paris, ORSTOM 205-219. (Collection colloques et séminaires). ISBN 2-7099-1423-9.

Bertness MD, Leonard GH. 1997. The role of positive interactions in communities: lessons from intertidal habitats. Ecology **78,** 1976-1989.

Bouazza Marouf K, Ighilhariz Z, de Lajudie P, Duponnois R, Bekki A. 2015. Assessing the native arbuscular mycorrhizal symbioses to rehabilitate a degraded coastal sand dune In Algeria. International Journal of Agriculture and Crop Sciences **8**, 194-202.

Brundrett M. 2002. Coevolution of roots and mycorrhizas of land plants. New Phytologist **154**, 275-304.

Brundrett MC. 1991. Mycorrhizas in natural ecosystems. In: Macfayden A, Begon, M, Fitter, AH, eds. Adv. Ecol. Res. London: Academic press **21,** 171-313.
http//dx.doi.org/10.1016/S0065- 504(08)60099-9

Callaway R. 1995. Positive interactions among plants, Botanical Review **61**, 306-349.
http:// dx.doi. org/ 10.1007/ BF02912621

Caravaca F, Barea JM, Figueroa D, Roldán A. 2002. Assessing the effectiveness of mycorrhizal inoculation and soil compost addition for enhancing reaforestation with *Olea europaea* subsp. *sylvestris* through changes in: soil biological and physical parameters. Applied Soil Ecology **20,** 107-118.

Clark RB, Zeto SK. 2000.Mineral acquisition by arbuscular mycorhizal plants. Journal of Plant Nutrition **23,** 867-902.
http://dx.doi.org/ 10.1080/ 01904160009382068

Cruz RE, Garcia MU. 1992. Nitrogen fixation and mycorrhizae in acacias on degraded grass lands. Dans: Tropical acacias in East Asia and the pacific. Eds. Kamis A et Taylor DA 59-71.

Dommergues Y. et Mangenot F. 1970. Ecologie microbienne du sol. Masson et Cie édit. Paris 796.

Duponnois R, Bâ AM, Prin Y, Baudoin E, Galiana A, Dreyfus B. 2010. Les champignons mycorhiziens: une composante majeure dans les processus biologiques régissant la stabilité et la productivité des écosystèmes forestiers tropicaux. In : Dia A. (Ed.), Duponnois R. (Ed.). *Le projet majeur africain de la Grande Muraille Verte : concepts et mise en œuvre*. Marseille: IRD 421-440. (Synthèses). ISBN 978-2-7099-1696-7.

Duponnois R, Hafidi M, Wahbi S, Sanon A, Galiana A, Baudoin E, Sanguin H, Bâ AM, Prin Y, Bally R. 2012. La symbiose mycorhizienne et la fertilité des sols dans les zones arides : un outil biologique sous-exploité dans la gestion des terres de la zone sahélo-saharienne. In: *La grande muraille verte : capitalisation des recherches et valorisation des savoirs locaux*. Dia A. (Ed.), Duponnois R. (Ed.). Marseille: IRD, Marseille 351-369. ISBN 978-2-7099-1738-4.

Duponnois R, Ouahmane L, Kane A, Thioulouse J, Hafidi M, Boumezzough A, Prin Y, Baudoin E, Galiana A, Dreyfus B. 2011. Nurse shrubs increased the early growth of Cupressus seedlings by enhancing belowground mutualism and soil microbial activity. Soil Biology & Biochemistry **43**, 2160-2168.
http//dx.doi.org/doi: 10.1016/j. soilbio. 2011.06.020

Duponnois R, Plenchette C, Thioulouse J, Cadet P. 2001. The mycorrhizal soil infectivity and arbuscular mycorrhizal fungal spore communities in soils of different aged fallows in Senegal. Applied Soil Ecology **17**, 239-251.
http//dx.doi.org/ 10.1016/ S0929- 1393(01)00132-9

Duponnois R, Ramanankierana H, Hafidi M, Baohanta R, Baudoin É, Thioulouse J, Sanguin H, Bâ A, Galiana A, Bally R, Lebrun M, Prin Y. 2013. Des ressources végétales endémiques pour optimiser durablement les opérations de réhabilitation du couvert forestier en milieu méditerranéen et tropical: exemple des plantes facilitatrices vectrices de propagation des champignons mycorhiziens. Carnet de Recheche en Biologies **336**, 265-272.
http://dx.doi. org/10.1016/j. crvi.2013.04.015

Fortin JA, Plenchette C, Piché Y. 2008. Les mycorhizes: La nouvelle révolution verte. Ed. multimondes. Québec, Canada 131.

Franco AC, Nobel PS. 1989. Effect of nurse plants on the microhabitat and growth of cacti. Journal of Ecology **77,** 870-886.
http://dx.doi.org/ 10.2307/ 2260991

Garbaye J. 1991. Utilisation des mycorhizes en sylviculture, in: Lavoisier (Éd.), Les mycorhizes des arbres et plantes cultivées, Paris, France 19-248.

Garcia C, Roldan A, Hernandez T. 1997. Changes in microbial activity after abandonment of cultivation in a semi-arid Mediterranean environment, Journal of Environmental Quality **26**, 285-291.

Ghodbani T. 2008. Extraction du sable dunaire à Terga plage, Algérie ouest. Impacts sur l'environnement, conflits d'usagers et outils de gestion. Proceedings of the international pluridisciplinary conférence "The littoral: challenge, dialogue, action" 16-18 january 2008. Lille, France.

Gianinazzi-Pearson, V. 1982. Importance des mycorhizes dans la nutrition et la physiologie des plantes. In: Les mycorhizes, biologie et utilisations, Gianinazzi-Pearson V. et Gianinazzi S. (éd). INRA Pub 51-59.

Gianinnazzi-Pearson V. 1996. Plant cell responses to arbuscular mycorrhizalfungi: getting the roots of symbiosis. Plant Cell **8**, 1871-1883.
http:// dx.doi. org/10.1105/tpc.8.10.1871

Grimoldi AA, Kavanová M, Lattanzi FA, Schnyder H. 2005. Phosphorus nutrition mediated effects of arbuscular mycorrhiza on leaf morphology and carbon allocation in perennial ryegrass. New Phytologist **168**, 435-444.
Doi: 10.1111/j.1469-8137. 2005.01500.x.

Habibzadeh Y. 2015. The effects of arbuscular mycorrhizal fungi and phosphorus levels on dry matter production and root traits in cucumber (*Cucumis sativus* L.). African Journal of Environmental Science and Technology **9**, 65-70. DOI: 10.5897/AJEST2014.1691

Habte M, Manjunath A. 1991. Categories of vesicular-arbuscular mycorrhizal dependency of host species, Mycorrhiza **1**, 3-12.

Hamel C, Dalpé Y, Furlan V, Parent S. 1997. Indigenous populations of arbuscular mycorrhizal fungi and soil aggregate stability were major determinants of leek *(Allium porrum*L.) response to inoculation with *Glomus intraradices* Schenck and Smith or *Glomus versiforme* (Karsten) Berch. Mycorrhiza **7**, 187-196.

Hamel C. 2004. Impact of arbuscular mycorrhizal fungi on N and P cycling in the rootzone. Candian Journal of Soil Science **84**, 383-395.

Hatimi A, Tahrouch S. 2007. Caractérisations chimique, botanique et microbiologique du sol des dunes littorales du Souss- Massa. Biomatec Echo **2**, 85-97.

Herrmann P. 1980 Travaux pratique D.A.A. Science du sol-Aménagement. D.E.A. Agronomie, Ecole nationale supérieure agronomique, Montpellier, Chaire de géologie-science du sol 63.

Hodge A, Campbell CD, Fitter AH. 2001. An arbuscular mycorrhizal fungus accelerates decomposition and acquires nitrogen directly from organic material. Nature **413**, 297-299.
http://dx.doi.org/ 10.1038/35095041

Holevas CD. 1966 The effect of VA mycorrhiza on the uptake of soil phosphorus by strawberry (*Fragaria* sp. var. *Cambridge Favourite*). Journal of Horticultural Sciences **4**, 57-64.

Holl KD, Cairns JR. 2002. Monitoring and appraisal. In: Perrow, MR, Davy AJ. (Eds.), Handbook of Ecological Restoration, Vol. **1**, 411-432.
http://dx.doi.org/10.1017/CBO9780511549984.023

Hopkins WG. 2003. Physiologie végétale. Ed. De Boeck 464-467.

Jayasghearachchi HS, Seneviratne G. 2004b. A bradyrhizobial *Penicillium* spp. biofilm with nitrogenase activity improves N_2 fixing symbiosis of soybean. Biology and Fertility of Soils **40,** 432-434.
http//dx.doi.org/ 10.1007/s00374-004-0796-5

Jayasinghearachchi HS, Seneviratne G. 2004a. Can mushroom fix atmospheric nitrogen? Journal of Biosciences **23,** 293-296.

Jayasinghearachchi HS, Seneviratne G. 2006. Fungal solubilization of rockphosphate was enhanced by forming fungal- rhizobia biofilms. Soil Biology and Biochemistry **38,** 405-408.
http//dx.doi.org/10.1016/j.soilbio.2005.06.004

Johnson CN, Copeland PJ, Crookston RK, FL. 1992. Mycorrhizae: possible explanation for yield decline with continuous corn and soybean, Agronomy Journal **84,** 387–390.

Joret G, Hebert J. 1955. Contribution à la détermination du besoin des sols en acide phosphorique. Annual Agronomy **2**, 233-299.

Kjeldahl J. 1883. A new method for the determination of nitrogen in organic matter. Zeitschreft fur Analytische Chemie. 22-366.

Koske RE, Halvorson WL. 1981. Ecological studies of vesicular-arbuscular mycorrhizae in a barrier sand dune. Canadian Journal of Botany **59,** 1413-1422. http://dx.doi.org/ 10.1139/b81-193

Leroux I. 2002. La négociation dans la construction du territoire. Une approche institutionnaliste. Thèse de doctorat d'économie. Université de Toulouse 417 p.

Liu T, Sheng M, Wang CY, Chen H, Li Z, Tang M. 2015. Impact of arbuscular mycorrhizal fungi on the growth, water status, and photosynthesis of hybrid poplar under drought stress and recovery. Photosynthetica **53,** 250-258.

Manjunath A, Habte M. 1988**.** Development of vesicular-arbuscular mycorrhizal infection and the uptake of immobile nutrients in *Leucaena leucocephala*. Plant and Soil **106**, 97-103.

Marschner H, Dell B. 1994.Nutrient uptake in mycorrhizal symbiosis.Plant and Soil **159**, 89-102.

Masson S. 1987. Les mycorhizes. Maitrise de sciences naturelles, Université de Clermont-Ferrand 40 p.

Mouffak AA, Tsaki H, Bekki A, Krabia Laid. 2014. Bio-Revegetation Impact on the Physicoc-hemical Characteristics of a Sandy Quarry Soil in Terga Beach Region in Algeria. Journal of Agricultural Science **6**, 2014.

Mousain D, Matumoto-Pintro P, Quiquampoix H. 1997. Le rôle des mycorhizes dans la nutrition phosphatée des arbres forestiers. Revue Forêt Française. vol **49**, NS 255, 67-81.

Ouahmane L, Hafidi M, Kisa M, Boumezzough A, Thoulouse J, Duponnois R. 2006a. *Lavandula* species as accompanying plants in *Cupressus* replanting strategies: effect on plant growth, mycorrhizal soil infectivity and soil microbial catabolic diversity. Applied Soil Ecology **34**,190-199. http//dx.doi.org/ 10.1111/j.1365-2672.2007.03296.x

Perevolotsky A, Shachak M, Pickett STA. 2005. Management for biodiversity: Human and landscape effects on dry environments. In: Biodiversity in Drylands: Towards a Unified Framework, Shachak M, Gosz JR, Pickett STA, Perevolotsky A (Eds). Oxford University Press, New York 286-304.

Phillips JM, HaymanDS. 1970. Improved procedures for clearing roots and staining parasitic and vesicular arbuscular mycorrhizal fungi for rapid assessment of infection. Transaction of the British Mycology Society **5,** 158-161.

Plenchette C, Fardeau JC. 1988. Prélèvement du phosphore par les racines et les mycorhizes. Comptes Rendus de l'Académie Des Sciences **4**, 117-123.

Plenchette C, Fortin JA, Furlan V. 1983. Growth response of several plant species ina soil of moderate P-fertility.I. Mycorrhizal dependency under field conditions. Plant and Soil **70**, 199-209.

Plenchette C, Perrin R, Duvert P. 1989. The concept of soil infectivity and a method for its determination as applied to endomyconhizas. Canadian Journal of Botany **67**, 112-115.

Provorov NA, Borisov AY, Tikhonovich IA. 2002. Developmental Genetics and Evolution of Symbiotic Structures in Nitrogen-Fixing Nodules and Arbuscular Mycorrhiza. Journal of Theoretical Biology **214**, 215-232. http//dx.doi.org/ 10.1006/ jtbi.2001.2453

Querejeta JI, Roldan A, Albadalejo J, Castillo V. 1998. The role of mycorrhizae, site preparation, and organic amendment in the afforestation of a semi-arid Mediterranean site with *Pinus halepensis*. Forest Science **44**, 200–211.

Ramos AC, Façanha AR, Palma LM, Okorokov LA, Cruz ZMA, Silva AG, Siqueira AF, Bertolazi AA, Canton GC, Melo J, Santos WO, Schimitberger VMB, Okorokova-Façanha AL. 2011. An outlook on ion signaling and ionome of mycorrhizal symbiosis. Brazilian Journal of Plant Physiology **23,** 79-89.
http://dx.doi.org/10. 1590/ S1677-04202011000100010

Read DJ. 1989. Mycorrhizas and nutrient cycling in sand dune ecosystems. Proceeding of Royal Society. Edinburgh **96**, 89-110.
http://dx.doi.org/10. 1017/ S0269727000010873

Requena N, Perez-Solis E, Azcon-Aguilar C, Jeffries P, Barea JM. 2001. Management of indigenous plant-microbe symbioses aids restoration of desertified ecosystems, Applied Environmental Microbiology **67**, 495–498.

Rodriguez H, Fraga R. 1999. Phosphate solubilizing bacteria and their role in plant growth promotion. Advances in Biotechnology **17(4-5),** 319-339.

Sanon AA. Beguiristain T, Duponnois R. 2005. Rôle des champignons mycorhiziens à arbuscules dans les mécanismes régissant la coexistence entre espèces végétales. Mémoire en vue d'obtenir le D.E.A National de Science du sol. Université Henri Poincaré-Nancy.

Seneviratne G, Thilakaratne RMMS, Jayasekara APDA, Seneviratne KACN, Padmathilake KRE, De Silva MSDL. 2009. Developing beneficial microbial biofilms on roots of non-legumes : a novel biofertilizing technique. In: Khan MS, Zaidi A, Musarrat J (Eds) Microbial strategies for crop improvement. Springer-Verlag, Berlin, Heidelberg 51-62.
http://dx.doi.org/ 10.1007/ 978-3-642-01979-1_3

Smith A J. 1980. Soils classification and the cocoa grower. Cocoa Growers' Bulletin **30(5),** 5-10.

Smith SE, Read DJ. 2008. Mycorrhizal symbiosis. London, Academic Press, 800 p. Available online at ISBN 978-0-12-370526-6.

Smith SE, Smith FA. 2012. Fresh perspectives on the roles of arbuscular mycorrhizal fungi in plant nutrition and growth. Mycologia **104**, 11-13. http://dx.doi.org/ 10.3852/11-229.

Stachowicz JJ, Whitlatch RB, Osman RW. 2001. Species Diversity and Invasion Resistance in a Marine Ecosystem. DOI: 10.1126/science **286**, 5444-1577.

Strullu DG. 1991. Les mycorhizes des arbres et des plantes cultivées. Techniques et Documentation Lavoisier, Paris 242-250.

Tewksbury JJ, Lloyd JD. 2001. Positive interactions under nurse-plants: spatial scale, stress gradients and benefactor size, Oecologia **127**, 425-434.

Trouvelot A, Kouch J, Gianinazzi-Pearson V. 1986. Mesure du taux de mycorhization VA d'un système radiculaire: Recherche de méthode d'estimation ayant une signification fonctionnelle. Les mycorhizes: Physiologie et Génétique. 1er Séminaire, Dijon, Ed. INRA, Paris 217-221.

Williamson B, Alexander IJ. 1975. Acid phosphatases localized in the sheath of beech mycorrhiza. Soil Biology and Biochemistry **7**, 195-198.

Wright SF, Upadhyaya A. 1998. A survey of soils for aggregate stability and glomalin, a glycoprotein produced by hyphae of arbuscular mycorrhizal fungi. Plant Soil **198**, 97-107.
http://dx.doi.org/ 10.1023/ A:1004347701584

Xiao Lin L, Jun-ling Z, George E, Marschner H. 1997. Phosphorus acquisition from compacted soil by hyphae of a mycorrhizal fungus associated with red clover (*Trifolium pratense*). Canadian Journal of Botany **75**, 723-729.