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Could artificial reforestations provide as much production and diversity of fungal species as natural forest stands in marginal Mediterranean areas?

Juan Andrés Oria-de-Rueda*, María Hernández-Rodríguez[1], Pablo Martín-Pinto[2], Valentín Pando[3], Jaime Olaizola[1]

Fire and Applied Mycology Laboratory, Departments of Agroforestry Sciences, and Vegetal Production and Natural Resources, Sustainable Forest Management Research Institute, University of Valladolid (Palencia), Avda., Madrid 44, 34071 Palencia, Spain

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ABSTRACT

The aim of this work was to study and describe fungal communities in different habitats in dry Mediterranean areas. The objective was to determine whether artificial reforestations can develop fungal communities as productive and diverse as those found in natural stands. The results could provide ecological and economical implications for forest management in marginal areas, in order to recover the original forest dominated by *Quercus*, establishing as intermediate stage new forest stands dominated by *Pinus* which might play an essential role in restoring some type of degraded or marginal areas.

Reforestations in degraded soils in abandoned farmlands were dominated by *Pinus pinaster*, *P. sylvestris* and *P. halepensis* whereas natural forest stands were dominated by *Quercus pyrenaica*, *Q. faginea* and *Populus nigra*. During the autumn mushroom season of 2003, fruiting bodies found in the plots were identified, and production, mycological richness, diversity were measured.

Individual sporocarps (7841), classified into 136 taxa, were collected and classified according to functional groups (mycorrhizal and saprotrophic), edibility, as well as commercial importance in the study area. In *Pinus* plots, sporocarps collected (4506), were classified into 84 different taxa, 32 mycorrhizal and 52 saprotrophic. Eleven of the total collected taxa were classified as edible fungi; and 8 of them are marketed in the studied area. In *Quercus* plots, 1277 sporocarps were collected, classified into 46 taxa, 17 mycorrhizal and 29 saprotrophic fungi. Eleven species were edible and four marketed in the region. In *Populus* plots, 2058 sporocarps were classified into 28 taxa. Seven were classified as mycorrhizal and 21 as saprotrophic. Twelve were classified as edible fungi; and four species are marketed in the area.

Differences were found for richness variables, comparing mean values for host genus. Thus, values in *Pinus* plots were higher than in *Quercus* plots. In relation with fungal production, an average plot yield of 340.51 kg ha^{-1} fresh weight was found in *Pinus* plots. Fresh weight average plot production was 56.6 kg ha^{-1} and 226.2 kg ha^{-1} in *Quercus* and *Populus* plots respectively. Fresh weight production of edible taxa was found to be higher in *Pinus* and *Populus* plots than in *Quercus* stands.

Artificial reforestations play an essential role in Mediterranean ecosystems avoiding soil losses and desertification of large areas in order to recover the original forest. They also may provide fungal production and diversity as high as those found in natural forest stands.

1. Introduction

Since the 1950s in Spain, many extensive reforestation programs have been carried out in degraded slopes and areas initially broken up by agriculture and after abandoned, in order to prevent soil erosion in such areas. This controversial practice in which *Pinus* species were used in these plantations could hinder the establishment of a well-developed biological community. On the other hand, these *Pinus* species appear naturally in the Spanish successions as an early stage leading to a natural climacic forest (Blanco et al., 1997). In addition, according to Gómez et al. (2001), *Pine* plantations in Mediterranean countries, play an essential role as intermediate phase towards climacic forests, and can be used for the restoration of natural forests. Furthermore, these reforestations prevent numerous soil losses and desertification of large areas in Spain and other Mediterranean countries. Moreover, these reforested areas have also favoured fauna, as they are refuge and breeding grounds for endangered species such as the grey wolf (*Canis lupus signatus*)

* Corresponding author. Tel.: +34 979108364; fax: +34 108440.
E-mail addresses: oria@agro.uva.es (J.A. Oria-de-Rueda), pmpinto@pvs.uva.es (P. Martín-Pinto), vpando@eio.uva.es (V. Pando), jaimeos@pvs.uva.es (J. Olaizola).
[1] Tel.: +34 979108432; fax: +34 979108440.
[2] Tel.: +34 979108340; fax: +34 979108440.
[3] Tel.: +34 979108325; fax: +34 979108440.

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and several birds of prey like goshawk (*Accipiter gentilis*), booted eagle (*Aquila pennata*), short-toed eagle (*Circaetus gallicus*) or sparrowhawk (*Accipiter nisus*).

The role of fungi in these communities is very important. Mycorrhizal associations are vital to the existence of most vascular plants (Trappe, 1987; Trappe and Luoma, 1992; Smith and Read, 1997; Luoma et al., 2004). Symbiotic root fungi facilitate uptake of nitrogen, phosphorous, other minerals, and water to the plant (Marks and Kozlowski, 1973; Allen, 1991; Smith and Read, 1997; Luoma et al., 2004); confer resistance against pathogens especially at the root level (Marx, 1972; Duchesne et al., 1989; Martín-Pinto et al., 2006a), facilitate primary succession (Schram, 1966; Miller, 1987), and positively influence soil structure by creating micro-aggregation of soil particles thereby improving soil aeration and porosity (Tisdall and Oades, 1979; Fernández-Toirán et al., 2006). Saprotrophic fungi play an important ecological role since they guarantee dead matter transformation and, therefore, the recycling of nutrients in the ecosystems (Ferrisa et al., 2000).

Traditionally, main production used to estimate the value of forest ecosystems in Spain have been commodities, and particularly timber. *Pinus* species used in these plantations such as *Pinus halepensis*, very xerophilous species, capable of withstanding annual precipitations as low as 150 mm (Bocio et al., 2004), can be easily adapted to dry and degraded slopes reducing soil erosion. However these species do not present an optimum development under these ecological conditions making timber harvesting economically nonviable. Harvests of edible ectomycorrhizal mushrooms represent an important forest economical resource, in some cases generating higher benefits than timber production (Martín-Pinto et al., 2006b; Oria-de-Rueda et al., 2008).

Knowledge about community structure and dynamics of ectomycorrhizal fungi in natural environments are limited (Smith et al., 2002). However, sustainable production of edible fungi cannot be evaluated without a knowledge based on the existing fungal populations (Bonet et al., 2004). Consequently, studies like this are essential in order to develop a correct forest management in these areas where the mycological resources are important.

The aim of this investigation is to study and describe fungal communities in different habitats: natural *Quercus faginea* and *Quercus pyrenaica* forests, a riparian *Populus nigra* stand and *Pinus pinaster*, *P. halepensis* and *Pinus sylvestris* plantations. Our objective is to determine if artificial reforestations can develop fungal communities as productive and diverse as those found in natural stands. Ecological and economical implications for forest management are considered.

2. Materials and methods

2.1. Study site

The analysis was carried out in six Mediterranean ecosystems dominated by *Q. faginea*, *Q. pyrenaica*, *P. nigra*, *P. pinaster*, *P. halepensis* and *P. sylvestris*. These sites are located in the Palencia province (NW Spain), where Mediterranean-continental climate predominates. Nevertheless, two zones can be distinguished according to ecological and climatic differences:

1. Páramos del Cerrato: These high plateau lands in the South of the province are dry with limestone soils. This study site, comprised of *P. halepensis*, *Q. faginea* and *P. nigra* plots is located at 700 m above sea level and has a mean annual rainfall of about 400 mm.
2. Rañas de la Valdavia: Located between 800 and 1000 m above the sea level. This site is characterised by siliceous soils with a mean annual rainfall of 650 mm. This location includes *Q. pyrenaica*, *P. pinaster* and *P. sylvestris* forests.

All the studied stands can be considered as even-aged stands of 45–55 years. In order to avoid different light conditions which can influence on fungal production, canopy cover in the studied stands was always between 70% and 80%. *Q. faginea* and *Q. pyrenaica* are semi-deciduous trees which appear in sub-Mediterranean-continental areas, although *Q. faginea* is associated with calcareous soils and *Q. pyrenaica* is located in siliceous soils. *Quercus* plots are located in natural forests which were traditionally harvested to obtain firewood but nowadays soil protection is the only role played by forest stands in this kind of marginal areas. *P. nigra* plots are sited in a riparian forest where soil humidity presents high values even during the summer. *P. pinaster*, *P. sylvestris* and *P. halepensis* are artificial reforestations planted at the same time.

2.2. Sampling

Eighteen sampling plots were analysed, three replicates in each stand. These sampling plots consisted in transects of 2 m × 50 m, established in accordance with previous studies (Ohenoja, 1989; Luoma et al., 1991; Dahlberg and Stenlid, 1994; Smith et al., 2002). Fungal production and diversity were studied in these ecosystems during the autumn mushroom season from late October through late December 2003. In accordance with other studies (Dahlberg, 1991; Ohenoja, 1984), fungi were collected once a week. The sampling day was always Wednesday, in order to reduce errors due to mushroom removal by recreational weekend collectors. Every sampling day, all the fungi were fully harvested facilitating the identification of fungal species and the calculation of production. Fungal fruiting bodies were transported to the laboratory, stored at 4 °C, and processed within 24 h after collection for identification and fresh weight measurements.

2.3. Identification and classification

The sporocarps were identified at species level whenever possible according to the following keys: Lage et al. (1981), Bon (1987), Antonin and Noordeloos (1993), Breitenbach and Kratzlin (1984–2000), Kühner and Romagnesi (1974), Moser (1980) and Palazón (2001). As in previous works (Bonet et al., 2004; Martín-Pinto et al., 2006b) samples that could only be identified to the genus level were grouped into genus taxa. In this case there were 6 generic level taxa for which further identification was not possible and generally included more than one species: *Agaricus* sp., *Clitocybe* sp., *Conocybe* sp., *Entoloma* sp., *Inocybe* sp. and *Mycena* sp.

Sporocarps were dried in air-vented ovens at 35 °C and were dry weighed in order to obtain comparable biomass data. Data were grouped into categories (saprotrophic/mycorrhizal; edible/inedible) for further statistical analysis.

2.4. Production, diversity, uniformity and richness calculations and statistical analysis

Shannon's H' diversity index (Shannon and Weaver, 1949), based on dry weight of the fruiting bodies (Dahlberg, 1991) was calculated. An analysis of species Evenness J' (Pielou, 1969) and richness (S) (Martínez-Ruíz et al., 2001; Straatsma and Krisai-Greilhuber, 2003) was also done These variables were calculated using the following formula where coefficient *pi* indicates the relative importance of each fungal species and S is the total number of species found:

$$H' = -\Sigma pi(\ln pi)$$

S = number of species.

$$E = \frac{H'}{\ln S}$$

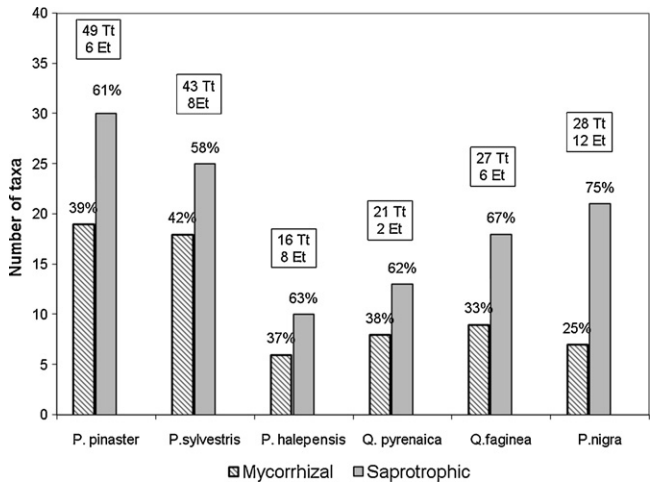

Fig. 1. Number and % of taxa found in the studied forest stands depending on vital strategy (mycorrhizal or saprotrophic). (Tt): number of total taxa. (Et): number of edible taxa.

Fresh and dry weights were measured to determine and compare production among treatments. Also, number of fruiting bodies, H', S and E were analysed statistically. Overall and categorized data (saprotrophic/mycorrhizal; edible/inedible) were considered. Data were subjected to a Multivariate Analysis MANOVA GLM and means were compared by LSD Fisher test ($P < 0.05$). STATISTICA 6.0 software (StatSoft, Inc., 1984–2001) was used for the analysis.

3. Results

3.1. General data

Individual sporocarps (7841) were collected from 18 plots (1800 m^2 total), corresponding with a total of 136 taxa (Table 1).

Taxa were classified according to functional groups (mycorrhizal and saprotrophic), edibility, as well as commercial importance in the study area. From the total taxa list, 50 can be identified as mycorrhizal and 86 as saprotrophic fungi. Twenty six of the total taxa found were edible; fourteen of them are marketed in the region.

3.1.1. Pinus plots

Sporocarps collected (4506) from 9 *Pinus* plots (900 m^2) were classified into 84 different taxa. In this case there were three generic level taxa for which further identification was not possible: *Clitocybe* sp., *Conocybe* sp. and *Entoloma* sp.

From the total taxa found, 32 can be classified as mycorrhizal and 52 as saprotrophic fungi. Eleven of total collected taxa were classified as edible fungi; and 8 of them are marketed in the studied area.

At the species level, *P. halepensis* presented a lower value of number of total taxa (16) but the number of edible taxa was very similar to the values observed in the other two *Pinus* species (Fig. 1).

3.1.2. Quercus plots

A total of 1277 sporocarps were collected from 6 *Quercus* plots (600 m^2). Fungi were classified into 46 taxa. There are two generic level taxa for which further identification was not possible: *Inocybe* sp. and *Mycena* sp.

From the total taxa found, 17 can be classified as mycorrhizal and 29 as saprotrophic fungi. Eleven of the total taxa found were edible; four of them are marketed in the region.

Six edible fungal species were collected in *Q. faginea* plots, higher than the two edible taxa found in the *Q. pyrenaica* plots (Fig. 1).

3.1.3. Populus plots

Individual sporocarps (2058) were collected from 3 *P. nigra* plots (300 m^2) and classified into 28 different taxa (Fig. 1). Seven of the taxa found (25%) were classified as mycorrhizal and 21 (75%) as saprotrophic fungi. Twelve of total collected taxa (43%) were classified as edible fungi; and four species (*Agaricus campestris*, *Agrocybe aegerita*, *Tricholoma populinum* and *Tricholoma scalpturatum*) are marketed in the area.

3.2. Diversity, richness and Evenness

Differences were found for richness variables, comparing mean values found in the three tree genus (*Quercus*, *Pinus* and *Populus*) stands. Thus, values in *Pinus* plots were higher than in *Quercus* plots (Contrast test; $P < 0.05$) (Table 2).

Shannon's H' diversity index was not significantly different (Contrast test; $P < 0.05$) among *Pinus* species (Table 3). This result was also observed in *Quercus* plots. However, although species richness was not significantly different between *Quercus* species, in *Pinus* treatments lower values were observed for *P. halepensis* plots. For Evenness J' index, no differences were found.

In relation with functional groups, differences were found depending on the host genus according to the number of species. Thus, the number of saprotrophic and mycorrhizal species in *Pinus* plots was significantly higher than in *Quercus* (Contrast test $P < 0.05$) (Table 2).

According to the number of taxa in common or Jaccard similarity coefficients, *P. pinaster* and *P. sylvestris* were found to be the most similar with 22 taxa in common (Table 4). *Q. pyrenaica* was closer to *P. pinaster* and *P. sylvestris* than to *Q. faginea*, in relation with the number of taxa in common. Furthermore, *P. halepensis* and *Q. faginea* had 6 taxa in common. Results also show that *P. nigra* is the most different host species in relation with taxa found.

Mycorrhizal and saprotrophic species were not significantly different in relation with Shannon's H' diversity index (MANOVA test; $P < 0.05$) considering each species individually (Fig. 2). This result was also observed in relation with Evenness J' index. Among *Pinus* species, richness for saprotrophic species was significantly lower in *P. halepensis* plots than in *P. pinaster* or *P. sylvestris* plots (Fig. 2). Mycorrhizal richness was significantly higher in *P. pinaster* than in *P. halepensis*.

3.3. Sporocarp production

In *Pinus* plots, the total fresh weight was 30.6 kg, representing an average plot yield of 340.51 kg ha^{-1} fresh weight (23.3 kg ha^{-1} dry weight). *P. pinaster* showed significantly higher values than *P. sylvestris* (Contrast test <0.05) (Table 3).

For *Quercus* plots, fresh weight was 3.4 kg which represented an average plot production of 56.6 kg ha^{-1} fresh weight (6.0 kg ha^{-1} dry weight). Very similar values, 56.9 and 56.3 kg ha^{-1} fresh weight, were found in *Q. pyrenaica* and *Q. faginea* respectively (Table 3).

In *Populus* plots, the total fresh weight was 6.8 kg, which represented an average plot yield of 226.2 kg ha^{-1} fresh weight (34.5 kg ha^{-1} dry weight).

For the different functional groups, dry weight for mycorrhizal species was significantly higher in *Pinus* plots than in *Quercus* plots (Table 2). In *Populus* treatments, biomass for saprotrophic species was also higher than in *Pinus* or *Quercus* plots. The same trends were observed for fresh weight.

The number of saprotrophic sporocarps found in *P. pinaster* plots was significantly higher than saprotrophic sporocarps found in *P. halepensis* plots (Fig. 3). Moreover, fresh weight for mycorrhizal

Table 1
Total taxa collected from natural and reforestation forest stands.

Taxa	P p	P s	P h	Q p	Q f	P n	Group	Edible	Marketed
Agaricus campestris L.:Fr.						+	S	E	M
Agaricus sp.						+	S	E	
Agaricus sylvicola (Vittad.) Peck				+			S		M
Agrocybe aegerita (Brig.) Quél.						+	S	E	M
Amanita ovoidea (Bull.:Fr.) Quél.			+				MY	E	
Amanita pantherina (D.C.:Fr.) Kummer				+			MY		
Auriculariopsis ampla (Lév.) Maire.						+	S		
Clitocybe brumalis (Bull.:Fr) Kumm		+					S		
Clitocybe costata Kühn. & Romagn.					+		S	E	
Clitocybe cyanthiformis Fr.			+		+		S	E	
Clitocybe dealbata (Sow.: Fr) Kummer	+		+		+		S		
Clitocybe diatreta (Fr.) Kumm.			+				S		
Clitocybe ditopa (Fr.) Gill	+						S		
Clitocybe gibba (Pers.: Fr) Kummer					+		S	E	M
Clitocybe odora (Bull). Kumm.			+	+	+		S		
Clitocybe phaeophthalma (Pers.) Kuyper					+		S		
Clitocybe sp.		+					S		
Clitocybe vibecina (Fr.: Fr.) Gillet	+	+					S		
Collybia butyracea (Bull.: Fr.) Kummer		+			+		S		
Collybia dryophila (Bull.: Fr.) Kummer	+	+	+	+	+		S		
Collybia fusipes (Bull.: Fr.) Quél.						+	S	E	
Collybia kuehneriana Sing.					+		S		
Collybia peronata (Bolt.) Kumm.					+		S		
Conocybe brunneola Kühn. & Watl.		+					S		
Conocybe sp.	+						S		
Conocybe tenera (Sch.) Fayod.						+	S		
Coprinus comatus (Müll.: Fr) Pers.						+	S	E	
Coprinus diseminatus (Pers.: Fr.) S. F. Gray						+	S	E	
Cortinarius camphoratus Fr.					+		MY		
Cortinarius elatior Fr.					+		MY	E	
Cortinarius gr, cinnamomeus (L.) Fr.						+	MY	E	
Cortinarius gr. Splendens Hry.					+		MY		
Cortinarius porphyropus (A.-S.) Fr.		+					MY		
Cortinarius trivialis Lange				+			MY		
Crepidotus mollis (Schaeff.: Fr) Kummer		+					S		
Cyathus olla Batsch.: Pers.			+			+	S		
Cystoderma amianthinum (Scop.: Fr.) Fayod	+	+					S		
Cystoderma granulosum (Batsch.: Fr.) Fayod		+					S		
Entoloma cetratum (Fr.: Fr.) Moser		+					S		
Entoloma formosum (Fr.: Fr.) Noordel.				+			S		
Entoloma hirtipes (Schum.) Moser	+						S		
Entoloma jubatum (Fr.) P. Karst.				+			S		
Entoloma mougeotii (Fr.) Hesl.	+	+					S		
Entoloma sericeum (Bull.) Quél.				+			S		
Entoloma sp.	+						S		
Entoloma xanthochroum (P.D. Orton) Noordel.				+			S		
Galerina marginata (Batsch) Kühn.	+	+					S		
Galerina sideroides (Bull.) Kühn.		+					S		
Galerina uncialis (Britz.) Kühn	+						S		
Geastrum rufescens Pers.: Pers.					+		S		
Hebeloma crustuliniforme (Bull.) Quél.	+					+	S		
Hebeloma edurum Métrod ex M. Bon			+		+		MY		
Hebeloma sinapizans (Paul.) Gill					+		MY		
Hohembuehelia geogenia (D.C.) Sing.				+			S		
Hygrophoropsis aurantiaca (Wolf.) R. Maire.		+					S		
Hygrophorus hypothejus (Fr.: Fr.) Fr.		+					MY	E	
Hypholoma fasciculare (Huds.) Kumm.		+					S		
Inocybe dulcamara (A.-S.) Kumm.			+			+	MY		
Inocybe fastigiata (Sch.) Quél.	+					+	MY		
Inocybe lanuginosa (Bull.) Kumm.					+		MY		
Inocybe piriodora (Britx.) Sacc.		+					MY		
Inocybe rimosa (Bull.: Fr.)						+	MY		
Inocybe sp					+		MY		
Inocybe terrigena (Fr.) Kühn.		+					MY		
Inonotus hispidus (Bull.:Fr.) P. Karst.						+	S		
Laccaria laccata (Scoop.) Bk. & Br.	+	+		+			MY	E	
Lactarius aurantiacus (Vahl) S.F. Gray	+	+		+			MY		
Lactarius chrysorrheus Fr.		+		+			MY		
Lactarius luridus (Pers.:Fr.) S.F. Gray				+			MY		
Lactarius pallidus Pers.				+			MY		
Lepiota cristata (Bolt.:Fr.) Kummer						+	S		
Lepiota helveola Bresad.						+	S		
Lepista nuda (Bull.:Fr.) Cooke					+	+	S	E	
Lepista sordida (Schum.: Fr.) Sing.			+				S	E	
Lycoperdon perlatum Pers.	+	+		+			S		M

Table 1 (Continued.)

Taxa	P p	P s	P h	Q p	Q f	P n	Group	Edible	Marketed
Lyophyllum decastes (Fr.) Sing						+	S	E	
Marasmius androsaceus (L.: Fr.) Fr.			+		+	+	S		
Marasmius epiphyllus (Pers.:Fr.) Fr.					+		S		
Marasmius rotula (Scop.) Fr.	+						S		
Marasmius scorodonius (Fr.) Fr.		+					S		
Micromphale rufocarneum (Vel.) Knudsen.				+			S		
Mycena alcalina (Fr.) Kumm.	+					+	S		
Mycena bryophila (Vogl.) Sing.	+						S		
Mycena elegans (Pers.) Kumm.	+	+					S		
Mycena flavoalba (Fr.) Quél.				+			S		
Mycena galopoda	+						S		
Mycena leptocephala (Pers.) Gill.	+	+					S		
Mycena leptophylla (Peck.) Sacc.	+			+			S		
Mycena mougeotii	+						S		
Mycena pura (Pers.: Fr.) Kummer						+	S		
Mycena seynii Quél.	+	+					S		
Mycena sp					+		S		
Mycena vitilis (Fr.) Quél.			+		+		S		
Omphalina pyxidata (Bull.: Fr.) Quél.	+						S		
Panaeolus rickenii Hora			+				S		
Paxillus involutus (Batsch) Fr.						+	MY		
Pholiotina aporos K. v. Wav.	+	+					S		
Pluteus salicinus (Pers.: Fr.) Kühn.						+	S		
Psathyrella chondroderma (Berk. & Broome) A.H. Smith		+					S		
Psathyrella hydrophilla (Bull.: Mérat) Maire		+					S		
Psathyrella marcescibilis (Britz.) Sing.					+		S		
Psathyrella melanthina (Fr.) Kits van Wav.						+	S		
Psathyrella niveobadia (Rom.) Mos	+						S		
Russula albonigra Krombholz		+					MY		
Russula amara Kucera	+						MY		
Russula cessans Pears.	+						MY		
Russula decolorans (Fr.) Fr.	+						MY		
Russula delica Fr.				+			MY		
Russula emetica (Schaeff.: Fr.) Pers.	+						MY		
Russula fellea (Fr.) Fr.	+	+					MY		
Russula grisea (Pers.: Secr.) Fr. Ss. Gillet.	+						MY		
Russula heterophylla (Fr.) Fr.	+						MY		
Russula lepida Fr.	+						MY		
Russula olivacea (Schaerff. Ex Secr.) Fr.	+	+					MY		
Russula sardonia Fr. Ss. Melz. & Zv.	+	+					MY		
Russula torulosa Bresad.	+	+					MY		
Russula vesca Fr.	+	+					MY		M
Strobilurus tenacellus (Pers.: Fr.) Sing.	+						S		
Stropharia semiglobata (Batsch: Fr.) Quél.					+		S		
Suillus bellini (Inzenga) Watling		+	+				MY	E	M
Suillus collinitus (Fr.) Kuntze			+				MY	E	M
Suillus granulatus (L.: Fr.) Kuntze		+					MY	E	M
Suillus luteus (L.) S.F. Gray	+	+					MY	E	M
Tricholoma equestre (L.: Fr.) Kummer	+	+					MY		
Tricholoma fracticum (Britz.) Kreisel	+						MY		
Tricholoma populinum Lange						+	MY	E	M
Tricholoma portentosum (Fr.) Quél.	+	+					MY	E	M
Tricholoma scalpturatum (Fr.) Quél.					+	+	MY	E	M
Tricholoma sulphurescens Bresad.					+		MY		
Tricholoma terreum (Schaeff.: Fr.) Kummer			+				MY	E	M
Tricholomopsis rutilans (Schaeff.: Fr.) Sing.	+						S		
Tubaria furfuracea (Pers.: Fr.) Gillet	+	+		+			S		
Xerocomus chrysentheron (Bull.) Quél.						+	MY	E	
Xeromphalina campanella (Batsch) R. Maire.	+						S		
Xeromphalina caulicinalis (With.: Fr.) Kühn. & Maire							S		
Xeromphalina fellea Maire & Malençon	+	+					S		

Pp: *P. pinaster* plots; Ps: *P. sylvestris* plots; Ph: *P. halepensis* plots; Qp: *Q. pyrenaica* plots; Qf: *Q. faginea* plots; Pn: *Populus nigra* plots; MY: mycorrhizal; S: saprotrophic; E: edible; M: marketed.

species decreased significantly from *P. pinaster* and *P. halepensis* plots to *P. sylvestris* plots. Considering all the host species individually, *Quercus* species showed a lower fresh weight of mycorrhizal production than *P. pinaster* and *P. halepensis*. No differences were found in fresh or dry weight production of saprotrophic species.

3.4. Edible production and marketed species

Fresh weight production of edible taxa was found to be higher in *Pinus* and *Populus* plots than in *Quercus* plots. Similar results were observed for richness of edible species (Table 2). In relation with Evenness J' index, no differences were found.

Fresh weight production of edible taxa represented 62% (294.8 kg ha^{-1} fresh weight) of the total in *P. pinaster* plots, 56% (99.9 kg ha^{-1} fresh weight) in *P. sylvestris* and 52% (191.3 kg ha^{-1} fresh weight) in *P. halepensis* plots.

Fresh weight production of edible taxa represented 31% (17.8 kg ha^{-1} fresh weight) of the total in *Q. pyrenaica* plots and was significantly lower in *Q. faginea* treatments (6%; 3.2 kg ha^{-1} fresh weight).

Table 2
Contrast test matrix at genus level for different variables.

Contrasted factors		Contrasted categories									Test
Genus (a)	Genus (b)	Total	M	S	E	IE	M-E	M-IE	S-E	S-IE	
Pinus	*Quercus*	–	a*	–	a*	–	–	a*	–	–	
Pinus	*Populus*	–	–	b*	–	–	–	a*	b*	–	DW
Quercus	*Populus*	b*	–	b*	b*	–	b*	–	b*	–	
Pinus	*Quercus*	a*	a*	–	a*	a*	a*	a*	–	–	
Pinus	*Populus*	–	–	b*	–	a*	–	a*	b*	–	FW
Quercus	*Populus*	–	–	b*	–	–	–	–	b*	–	
Pinus	*Quercus*	–	–	–	–	–	–	a*	–	–	
Pinus	*Populus*	–	–	–	–	–	–	a*	b*	–	*N*
Quercus	*Populus*	–	–	–	–	–	–	–	b*	–	
Pinus	*Quercus*	–	–	–	–	–	a*	–	–	–	
Pinus	*Populus*	–	–	–	–	–	–	–	b*	–	*H*
Quercus	*Populus*	–	–	–	b*	–	–	–	–	–	
Pinus	*Quercus*	a*	a*	a*	a*	a*	a*	–	–	a*	
Pinus	*Populus*	–	–	–	–	a*	a*	–	b*	a*	*S*
Quercus	*Populus*	–	–	–	b*	–	b*	–	b*	–	
Pinus	*Quercus*	–	–	–	–	–	a*	–	–	–	
Pinus	*Populus*	–	–	–	–	–	–	–	–	–	*E*
Quercus	*Populus*	–	–	–	–	–	–	–	–	–	

Contrasted categories: M, mycorrhizal spp; S, saprotrophic; E, edible; IE, inedible; M-E, M-IE, S-E, S-IE, combinations; Variables: DW, dry weight; FW, fresh weight; *N*, number of carpophores; *H*, Shannon index; *S*, richness; *E*, Evenness index.
* Significant differences (Contrast Test; $P < 0.05$), if a* higher value for Genus (a), if b* higher value for Genus (b).

Table 3
Variable comparisons among host species (within their genus).

	Genus					
	Pinus			*Quercus*		*Populus*
	P. pinaster[a]	*P. sylvestris*[a]	*P. halepensis*[a]	*Q. pyrenaica*[a]	*Q. faginea*[a]	*P. nigra*[a]
Dw (kg ha^{-1})	18.4a	12.4a	39.2a	6.5a	5.6a	34.5
Fw (kg ha^{-1})	476.3a	178.1b	367.1ab	56.9a	56.3a	226.3
S	49a	43a	16b	21a	27a	29
H	1.4a	1.6a	1.3a	1.2a	1.3a	1.3
E	0.4a	0.5a	0.6a	0.5a	0.5a	0.5

Dry weight, fresh weight, richness, Shannon index and Evenness index are showed. Values within a row followed by the same letter are not significantly different.
[a] Sp.

Table 4
Jaccard similarity coefficients (lightface) and the numbers of taxa in common (boldfaces) among habitats.

	P. pinaster	*P. sylvestris*	*P. halepensis*	*Q. pyrenaica*	*Q. faginea*	*P. nigra*
Pinus pinaster		0.314	0.032	0.094	0.027	0.041
Pinus sylvestris	**22**		0.035	0.103	0.029	0.000
Pinus halepensis	**2**	**2**		0.057	0.194	0.073
Quercus pyrenaica	**6**	**5**	**1**		0.043	0.000
Quercus faginea	**2**	**1**	**6**	**2**		0.058
Populus nigra	**3**	**0**	**2**	**0**	**3**	

Fresh weight production of edible taxa represented 82% (185.1 kg ha^{-1} fresh weight) of the total in *P. nigra* plots.

4. Discussion

4.1. General data

General data obtained in the present study are interesting since fungal diversity and production are considered useful tools in order to describe the general biodiversity in ecosystems (Arnolds, 1992; Hawksworth, 2001).

It is important to take into account that sporocarp production varies considerably between different years in the same locality (Luoma et al., 1991; Durall et al., 1999; Ohenoja, 1993; Smith et al., 2002). Variations in annual production reported reveal yields of 0–940 kg of fresh weight ha^{-1} in mixed pine plots (Mehus, 1986) and of 1.1 kg of dry weight ha^{-1} in the poorest season and of 9.7 kg of dry weight ha^{-1} in the best (Väre et al., 1996).

4.2. Diversity, richness and Evenness

Species richness values in *Pinus* plots were higher than in *Quercus* plots. This result is in agreement with those by Allen et al. (1995) who found that natural conifer forests present higher fungal richness than observed in broadleaved forests. Thus, they report until 1000 ectomycorrhizal fungal species in the Pacific Northwestern Region, associated to natural old-growth forests. However, our data provide information from Mediterranean abandoned farmlands where ecological conditions are absolutely unfavourable.

A relatively high fungal diversity (49 taxa) was found in *P. pinaster* plots. Martín-Pinto et al. (2006b) reported 39 species in *P. pinaster* reforestations in Northwest Spain where low depth and

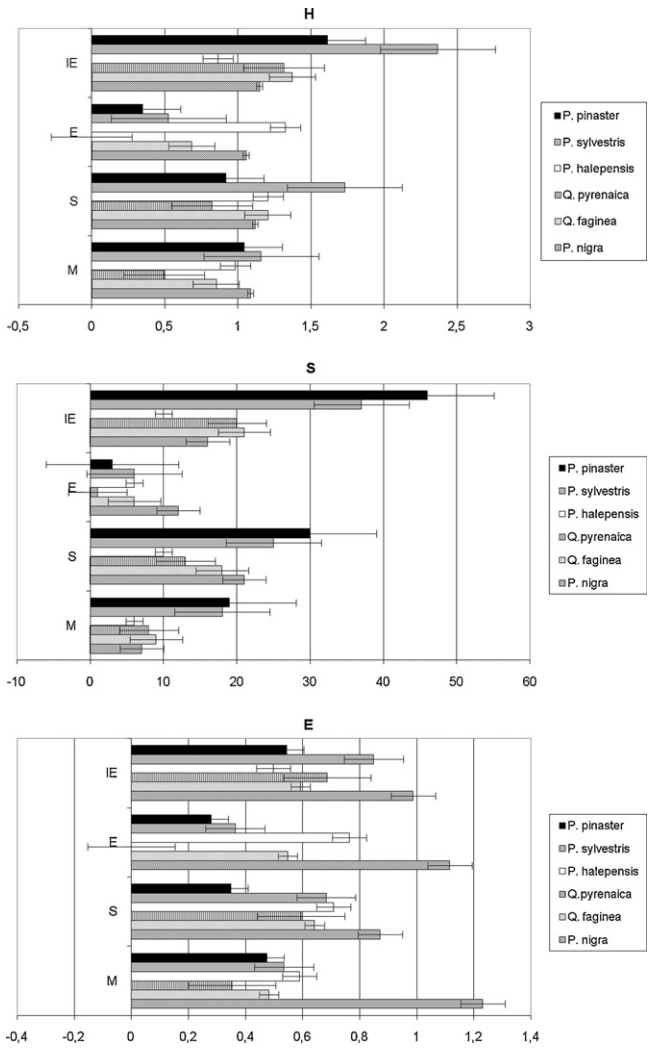

Fig. 2. Diversity variables analysed depending on functional groups and edibility. (H): Shannon index. (S): richness. (E): Evenness. (S/M): Saprotrophic/Mycorrhizal (E/IE): Edible/Inedible.

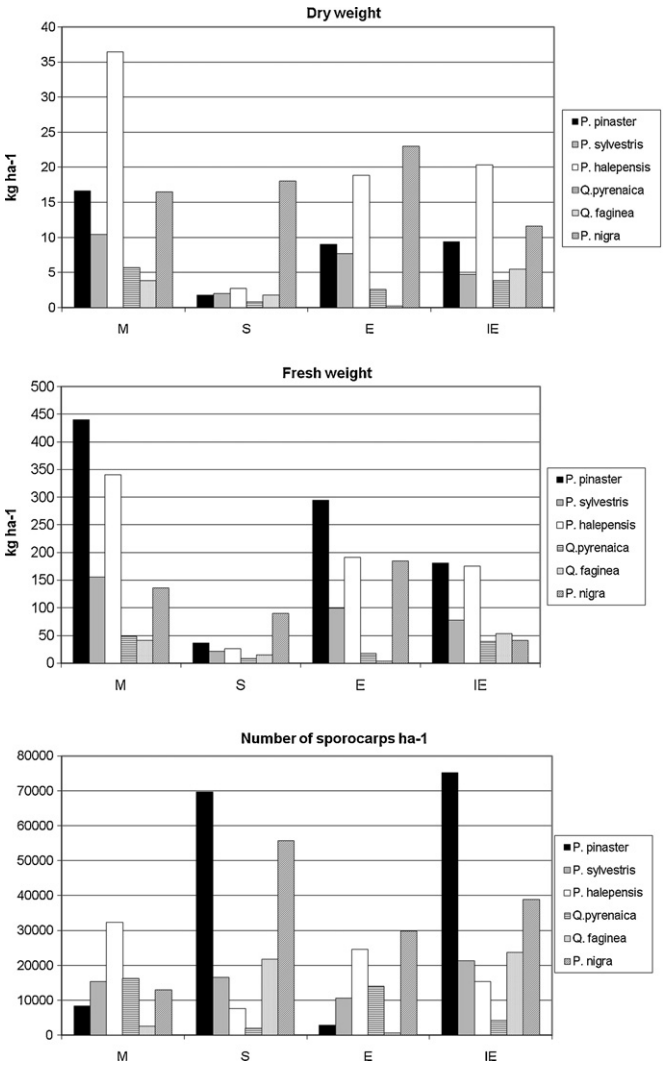

Fig. 3. Production variables analysed depending on functional groups and edibility; Dry weight, Fresh weight and number of sporocarps ha^{-1}. (S/M): Saprotrophic/Mycorrhizal (E/IE): Edible/Inedible.

stony soils predominate. However, in both cases richness values are higher than those cited by Bruns et al. (2002). These authors note that in single-species pine stands of approximately 0.1 ha, 15–35 taxa of fungi are typically reported. *P. pinaster* plots in this study are located in siliceous soils where a high number of fungal species is frequently collected. On the other hand, higher diversity was reported in *P. pinaster* natural stands in Spain (Fernández-Toirán et al., 2006).

Sporocarps found in *P. sylvestris* plots (300 m^2), were classified into 43 taxa. Higher results were reported by Bonet et al. (2004) with 164 different taxa in 3600 m^2 over 3 years in *P. sylvestris* central Pyrenees, by Hintikka (1988) with 80 species in 25 stands of 0.3–0.5 ha in southern Finland, and by Väre et al. (1996) with 152 species associated with *P. sylvestris* in Finnish Lapland. All these studies are focused on natural stands and confirm the high diversity associated with natural conifer forests (Allen et al., 1995). Also, environmental conditions in all those studies are more favourable than those present in our study area.

Forty-six different taxa were found in 6 *Quercus* plots (600 m^2), 21 in *Q. pyrenaica* plots and 27 in *Q. faginea* plots. Similar results were found in fresh weight, dry weight, richness, diversity and Evenness for *Q. pyrenaica* and *Q. faginea* plots. Diversity values observed for both natural *Quercus* stands were significantly lower than those for *Pinus* artificial reforestations. There is a lack of information on the diversity and production of fungal communities associated with these marcescent oak forests. However, based on personal observation, many species present in these forests are collected in open areas. In fact, some species such as *Amanita caesarea*, *Boletus aereus* and some *Clitocybe* species were observed in these open areas but were not detected in the study plots. Fungal species found is strongly affected by the canopy cover as proposed by Dickie et al. (2009). In that case, fungal communities associated with the oak savanna were significantly different to those observed in oak dense stands. The relatively low values for richness in *Quercus* forest plots could be due to the location of the plots, since they were sited in similar canopy cover conditions as those in *Pinus* and *Populus* stands, where canopy cover was higher than 70–80%.

High similarity (22 fungal species in common) was found between *P. sylvestris* and *P. pinaster* plots. This result is due to the similar ecology of both species, located in a siliceous soil area with an annual rainfall higher than 600 mm.

Noteworthy is the high similarity between fungus species found in *P. halepensis* and *Q. faginea* plots. These species are located in similar ecological conditions with marl soils and dry Mediterranean climate conditions (400 mm of annual rainfall). Thus, it appears that *P. halepensis* plantations are correctly adapted to these dry and poor soils. It could be due to the fungal community associated with this

host species. This result suggests that soil and climate are decisive factors in fungal compositions when comparing forest type and vegetation composition. This also explains the closer similarity found between *Q. pyrenaica* and *P. sylvestris* and *P. pinaster* than the number of species in common found between *Quercus* species.

P. nigra forest is growing under different microclimate conditions in a riparian area. Differences were observed analysing qualitative information, since 20 of the 28 species collected in these plots were only found in this forest stand. However, no differences were found comparing richness values with respect to *Pinus* and *Quercus* stands.

For the studied functional groups in all the studied stands, 50 taxa were mycorrhizal and 86 were saprotrophic. In contrast, Roberts et al. (2004) found an overall ratio of about 1:1 between mycorrhizal and saprotrophic in six habitats in Vancouver Island, British Columbia over 5 years, and Straatsma et al. (2001) found that there were about twice as many ectomycorrhizal as saprotrophic fungi in a Swiss forest formed by a mixture of deciduous trees and conifers. Poor and degraded soils present in the studied area could explain the lower presence of mycorrhizal species.

In *P. sylvestris* plots, 42% of the taxa were classified as mycorrhizal and 58% saprotrophic. Other studies report higher percentages of mycorrhizal species, such as Bonet et al. (2004) with 88% of mycorrhizal taxa or Väre et al. (1996) with 59%. These studies were carried out on natural *P. sylvestris* stands in areas where optimal ecological conditions for the growth of this species are observed.

Seventeen mycorrhizal and 29 saprotrophic taxa were found in *Quercus* plots. In contrast, Richard et al. (2004) found higher number of mycorrhizal species (166) than saprotrophic fungi (68 taxa) in an old-growth Mediterranean forest dominated by *Q. ilex*. No differences were found in *Q. pyrenaica* or *Q. faginea* in diversity and production according to functional groups.

Twenty-eight different taxa were collected from *P. nigra* plots, 25% of them were classified as mycorrhizal and 75% as saprotrophic fungi.

In all the plots higher proportion of saprotrophic compared to mycorrhizal fungi was observed. This fact could be due to the presence of high amounts of organic matter in the forests, since decomposition rates are particularly low in Mediterranean ecosystems where no coincidence of high precipitations and high temperatures is observed. This fact was accentuated in the *Populus* plots since it could be considered as an over-mature stand. Therefore, this stand was more susceptible to diseases and pests, and dead stems and roots are present on the soil, causing a higher accumulation of organic matter than that observed in *Pinus* and *Quercus* stands. Furthermore, *Populus* plots are located in Riparian areas where presence of saprotrophic fungal species is favoured by higher values for soil humidity when high temperature is present during the summer. However, no differences were observed between *Quercus* and *Pinus* treatments. It could be due to the similar soil humidity and temperature conditions observed in this Mediterranean area where dry and warm summers occur. Also, no differences were found in relation to the amount of accumulated organic matter on the soil, due to the semi-deciduous characteristics of the studied *Quercus* species, which reach low growth in these dry marginal areas.

4.3. Sporocarp production

High fresh weight production (476.3 kg ha^{-}1) was found in *P. pinaster* plots. Lower values had been referenced by Martín-Pinto et al. (2006b) with an average plot yield of 332.7 kg ha^{-1}. It is known that higher primary production is associated with the initial stages of the vegetal succession. In this sense, the studied *Pinus* reforestations stands can be considered as in their initial phase.

Total fresh yield for *P. sylvestris* plots was 178.1 kg ha^{-1}. Lower results were reported by Bonet et al. (2004) with a total fresh weight production of 60.6 kg ha^{-1}, were natural forests were studied.

Sporocarp production of mycorrhizal fungi was significantly higher in *Pinus* plots than in *Quercus* plots. This result can be explained by the different growth rates of both stands. *Pinus* species, classified as fast-growing species, produce biomass faster than *Quercus* (considered a slow-growing genus) stands. Mycorrhizal fungi production depends directly on tree production, and consequently, it is higher in *Pinus* than in *Quercus*. In contrast, saprotrophic species production depends on the organic matter present on the soil as well as environmental conditions such as soil humidity and temperature. As it was mentioned above, the decomposition rate in the dry Mediterranean ecosystems is very low, due to the lack of coincidence of precipitations and high temperatures. This peculiarity is found in *Pinus* stands as well as in semi-deciduous *Quercus* stands, where there is a similar accumulation of undecomposed leaves and needles, in contrast with the high amount of decomposed organic matter that is found in other deciduous forest located in more humid areas. Thus, no significant differences were found between *Quercus* and *Pinus* saprotrophic production.

Saprotrophic species production was significantly higher in *Populus* plots compared to *Quercus* and *Pinus* plots. In previous works, high production of mycorrhizal fungus such as *Lactarius controversus*, *Paxillus involutus*, *Tricholoma populinum* and *Tricholoma scalpturatum* were found in a 6-year poplar stand (data not shown). Thus, although all the studied stands are between 45 and 55 years old, *P. nigra* is a fast-growing species, so these stands are considered over-mature stands. According to Senn-Irlet and Bieri (1999), response to stand aging differed among functional groups, and this differential response can be related to the different availability of substrata. As a forest stand matures, the humus layer develops. As a result, forest soil increases its capacity to maintain a comfortable temperature and adequate moisture. Such conditions, in addition to the important amount of water available in this riparian habitat throughout the year, enhance fungal growth and fruiting, especially for saprotrophic fungi (Straatsma et al., 2001; Fernández-Toirán et al., 2006). Furthermore, the *Populus* stand is highly susceptible to diseases and pests since dead stems and roots can be observed in the area.

4.4. Edible production and marketed species

The harvest of edible ectomycorrhizal mushrooms from forests can be an important source of rural income, in some cases generating higher revenues than timber production (Oria-de-Rueda, 1991; Pilz and Molina, 2002; Kranabetter et al., 2002, 2005). During the last decade, there has been a sharp increase in the demand for edible fungi. In the study area, as well as in many countries, the commercial value of forests can be increased through well-planned timber removals that may improve the habitat for commercially valuable edible mushrooms and provide wood and employment at the same time (Pilz et al., 1999, 2003; Bonet et al., 2004; Wang and Hall, 2004; Pilz et al., 2004).

In this study, fresh weight production of edible taxa in *P. pinaster* plots represented 12% of the total taxa but comprised 62% (294.8 kg ha^{-1}) of fresh weight yield. Similar results were found by Martín-Pinto et al. (2006b) who collected 272.8 kg ha^{-1} of edible fungi from *P. pinaster* stands in Northwest Spain. Lower values were found by Fernández-Toirán et al. (2006), who studied the production of edible fungal species in natural *P. pinaster* stands. Again, fungal communities associated with young artificial reforestations seems to be more active generating higher production than those observed in well established natural forests.

Edible taxa in *P. sylvestris* represented 14% of the total taxa but comprised 56% of fresh weight production. Total fresh edible yield was 99.9 kg ha^{-1}. Lower fresh production were reported by Bonet et al. (2004) in *P. sylvestris* forest of the central Pyrenees with 44.7 kg ha^{-1} of edible mushrooms and by Kardell and Eriksson (1987) from Sweden with 43.2 kg ha^{-1} of edible fungi. Higher fresh yields of edible mushrooms (153 kg ha^{-1}) were found by Shubin (1988) from *P. sylvestris* stands in Russia.

The number of edible species in *P. halepensis* plots was similar to the number of edible species found in *P. sylvestris* and *P. pinaster* ecosystems. An important production of *Suillus* species was found in *P. halepensis* plots, according to Torres and Honrubia (1997) who found the ectomycorrhizas formed by species of *Suillus* one of the most abundant in a *P. halepensis* forest in Southeast Spain.

The results reported here showed the important role of artificial reforestations generating interesting incomes from the production of edible and appreciated fungal species. Furthermore, these *Pinus* reforestations may be an adequate intermediate stage in the recovery of the native vegetation in degraded and abandoned farmlands (Onaindia and Mitxelena, 2009).

5. Conclusions and management considerations

The reforested areas were located in very degraded and eroded soils without any kind of vegetation. For this reason, it was to be expected that artificial coniferous stands would have shown a low diversity. However, the results of this study showed a high fungal diversity and production in *Pinus* treatments. Thus, as well as playing an essential role in Mediterranean ecosystems preventing soil losses and desertification of large areas, artificial reforestations can provide rates of fungal production and diversity similar to those found in natural forest stands.

According to Richardson (2000), in many places around the Mediterranean Sea, the pine-dominated vegetation is undeniably an intermediate step in succession to a climax state dominated by broadleaved forest. Thus, these coniferous stands are considered as an intermediate stage of vegetation in order to reach, after some time, the natural vegetation in the area (*Quercus* and *Populus* stands). During plant succession, these stands protect the soil from erosion and keep an appreciable diversity, providing also valuable natural resources (timber and mushrooms), important for the sustainable development of the region.

Moreover, some commercially valuable fungi harvested in these reforestations provide income that must be considered in light of the cost of forest treatments such as thinning, clearings, brushouts and other interventions. Furthermore, adequate management in these forest stands will improve trees health and vigour and it is likely to improve the production of mycorrhizal fungi. Management may also prevent or alleviate stand-replacing wildfire in these Mediterranean forests.

The harvest of edible ectomycorrhizal mushrooms from forests can be an important source of rural income. Therefore, conservation of existing edible mycorrhizal fungi ecosystems is an urgent matter, particularly in developing countries. In this sense the results shown in this study provide interesting information to local forest managers in order to optimize forest management in arid zones.

The aim of this study is not to justify the substitution of the natural forest of *Quercus* with an artificial reforestation of *Pinus*, but, in contrast, to justify *Pinus* plantations in degraded areas as a means to achieve a natural forest, which provide fungal production and diversity as high as those found in natural forest stands.

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