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Original article

# Comparative analyses of Turkey agricultural soils: Potential communities of indigenous and exotic mycorrhiza species' effect on maize (*Zea mays* L.) growth and nutrient uptakes

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ABSTRACT

The objective of this study was to examine the mycorrhizal spore abundance and identity in three soils from three ecological sites, and also to determine the effect of indigenous and "exotic" mycorrhiza strains on maize (*Zea mays* L.) plant growth and phosphorus (P) and zinc (Zn) uptake in three agricultural soils. Soil samples were collected from three great agricultural areas with a large expanse of soil series such as Sultanönü, Harran and Menzilat from Central Anatolia (CA), Coast of the Mediterranean (CM) and Southeastern Anatolia (SA) areas of Turkey, respectively.

A total of 12 species of *Glomeromycota* was detected in the soil surveys. Two, four and four species belonged to *Funneliformis*, *Glomus* and *Rhizophagus*, respectively, and two species belonged to Acaulospora. The indigenous mycorrhizae density and species were determined, and their effect on maize growth was tested using two pot experiments. In the first pot experiment, indigenous mycorrhiza spores increased maize plant growth and P and Zn concentration in non-sterilized soils when compared with maize in sterile soil. Maize plants grown in non-sterile soils had a higher root colonization ratio (%) than plants grown in sterile soils. Sterilization, in the three soils, significantly increased root dry weight and root length.

In the second pot experiment, the effect of selected arbuscular mycorrhizal fungal (AMF) species and re-inoculated indigenous mycorrhiza spores on maize growth was evaluated under sterile soil conditions. Maize plants inoculated with *Funneliformis mosseae, Funneliformis caledonium* and *Claroideoglomus etunicatum* strains produced more dry weight and had a higher root colonization (%) than indigenous Sultanönü, Harran and Menzilat spore inoculation. Plant P and Zn concentrations increased with indigenous and selected AM fungal inoculation. It was concluded that although indigenous mycorrhizae contribute to plant growth, the contribution of selected mycorrhizae is much greater.



## 1. Introduction

Increasing environmental concern demands that we employ ecological management, such as using organic inputs and managing soil-plant and microorganism relationships in the rhizosphere. In sustainable agriculture, soil and crop management systems are of vital importance for biological soil fertility. The establishment of functional arbuscular mycorrhizal (AM) symbioses improves the soil nutrient availability to plants.

However, crop and soil management strategies may have strong negative and positive impacts on mycorrhizal communities [1–3]. Also under low-input cropping system soil characteristics have significant influence on the species richness and composition [4]. Gosling et al. [5] observed that the AM spore population in soil was significantly higher in the organically managed soils compared with conventionally managed field soils. Since arbuscular mycorrhizal fungi (AMF) play an important role in plant health and fitness, the productivity of agro-ecosystems is affected by their abundance and diversity in the soil [6]. Smith and Read [7] reported that AM can be found in all climatic sites, and so far as is known, in all soils carrying vegetation. AM are found on the majority of the world's vegetation, including tropical tree species. AMF are able to infect most crop species, depending on soil conditions and, in particular, soil fertility. An important fact is that AMF have been shown to significantly increase the nutrient uptake of plants,

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mainly by improving P uptake, especially those growing in nutrient-poor sites [7–9]. Mycorrhizal root systems seem to be able to selectively absorb P from deficient soils. Under low soil P conditions, mycorrhizal inoculation can increase P uptake several fold more than found in non-inoculated soil [7]. Under such conditions, mycorrhizal inoculated roots have a higher P absorption capacity compared with non-mycorrhizal roots [10]. Singh et al. [11] and Ortas and Akpinar [9] reported that root and shoot P, and shoot Zn concentrations were significantly higher in AM compared with non-mycorrhizal plants at various P levels. AMF and communities of other soil organisms do not benefit plant growth in highly fertile soil, however, they did improve maize growth in soil of low fertility [12].

The South-eastern Anatolian Project (SAP, Turkish acronym GAP) is the largest irrigation and development project in Turkey, covering approximately 2 million ha of cultivated land. The Harran plain, called the 'Fertile Crescent' is located in the upper part of the Mesopotamia plain. Maintenance of sustainable agricultural production in the face of desertification is a major issue in the eastern Mediterranean, south Anatolia and central Anatolia. For thousands of years, crop production in the Harran plain area has been carried out without the application of fertilizer, it is therefore worthwhile studying the nutrient uptake of several plant species. Many research projects were carried out between 1976 and 2002 in the Research Institute of Rural Services of Sanlıurfa, which is located in the south of Turkey. Several greenhouse and field experiments in the region using different crops including maize (*Zea mays* L.), wheat (*Triticum aestivum*), barley *(Hordeum vulgare),* lentil (*Lens culinarista* Med) and cotton (*Gossypium hirsutum*) have repeatedly shown that applications of P fertilizers (from 0 to 300 kg $P_2O_5$ $ha^{-1}$) do not lead to any increase in crop yield in soils with a low plant-available P concentration. After several years of research, scientists working in the area have reached the conclusion that there is no clear recommendation for P fertilizer. Several similar experiments were performed in one of the biggest agricultural areas on the Mediterranean coast, the region plane of Çukurova. Also, in central Anatolia, known as a storehouse of wheat, some other field experiments performed by the National Soil and Fertilizer Research Institution Eskisehir, Konya, Ankara, have shown that sometimes there are no differences between low and high P application [8]. The main objectives of these studies were to determine the optimal amount of fertilizer for barley and wheat crops in central Anatolia. The impact of cultivation on AMF effectiveness and its effect on plant growth in three main ecological sites of Turkey is less understood. A comparison of the effects of native (indigenous) versus exotic mycorrhizae on maize performance in Harran soil was carried out by Ortas [8] and it has been indicated that indigenous mycorrhiza have less effect on maize growth compared with exotic AM species.

Since fertilizers are expensive, it is important to study the potential mycorrhizae spore abundance and its effect on industrial maize growth in three important ecological sites. Thus, the objective of this study was to examine the mycorrhizal spore abundance and identity in three soils located in three ecological sites, and also to determine the effect of indigenous and selected indigenous arbuscular mycorrhiza strains on maize plant growth, and phosphorus (P) and zinc (Zn) uptake in three agricultural soils. The study was based on the hypothesis that indigenous mycorrhizae are as effective on the maize crop as selected (exotic) AM species.

## 2. Materials and methods

### 2.1. Sampling location

Three common soil series Sultanönü (Typic Calcixercept [13]), Harran (Vertic Calciorthid) and Menzilat (Typic Xerofluvents), were selected in natural and agricultural plant communities from three different agro-ecological sites (regions) of Turkey, Coast of the Mediterranean (CM), Southeastern Anatolia Area (SA) and Central Anatolia (CA) respectively (Fig. 1 and Table 1). At each location, four soil samples were collected at 0–20 cm depth during the summer of 2002 and the soil samples were merged into a single sample which was then analysed. The physical, chemical and biological properties of the soil from each site are presented in Table 1. Plant species in the area were also sub-sampled and plant roots were collected to determine the mycorrhizal colonization ratio (%).

### 2.2. Field survey

Mycorrhizal propagules were directly isolated from the original rhizosphere soil samples by wet sieving and sucrose gradient centrifugation [14].

### 2.3. AMF species identification

After extracting the spores from the soils, the spores were preserved in sodium azide (0.05%). Prior to identification, spores were separated according to their colour and size. Spore colour was examined under a dissecting microscope on fresh specimens immersed in water. Colours were determined according to the INVAM colour chart [15]. The separated spores were then mounted on microscope slides. Both intact and crushed spores were placed in polyvinyl alcohol/lactic acid/glycerol (PVLG) [16] and Melzer's reagent (1:1, v/v) [17], and then examined. Spores were identified by microscopy according to their colour, shape and size.

### 2.4. Pot experiment (I) on the effect of indigenous mycorrhiza

The soil and quartz sand, used as a substrate, were sterilized (autoclaved for 2 h at 120 °C) and kept in laboratory conditions for three weeks before being repacked into pots. Sterilized and non-sterilized soil samples were placed into sterilized sand in a 1:30 soil:sand ratio. Growth material, soil and sand were placed into 3 L pots with three replicates. Five maize seeds were sown into the soil: sand medium and thinned one week after germination to two plants per pot. The pots were randomly rearranged once a week. Distilled water was added daily to maintain moisture close to 80% of field capacity for normal plant growth. Plants were fertilized twice with additional nitrogen (50 mg $kg^{-1}$ N [25 mg $kg^{-1}$ soil, N-$(NH_4)_2SO_4$, 25 mg $kg^{-1}$ soil, N–$KNO_3$]) with 1/4 strength P Hewitt nutrient solution [18]. In the first pot experiment, plants were harvested following 56 days of growth.

### 2.5. Pot experiment (II) comparing indigenous and selected inoculations

Three soils (Sultanönü, Harran and Menzilat) were sterilized (autoclaved for 2 h at 120 °C) and placed into 3 L pots with three replicates. The soils were fertilized with 200 mg N $kg^{-1}$ soil [100 mg $kg^{-1}$ soil, N-$(NH_4)_2SO_4$, 100 mg $kg^{-1}$ soil, N–$KNO_3$], 50 mg P $kg^{-1}$ soil as monocalcium phosphate $Ca(H_2PO_4)$, 2.5 mg Zn $kg^{-1}$ soil as $ZnSO_4$ and 5 mg Fe $kg^{-1}$ soil as Fe-EDTA. Five maize seeds were sown per pot and thinned to two plants after 12 days. Before the seeds were sown, 1000 spores of each mycorrhizae species were inoculated per pot, i.e., *Claroideoglomus etunicatum* ((W.N. Becker & Gerd.) C. Walker & Schuessler (2010) [19]) Nutri-Link isolate; USA, *Funneliformis caledonium* ((T.H. Nicolson & Gerd.) C. Walker & Schuessler (2010) [19]) Rothamsted isolate, UK; as well as *Funneliformis mosseae* ((T.H. Nicolson & Gerd.) C. Walker & Schuessler (2010) [19]) Rothamsted isolate, UK . The AMF inocula

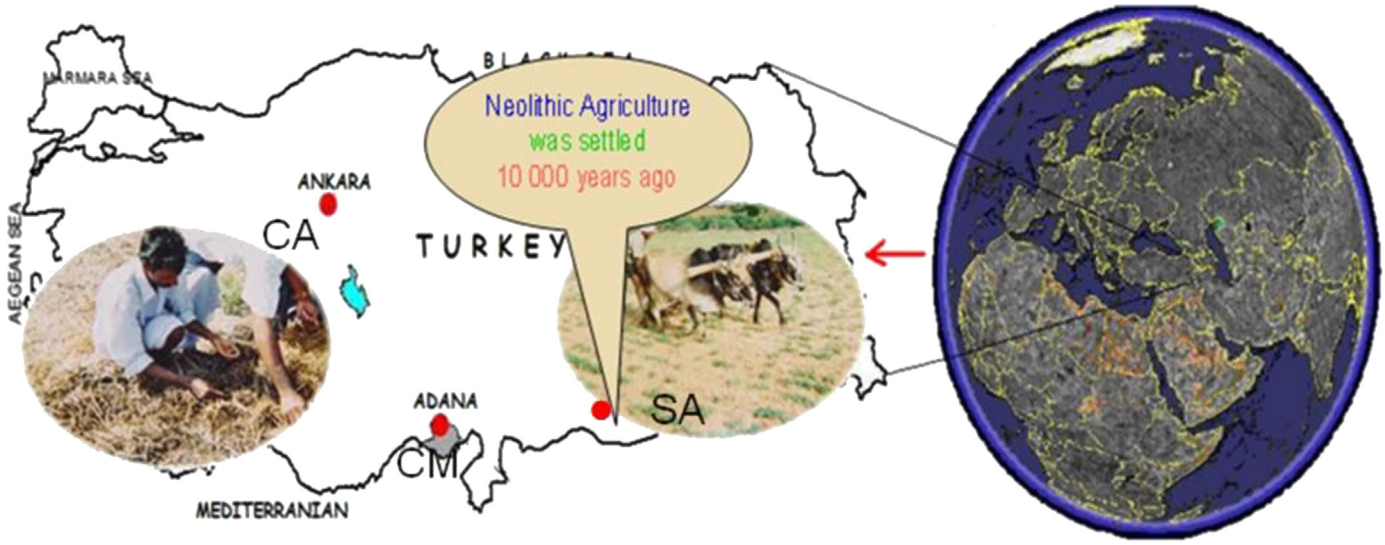


**Fig. 1.** Sampling area, Central Anatolia (CA), Southeastern Anatolian Project Area (SA) and the Coast of Mediterranean (CM). GPS location and precipitation for each location is presented.

were multiplied in the greenhouse using Sudan grass [*Sorghum bicolor* (L.) Moench] as the host plant and grown in a mixture of andesitic tuff + soil + peat (6 + 3+1, V:V:V)). In addition, 1000 extracted indigenous spores (propagated from on the same growth medium and with same host plant) from each soil series Sultanönü (indigenous), Harran (indigenous) and Menzilat (indigenous) were applied. Control treatments received the same amount of mycorrhizae-spore-free sterile inocula medium. Distilled water was added daily to maintain moisture at 80% field capacity. The plants were grown in a greenhouse at 23–25 °C and a relative humidity of 80%. Plants were harvested following 49 days of growth.

### 2.6. Harvest and measurements

At harvest, shoot and root dry weights, root colonization and root length were measured. Root colonization was determined on washed roots collected from the field and pot experiments. Roots were separated from the soil by washing under a running tap and distilled water. Before drying the roots, small sub-samples were taken and preserved in a mixture of ethanol, glacial acetic acid and formalin, for the determination of root length and mycorrhizal infection. The length of the roots was estimated by the Tennant's [20] modified line intersect method. The samples of root were cleaned in KOH solution (2.5%) and stained using the Trypan Blue (0.05%) procedure, the degree of mycorrhizal infection in the root cortex was assessed according to Koske and Gemma [21] using a grid-line intersect method [22].

Shoot and root samples were dry-ashed at 500 °C followed by dissolution in 3.3% HCl. After digestion of the plant material, the concentration of P in this solution was determined colourimetrically [23]. An atomic absorption spectrophotometer was employed to determine the zinc content of the plant samples.

### 2.7. Calculations and data analysis

Mycorrhizal growth responses (MGR) were calculated using the individual mycorrhiza (M); non-mycorrhiza (NM) total dry weight data of second experiment using the following formula of Cavagnaro, Smith, Ayling and Smith [24].

$$\text{Mycorrhizal growth responses MGR}(\%) = ((\text{M} - \text{NM})/(\text{NM})) \times 100$$

### 2.8. Statistical analysis

The data were analysed using the one-way ANOVA model to test for significant differences between mycorrhizae applications. All statistical analyses were performed using the SAS (version 9.2) package program. Least significance differences (LSD) at $P = 0.05$ were tested to determine the significant differences between treatment means.

## 3. Results

### 3.1. AMF spore number

The soils of the three ecological sites (Central Anatolia (CA), the Southeastern Anatolia Area (SA) and the Coast of Mediterranean (CM)) differed from each other in spore numbers (three replicates), with SA containing the greatest number (348 ± 63 spores 10 $g^{-1}$ soil) of the three sites. An agricultural field with maize in the CM zone contained 318 ± 45 spores 10 $g^{-1}$ soil, whereas in another agricultural field containing lentils (*L. culinarista* Med), stubble in the CA zone had the lowest spore numbers, 68 ± 28 spore 10 $g^{-1}$ soil (Table 1). In contrast, roots of plants growing in the three sites exhibited similar mycorrhizal colonization rates.

### 3.2. AMF species richness

Twelve species of the Glomeromycota were detected in the three soil sites (Table 2). Two, four and four species belonged to *Funneliformis, Glomus* and *Rhizophagus*, respectively, and two species belonged to Acaulospora The most common species were *F. mosseae, G. microcarpum, G. pansihalos, G. dimorphicum, R. manihotis*, *R. fasciculatum, R. clarus,* and *R. irregularis*.

*Glomus* species with unclear taxonomical characteristics or moribund were not identified to species level. The total number of

**Table 1**
Selected physical, chemical and biological properties of Sultanönü, Haran and Menzilat soil series.

| Location region | Preci. mm | PLC | RC (%) | AMF spore 10 $g^{-1}$ soil | Clay | Silt | Sand | SOC | IC | TN | $NH_4$ | $NO_3$ | Min.N | CEC $Cmol^+$ $kg^{-1}$ | pH (1/2.5$H_2O$) | Salt % | P kg $ha^{-1}$ | Av. K | Fe | Mn | Zn | Cu |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | g $kg^{-1}$ | | | g $kg^{-1}$ soil | | | | | | | | | | | mg $kg^{-1}$ soil | | | |
| Sultanönü (CA) | 330 | Straw (Wheat) | 21 | 68 | 470 | 340 | 190 | 0.86 | 1.35 | 0.07 | 21.2 | 7.6 | 28.8 | 38.0 | 7.85 | 0.02 | 125 | 1020 | 0.25 | 7.20 | 0.21 | 0.95 |
| Harran (SA) | 380 | Lentil Stubble | 38 | 348 | 460 | 350 | 190 | 0.95 | 2.61 | 0.07 | 3.1 | 4.3 | 7.4 | 58.0 | 7.50 | 0.08 | 77 | 1520 | 0.27 | 1.22 | 0.15 | 1.59 |
| Menzilat (CM) | 700 | Maize | 42 | 318 | 540 | 280 | 180 | 1.05 | 3.77 | 0.08 | 6.2 | 14.7 | 21.0 | 19.1 | 7.67 | 0.05 | 78 | 1680 | 0.40 | 4.66 | 0.24 | 1.07 |

Values are the averages of three samples ± standard deviation * Not measured.
CA: Central Anatolia SA: Southeastern Anatolia Area, CM: Coast of Mediterranean.
Preci: Precipitation, MPC: Major Plant Community, RC: Root Colonization, AMF Spore: Number of AMF spores.
CEC: Cation Exchange Capacity. % denotes the mass in percentage, the notation.
SOC: Soil Organic Carbon; IC, Inorganic carbon; TN, Total Nitrogen.
Min.N: mineralize nitrogen, Av.K: available potassium, $NH_4$, ammonium; $NO_3$, Nitrate.
P: phosphorus, Zn: Zinc, Fe: Iron, Mn: Manganese, Cu: Cupper.

**Table 2**
Mycorrhizae species in three different soil series in three big ecological sites of Turkey.

| Mycorrhizae species | Soil series | | |
|---|---|---|---|
| | Sultanönü (CA) | Menzilat (CM) | Harran (SA) |
| *Acaulospora denticulata* | | | x |
| *A. lacunosa* | x | x | x |
| *Funneliformis geosporum* | | x | |
| *F. mosseae* | x | x | x |
| *Glomus citricola* | x | | |
| *G. dimorphicum* | x | | x |
| *G. microcarpum* | | | x |
| *G. pansihalos* | | | x |
| *Rhizophagus fasciculatus* | x | x | x |
| *R. manihotis* | x | x | x |
| R. irregularis | x | x | x |
| *R. clarus* | x | x | x |

CA (Sultanönü soil series is located in Central Anatolia).
SA (Harran soil series is located in South Anatolia Area).
CM (Menzilat soil series is located in Coast of Mediterranean).

AMF species detected was higher in the Harran soil (SA) than in the CM and CA soil.

### 3.3. Pot experiment I

The effect of the soil sterilization treatment on maize shoot dry weight (SDW) was significant ($P < 0.03$) in comparison with non-sterilized soils. In the non-sterile Sultanönü soil, 3.75 g $pot^{-1}$ SDW was produced, however, the non-sterile Menzilat soil produced 5.74 g $pot^{-1}$ SDW (Table 3). In the sterilized Sultanönü soil, 3.87 g $pot^{-1}$ SDW was produced, however, the sterilized Menzilat soil produced 5.02 g $pot^{-1}$ SDW. In the non-sterile and non-inoculated Harran and Menzilat soils, the maize plant had more SDW than found in the sterile soil. In addition, there was a significant difference in root dry weight (RDW) between sterilized and non-sterilized soils. Plants grown in sterile soils produced higher RDW than plants grown in non-sterile soils. Soil sterilization significantly increased root length and reduced root colonization compared with non-sterilized soil treatment. The root length in non-sterile soils ranged from 60 m (m) per pot in the Sultanönü soil to 137 m per pot in the Menzilat soil (Table 3), however, in the sterile soil it ranged from 102 m per pot in the Sultanönü soil to 222 m per pot in the Menzilat soil. The root length increase was higher in the sterilized soil, since the interaction was significant ($p < 0.0129$), this indicates the root length depended on soil origin and soil sterilization, and soil sterilization in different soils affected root length differently.

Compared with sterile soils, the non-sterile soil indigenous mycorrhizae increased the maize root colonization ratio (%) (Table 3). Plant roots in the non-sterile Sultanönü soil had less root colonization (11%) compared with the Menzilat soil, which had the highest root colonization (36%).

Soil sterilization significantly ($P < 0.0026$) increased P concentration. Although the plant Zn concentration was higher in non-sterile than in sterile soil, the increase was not statistically significant ($P < 0.2464$).

### 3.4. Pot experiment II

Inoculation with indigenous mycorrhizae significantly increased shoot growth ($P < 0.0001$) compared with the control (Table 4). However, the exotic mycorrhiza species were always efficient. In the Sultanönü soil, 8.2 g $pot^{-1}$ shoot DW was produced in the control treatment, compared with 13.7 g $pot^{-1}$ produced using

**Table 3**
Effect of sterile and non-sterile soil treatments on maize plant parameters, phosphorus and zinc concentration.

| Soils | Treatments | Shoot DW (g pot$^{-1}$) | Root DW (g pot$^{-1}$) | Root length (m pot$^{-1}$) | Root colonization (%) | P (%) | Zn (μg g$^{-1}$) |
|---|---|---|---|---|---|---|---|
| Sultanönü | S | 3.87 ± 0.22c | 3.49 ± 0.27cd | 102 ± 7c | 3 ± 1d | 0.17 ± 0.02c | 16.9 ± 2.5b |
| | NS | 3.75 ± 0.13c | 2.96 ± 0.35d | 60 ± 5c | 11 ± 3c | 0.18 ± 0.01b | 18.2 ± 0.5b |
| Harran | S | 4.75 ± 0.32b | 4.18 ± 0.39 ab | 124 ± 3b | 4 ± 1d | 0.18 ± 0.02b | 19.0 ± 2.6 ab |
| | NS | 5.14 ± 0.39 ab | 3.74 ± 0.48bc | 83 ± 11c | 24 ± 7b | 0.20 ± 0.01a | 20.9 ± 1.4 ab |
| Menzilat | S | 5.02 ± 0.46b | 4.63 ± 0.21a | 222 ± 12a | 3 ± 1d | 0.19 ± 0.01 ab | 20.9 ± 2.8 ab |
| | NS | 5.74 ± 0.47a | 4.61 ± 0.02a | 138 ± 22b | 36 ± 5a | 0.21 ± 0.01a | 22.1 ± 1.8a |
| Treatments | Df | | | | | | |
| Soil | 2 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | 0.0044 | 0.0417 |
| Sterilization | 1 | 0.0288 | 0.0770 | <0.0001 | <0.0001 | 0.0426 | 0.2464 |
| Soil × Sterile | 2 | 0.3696 | 0.2430 | 0.0129 | <0.0001 | 0.1480 | 0.7875 |

Mean of three replicates and ± is standard deviation.
S: Sterile NS: Non-sterile. Df: Degree of freedom.
Mean followed by the different letters (a. b. c and d) within the same column indicate significant differences ($P < 0.05$).

**Table 4**
Effect of several indigenous and exotic mycorrhiza on growth parameters of maize in three soils. Significance of P-values (probability) from analysis of variance for plant shoot and root growth.

| Mycorrhizae species | Soils | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Sultanönü (CA) | | | Harran (SA) | | | Menzilat (CM) | | |
| | Shoot DW | Root DW | R/S | Shoot DW | Root DW | R/S | Shoot DW | Root DW | R/S |
| | g pot$^{-1}$ | | | g pot$^{-1}$ | | | g pot$^{-1}$ | | |
| Control | 8.2 ± 0.5c | 5.8 ± 0.8 ab | 0.7 | 10.3 ± 0.2c | 6.3 ± 0.0a | 0.6 | 8.5 ± 1.1e | 4.2 ± 0.2d | 0.5 |
| *F. mosseae* | 11.2 ± 0.1ac | 6.9 ± 0.4 ab | 0.6 | 16.6 ± 0.6 ab | 7.3 ± 0.1a | 0.4 | 18.5 ± 0.8a | 7.1 ± 0.3b | 0.4 |
| *F. caledonium* | 13.7 ± 0.1a | 6.4 ± 0.3 ab | 0.5 | 17.1 ± 1.9 ab | 7.8 ± 0.4a | 0.5 | 16.3 ± 0.7b | 8.5 ± 0.4a | 0.5 |
| *C. etunicatum* | 13.0 ± 0.3a | 8.0 ± 1.3a | 0.6 | 19.0 ± 0.5a | 7.1 ± 0.6a | 0.4 | 18.5 ± 0.8a | 8.9 ± 0.4a | 0.5 |
| Sultanönü (indig.) | 8.4 ± 2.5c | 6.9 ± 0.1b | 0.6 | 12.3 ± 0.2bc | 6.3 ± 0.4a | 0.5 | 9.4 ± 0.4de | 5.8 ± 0.2c | 0.5 |
| Harran (indig.) | 12.1 ± 0.1 ab | 5.6 ± 1.9 ab | 0.7 | 15.0 ± 3.9ac | 6.9 ± 2.5a | 0.5 | 12.4 ± 0.5c | 6.9 ± 0.3b | 0.7 |
| Menzilat (indig.) | 9.3 ± 2.7bc | 6.4 ± 1.1 ab | 0.7 | 14.8 ± 3.5ac | 7.9 ± 1.2a | 0.5 | 10.7 ± 1.2dc | 6.5 ± 0.3bc | 0.6 |

| Treatments | Df | Shoot DW | Root DW |
|---|---|---|---|
| Soil | 2 | <0.0001 | 0.3305 |
| Mycorrhizae | 6 | <0.0001 | 0.0008 |
| Soil × Mycorrhizae | 12 | 0.1049 | 0.1957 |

Mean of three replicates and ± is standard deviation; R/S: Root/shoot ratio.
Mean followed by the different letters (a. b. c and d) within the same column indicate significant differences ($P < 0.05$).
Df: Degree of freedom; DW: dry weight.
CA (Sultanönü soil series is located in Central Anatolia), SA (Harran soil series is located in South Anatolia Area).
CM (Menzilat soil series is located in Coast of Mediterranean).
F: *Funneliformis*, C: *Claroideoglomus*.

*F. caledonium* as the inocula. However, 8.4 g pot$^{-1}$ was produced in the indigenous Sultanönü mycorrhiza inoculation and 12.1 g pot$^{-1}$ was produced in the indigenous Harran mycorrhizal inoculation. In the Harran soil, 10.3 g pot$^{-1}$ SDW was produced in the control treatment, compared with 19.0 g pot$^{-1}$ using *C. etunicatum* as a inoculum and 15.0 g pot$^{-1}$ in the indigenous Harran mycorrhiza inoculation. In the three soils, inoculation with AMF isolated from Harran resulted in the largest increase in maize growth compared with the control. MGR was much higher after inoculation with exotic AMF than after inoculation with indigenous AMF spore populations (Fig. 2). Among the indigenous inoculations, spores from the Sultanönü soil resulted in lower plant MGR % than when using spores from Menzilat and Harran soils.

Mycorrhizal inoculation significantly ($P < 0.0008$) affected root dry weight (RDW). However, the *C. etunicatum* inoculated soil had a high RDW and the control exhibited the lowest RDW of the three soils. The effect of the soil on RDW was not significant ($P < 0.3305$) (Table 4).

Table 5 summarizes the results of root length (m) per pot and root colonization (%) for different mycorrhiza inoculation treatments. Root length significantly increased with mycorrhizal inoculation in both Harran and Menzilat soils ($P < 0.0001$). The most notable increase was obtained with inoculation of indigenous

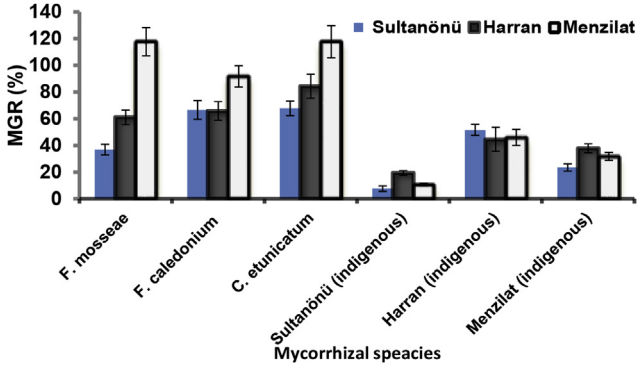


**Fig. 2.** Mycorrhizal growth responses (MGR) measured as total dry weights of maize plants after inoculation with exotic AMF and indigenous spore suspensions from three soil series. F: *Funneliformis*, C: *Claroideoglomus*.

mycorrhizae spores in the Harran soil. Among the exotic mycorrhizae, *F. mosseae* inoculated plants had a higher root length than inoculation with *F. caledonium* and *C. etunicatum*.

Mycorrhizal inoculation significantly increased ($P < 0.0002$) root colonization and was significantly higher with exotic

**Table 5**
Effect of several indigenous and exotic mycorrhizae species on root length and root colonization in three soil series. Significance of P-values (probability) from analysis of variance for plant root length and root colonization.

| Mycorrhizae species | Soils | | | | | |
|---|---|---|---|---|---|---|
| | Sultanönü (CA) | | Harran (SA) | | Menzilat (CM) | |
| | Colonization (%) | Root length (m) | Colonization (%) | Root length (m) | Colonization (%) | Root length (m) |
| Control | 2 ± 0d | 169 ± 22d | 1 ± 0a | 176 ± 26c | 1 ± 0f | 183 ± 33d |
| *F. mosseae* | 41 ± 1c | 210 ± 23b | 35 ± 9e | 188 ± 32b | 34 ± 7d | 173 ± 22e |
| *F. caledonium* | 95 ± 18a | 133 ± 22e | 96 ± 19a | 136 ± 23d | 85 ± 10a | 138 ± 12f |
| *C. etunicatum* | 70 ± 11b | 186 ± 28c | 62 ± 1b | 171 ± 24c | 59 ± 15b | 167 ± 23f |
| Sultanönü (indig.) | 9 ± 1d | 237 ± 3a | 12 ± 0f | 301 ± 44a | 13 ± 4f | 239 ± 33b |
| Harran (indig.) | 42 ± 11c | 197 ± 41 cb | 39 ± 11c | 300 ± 54a | 36 ± 11c | 248 ± 24a |
| Menzilat (indig.) | 41 ± 6c | 193 ± 11c | 42 ± 8d | 301 ± 36a | 35 ± 10cd | 198 ± 30c |

| Treatments | Df | Root length | Root Colonization |
|---|---|---|---|
| Soil | 2 | 0.0001 | 0.0001 |
| Mycorrhizae | 6 | 0.0001 | 0.0001 |
| Soil × Mycorrhizae | 12 | 0.0002 | 0.0001 |

Mean of three replicates and ± is standard deviation.
Mean followed by the different letters (a. b. c and d) within the same column indicate significant differences ($P < 0.05$).
Df: Degree of freedom; Indig: indigenous.
CA (Sultanönü soil series is located in Central Anatolia), SA (Harran soil series is located in South Anatolia Area).
CM (Menzilat soil series is located in Coast of Mediterranean).
F: *Funneliformis,* C: *Claroideoglomus.*

inoculants. The Sultanönü soil had a value of 2% in the control, compared with 95% using *F. caledonium* and 9% using the indigenous Sultanönu mycorrhizae spore inoculation. Similar trends were observed in Harran and Menzilat soils. An increase in the rate of colonization, for example, in the Sultanönü soil, inoculation with *F. caledonium* increased the mycorrhizal colonization to 93% and 86%, when compared to non-inoculated and Sultanönü indigenous inoculated soils, respectively.

Harran and Menzilat spore inoculation resulted in a higher root colonization than in the Sultanönü soil. In each of the three soils, the *F. caledonium* and *C. etunicatum* inoculum produced significantly higher root colonization than the *F. mosseae* inoculation.

### 3.5. Phosphorus and zinc concentration

Mycorrhizal inoculation significantly ($P < 0.0001$) increased plant P and Zn concentration in all three soils. There was a tendency for indigenous mycorrhizae to have less effect on the P concentration of plants (Table 6).

## 4. Discussion

We found that soil and plant management had a large effect on AMF populations (Table 1) and species richness. This is the first study that identifies some indigenous AMF at three large ecological sites of Turkey.

As seen in Table 1, AMF spore numbers varied among the three soil series, which is a result of their different plant history, actual standing crops and soil parameters [2,3,25–27].

AMF spores extracted directly from indigenous soils contained a percentage of low quality spores often difficult to identify to species level. The number of species and spore number per g of dry soil found in this study are generally similar to those obtained in many other studies [28,29]. A similar study by Camprubi et al. [30]

**Table 6**
Effect of several indigenous and exotic mycorrhizae species on maize plant P and Zn concentrations in three soil series. Significance of P-values (probability) from analysis of variance for plant phosphorus and zinc concentration parameters.

| Mycorrhizae species | Soils | | | | | |
|---|---|---|---|---|---|---|
| | Sultanönü (CA) | | Harran (SA) | | Menzilat (CM) | |
| | P (%) | Zn (μg $g^{-1}$) | P (%) | Zn (μg $g^{-1}$) | P (%) | Zn (μg $g^{-1}$) |
| Control | 0.18 ± 0.02c | 14.3 ± 1.9c | 0.18 ± 0.02c | 16.6 ± 2.3d | 0.20 ± 0.02b | 18.0 ± 2.1c |
| *F. mosseae* | 0.25 ± 0.03a | 21.2 ± 2.6a | 0.25 ± 0.03a | 26.3 ± 3.1a | 0.26 ± 0.03a | 29.2 ± 3.4a |
| *F. caledonium* | 0.23 ± 0.03 ab | 18.7 ± 2.2 ab | 0.25 ± 0.04a | 23.8 ± 2.8ac | 0.27 ± 0.03a | 28.6 ± 3.3a |
| *C. etunicatum* | 0.25 ± 0.03a | 20.0 ± 2.3 ab | 0.23 ± 0.03 ab | 25.4 ± 3.0 ab | 0.27 ± 0.03a | 26.8 ± 3.1 ab |
| Sultanönü (indig.) | 0.19 ± 0.02bc | 17.1 ± 1.6bc | 0.21 ± 0.02bc | 19.4 ± 1.7c | 0.20 ± 0.02b | 19.7 ± 1.8c |
| Harran (indig.) | 0.21 ± 0.02ac | 17.9 ± 2.1b | 0.24 ± 0.02 ab | 21.8 ± 2.5bc | 0.26 ± 0.03a | 27.8 ± 3.2 ab |
| Menzilat (indig.) | 0.21 ± 0.02ac | 16.4 ± 1.9bc | 0.22 ± 0.02 ab | 21.1 ± 2.5bc | 0.23 ± 0.03 ab | 23.1 ± 2.1b |

| Treatments | Df | P (%) | Zn (μg $g^{-1}$) |
|---|---|---|---|
| Soil | 2 | 0.0298 | 0.0001 |
| Mycorrhizae | 6 | 0.0001 | 0.0001 |
| Soil × Mycorrhizae | 12 | 0.9685 | 0.0995 |

Mean of three replicates and ± is standard deviation.
Mean followed by the different letters (a. b. c and d) within the same column indicate significant differences ($P < 0.05$).
Df: Degree of freedom; Indig: Indigenous, P: Phosphorus, Zn: Zinc.
CA (Sultanönü soil series is located in Central Anatolia), SA (Harran soil series is located in South Anatolia Area).
CM (Menzilat soil series is located in Coast of Mediterranean).
F: *Funneliformis*, C: *Claroideoglomus.*

showed that the highest diversity of fungi and abundance of AM fungal spores was found in well preserved and undisturbed dune systems, such as in the Mediterranean sand dune ecosystems of Spain. Menendez, Scervino and Godeas [31] and Tchabi et al. [1] observed higher spore density and richness in grassland soil than in cereal grown soils, and they also found that tillage and cereal monoculture negatively affected the diversity of AM fungal species. Tchabi et al. [1] found higher spore density at natural sites than at cultivated sites.

It seems that there is a potential effect of indigenous mycorrhizal fungal spores in the soil which successfully infected the plant roots, in particular, the Menzilat and Harran indigenous mycorrhizal inoculation increased plant productivity. As both the Menzilat and Harran soil had high indigenous mycorrhizae spore counts compared with the Sultanönü soil, they exhibited a high root colonization (%). Since Sultanönu soil had less number of spores, the effect of indigenous mycorrhizae on plant growth was less. Sultanönu soil which has been collected from semi-arid Central Anatolia where there is less precipitation, had fewer plant species and low root colonization of those plants (Table 1). Indigenous mycorrhiza (IM) spore diversity and richness depend much more on soil characteristics [4] and ecological conditions. Since IM includes several mycorrhiza species, the effect may be higher than a single mycorrhiza inoculum. The work of Wagg et al. [32] shows that AMF diversity can act as an insurance to sustain plant productivity under changing environmental conditions. Pellegrino et al. [33] and Williams, Norton and Ridgway [34] reported that the native inoculum was as effective as, or more effective than, exotic AM fungal isolates. Similarly Ortas [8] and Ortas and Ustuner [35] reported that if indigenous AMF inoculation is efficient, plants have significantly higher survival rate than those treated with commercial AMF.

In the present work a total of 12 species of Glomeromycota were detected in the soil surveys, two, four and four species belonged to *Funneliformis*, *Glomus* and *Rhizophagus*, respectively and two species belonged to *Acaulospora.* This is the first study on AMF species diversity in Turkish soil, but such studies have been done in other Mediterranean countries [36]. However, it has been reported [37] that Glomeraceae spores were associated with more fertile soils and disturbed ecosystems, and Acaulosporaceae spores were associated with less disturbed ecosystems.

The impact of mycorrhizal fungi is usually assessed by measuring plant growth following the inoculation of the fungi into sterilized soils [38]. However, growth responses are erratic and sometimes occur when AMF are added to non-sterile soil [10]. Statements regarding the mycorrhizal inoculation of sterile soils are still questionable due to the concern of the effect of mycorrhizal inoculation on plant growth under non-sterile soil conditions [38]. Compared with non-sterilization, soil sterilization resulted in a large decrease in yield in the three soils (Table 3), however, under sterile soil conditions mycorrhizal inoculation resulted in a great difference in maize yield (Table 4), similar to a previous report by Aggangan and Moon [39].

In pot experiment I, using the Sultanönü soil which had been sterilized, plant growth was higher than that in the non-sterile soil. Due to the mobilization of ammonium and nitrate, in particular, in autoclaved soils, plants may benefit from sterilization and grow better than the other two soils richer in nutrients and AMF species; soil sterilization also led to an increase in plant root length. This may result in reduced competition between soil borne organisms and plant roots to obtain nutrients. Comparisons between indigenous mycorrhizae and exotic inoculants on maize growth showed that *F. mosseae, F. caledonium* and *C. etunicatum* were the most efficient inoculants, improving plant growth and root colonization in the three soils studied. Since the Sultanönü soil contains less indigenous mycorrhizae spores, the shoot and root dry weight were low, and the root colonization was also very low compared with Harran and Menzilat soils. The data calculated show that Sultanönü indigenous spore inoculated plants had less MGR% than the other soil spore inoculated plants. Soils and mycorrhizal inoculation had statistically significant effects on shoot growth. In addition, mycorrhizal inoculation had a significant effect on root colonization. Ortas [8], and Almaca and Ortas [40] have previously shown that mycorrhizal inoculation, under sterilized and non-sterilized soil conditions, significantly enhanced maize root colonization.

Compared with inoculation with exotic mycorrhiza, the indigenous mycorrhizae of the three soils influenced maize root parameters which are related to the ecological zone and precipitation. The differences between sterilized and non-sterilized treatments were related to the effect of indigenous mycorrhiza on plant growth. It has previously been shown [8] that the effects of indigenous mycorrhizae depend on spore quantity and efficiency. Since there were several dead and non-viable spores in the indigenous media, it seems the quality of spores in the inoculum is more important than the number of spores. In the present study, *F. caledonium* and *C. etunicatum* inoculated plants seemed to induce higher root colonization levels, and P and Zn concentration compared with the *F. mosseae* species. On the other hand, *F. mosseae* and *C. etunicatum* inoculated plants exhibited a higher root length than *F. caledonium.*

Root length was significantly increased by indigenous mycorrhiza inoculation compared with exotic mycorrhizae inoculation. In general, Zn concentrations of the control and re-inoculated indigenous mycorrhiza plants were lower than plants inoculated with exotic mycorrhizal species. In general, for the three soils, P and Zn concentration in the control soil was under the critical level (0.20% for P and 20 $\mu g\ g^{-1}$ for Zn) [41] however, in the plants inoculated with exotic AMF strains, P and Zn concentrations increased over the critical level (Table 6). In Harran and Menzilat soils, the plant P and Zn concentrations were higher in the non-sterile treatments than in sterile treatments. Comparison of plant P content between soil sterilization treatments show that plants grown in non-sterile soils had a higher P concentration than in the sterile soil, and that the differences between treatments was possibly due to the indigenous mycorrhizal fungi. Hill et al. [42] observed that in response to P deficiency, the length and density of root hairs generally increased. Since plants inoculated with exotic AMF strains grew better, this may be attributed to nutrient uptake, mainly phosphorus (P). The results show that mycorrhizae inoculation is also vital for optimum growth. The results also indicate that a higher mycorrhizal colonization due to AM fungal inoculation was positively correlated with crop yields, and P and Zn uptake, which is agreement with the findings of Lekberg and Koide [6], and Almaca and Ortas [40]. Since plant tissue P and Zn concentrations after inoculation with indigenous AMF spore suspensions were less than the critical level and after inoculation with exotic AMF strains it was over the critical level, it is important to use mycorrhizal fungi to increase the plant nutrient concentration to an optimum level.

As it is difficult to use mycorrhizae for large field crops such as maize and wheat which are largely sown all over the world, it is reasonable to employ soil-crop-microorganism management. It has been found that there is a big difference between soil and plant management in terms of mycorrhiza population and diversity, which seems to influence plant growth parameters [43].

In this study, we sought to understand what role the AMF, of both natural and agricultural soils of the region might play in a major crop such as maize. Almaca and Ortas [40] used Harran soil in field and pot experiments, and found that previous crops have a significant influence on the growth of maize plants, which could be related to indigenous mycorrhizae potential and efficacy, allowing

the facilitation of P uptake and favouring plant growth, in agreement with the work of Martinez and Johnson [12]. Mickelson and Kaeppler [44] suggested the importance of cultivar choice in combination with the management of mycorrhizal populations by inoculation or crop rotation to optimize maize productivity in reduced input systems. It can be concluded that soil and crop management can benefit from indigenous mycorrhiza for sustainable agriculture, in spite of its highly variable potential in soils.

## 5. Conclusions

We studied species diversity and richness and spore numbers of AMF in agricultural soils of three regions of Turkey with different climate. A total of 12 species of Glomeromycota were detected in the three ecological sites soils, two, four and four species belonged to *Funneliformis, Glomus* and *Rhizophagus*, respectively and two species belonged to *Acaulospora*.

Under greenhouse conditions in non-sterile soil, indigenous mycorrhizae spores influenced maize plant growth, and P and Zn levels. Soil sterilization significantly affected root growth and root length.

Selected exotic *F. mosseae, F. caledonium* and *C. etunicatum* mycorrhiza species increased maize growth and nutrient uptake more than re-inoculated indigenous Sultanönü, Harran and Menzilat spores.

The pot experiments provide data on the effectiveness of the respective community inocula and an effectiveness comparison between the indigenous community inocula and exotic single species inocula. It can be concluded that although indigenous mycorrhizae contributed to plant growth, the mycorrhizal potential of selected exotic mycorrhizae was generally much higher. In the near future, our research direction will be to focus on soil and crop management systems for field crops.

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## References

[1] A. Tchabi, D. Coyne, F. Hountondji, L. Lawouin, A. Wiemken, F. Oehl, Arbuscular mycorrhizal fungal communities in sub-Saharan Savannas of Benin, West Africa, as affected by agricultural land use intensity and ecological zone, Mycorrhiza 18 (2008) 181–195.
[2] I. Brito, M.J. Goss, M. de Carvalho, Effect of tillage and crop on arbuscular mycorrhiza colonization of winter wheat and triticale under Mediterranean conditions, Soil Use Manag. 28 (2012) 202–208.
[3] S. Bedini, L. Avio, C. Sbrana, A. Turrini, P. Migliorini, C. Vazzana, M. Giovannetti, Mycorrhizal activity and diversity in a long-term organic Mediterranean agroecosystem, Biol. Fertil. Soils 49 (2013) 781–790.
[4] V.S. Harikumar, Arbuscular mycorrhizal associations in sesame under low-input cropping systems, Arch. Agron. Soil Sci. 61 (2015) 347–359.
[5] P. Gosling, A. Ozaki, J. Jones, M. Turner, F. Rayns, G.D. Bending, Organic management of tilled agricultural soils results in a rapid increase in colonisation potential and spore populations of arbuscular mycorrhizal fungi, Agric. Ecosyst. Environ. 139 (2010) 273–279.
[6] Y. Lekberg, R.T. Koide, Is plant performance limited by abundance of arbuscular mycorrhizal fungi? A meta-analysis of studies published between 1988 and 2003, New Phytol. 168 (2005) 189–204.
[7] S.E. Smith, D.J. Read, Mycorrhizal Symbiosis, third ed., Academic Press, San Diego, CA, 2008.
[8] I. Ortas, Effect of selected mycorrhizal inoculation on phosphorus sustainability in sterile and non-sterile soils in the Harran Plain in South Anatolia, J. Plant Nutr. 26 (2003) 1–17.
[9] I. Ortas, C. Akpinar, Response of maize genotypes to several mycorrhizal inoculums in terms of plant growth, nutrient uptake and spore production, J. Plant Nutr. 34 (2011) 970–987.
[10] I. Ortas, P.J. Harris, D.L. Rowell, Enhanced uptake of phosphorus by mycorrhizal sorghum plants as influenced by forms of nitrogen, Plant Soil 184 (1996) 255–264.
[11] C. Singh, A.K. Sharma, B.N. Johri, Host genotype determines the impact of soil phosphorus on arbuscular mycorrhizal symbiosis in maize (*Zea mays* L.), Symbiosis 33 (2002) 145–164.
[12] T.N. Martinez, N.C. Johnson, Agricultural management influences propagule densities and functioning of arbuscular mycorrhizas in low- and high-input agroecosystems in arid environments, Appl. Soil Ecol. 46 (2010) 300–306.
[13] SSS, Keys to soil taxonomy. Natural Resources Conservation Service, in: USDA (Ed.), Soil Survey Staff, Wahington D.C. USA, 1996.
[14] H. Esch, B. Hundeshagen, H. Schneiderpoetsch, H. Bothe, Demonstration of abscisic acid in spores and hyphae of the arbuscular-mycorrhizal fungus *Glomus* and in the $N_2$-fixing cyanobacterium *Anabaena* variabilis, Plant Sci. 99 (1994) 9–16.
[15] J.B. Morton, S.P. Bentivenga, W.W. Wheeler, Germ plasm in the international collection of arbuscular and vesicular-arbuscular mycorrhizal fungi (INVAM) and procedures for culture development, documentation and storage, Mycotaxon 48 (1993) 491–528.
[16] R.E. Koske, B. Tessier, A convenient, permanent slide mounting medium, in: Mycological Society America Newletter, 1983, p. 59.
[17] M.B. Omar, L. Bollan, W.A. Heather, A permanent mounting medium for fungi, Bull. Br. Mycol. Soc. 13 (1979) 31–32.
[18] E.J. Hewitt, Sand and Water Culture Methods Used in the Study of Plant Nutrition, C.A. B. Commonwealth Agricultural Bureaux Farnham Royal., Bucks, England, 1966.
[19] A. Schüßler, C. Walker, The Glomeromycota: a species list with new families. Arthur Schüßler & Christopher Walker, Gloucester, in: A.S.C. Walker (Ed.), The Royal Botanic Garden Edinburgh, The Royal Botanic Garden Kew, Botanische Staatssammlung Munich, and Oregon State University., 2010. Available at: http://www.amf-phylogeny.com.
[20] D. Tennant, A test of modified line intersect method of estimating root length, J. Ecol. 63 (1975) 995–1001.
[21] R.E. Koske, J.N. Gemma, A modified procedure for staining roots to detect VA-mycorrhizas, Mycol. Res. 92 (1989) 486–488.
[22] M. Giovanetti, B. Mosse, An evaluation of techniques for measuring vesicular-arbuscular mycorrhiza in roots, New Phytol. 84 (1980) 489–500.
[23] J. Murphy, J.P. Riley, A modified single solution method for determination of phosphate in natural waters, Anal. Chim. Acta 27 (1962) 31–36.
[24] T.R. Cavagnaro, F.A. Smith, S.M. Ayling, S.E. Smith, Growth and phosphorus nutrition of a *Paris*-type arbuscular mycorrhizal symbiosis, New Phytol. 157 (2003) 127–134.
[25] I. Ortas, A. Coska, C. Akpinar, Mycorrhizal potential in three different semi-arid ecological zones in Turkey in relation to plant communities, Symbiosis (2012) (in print).
[26] M. Vestberg, K. Saari, S. Kukkonen, T. Hurme, Mycotrophy of crops in rotation and soil amendment with peat influence the abundance and effectiveness of indigenous arbuscular mycorrhizal fungi in field soil, Mycorrhiza 15 (2005) 447–458.
[27] M.C. Pagano, R.B. Zandavalli, F.S. Araujo, Biodiversity of arbuscular mycorrhizas in three vegetational types from the semiarid of Ceara State; Brazil, Appl. Soil Ecol. 67 (2013) 37–46.
[28] J. Blaszkowski, Arbuscular fungi and mycorrhizae (Glomales) of the Hel Peninsula, Poland, Mycorrhiza 5 (1994) 71–88.
[29] J. Blaszkowski, B. Czerniawska, The occurrence of arbuscular mycorrhizal fungi of the phylum Glomeromycota in Israeli soils, Acta Soc. Bot. Pol. 75 (2006) 339–350.
[30] A. Camprubi, C. Calvet, P. Cabot, M. Pitet, V. Estaun, Arbuscular mycorrhizal fungi associated with psammophilic vegetation in Mediterranean coastal sand dunes, Span. J. Agric. Res. 8 (2010) S96–S102.
[31] A.B. Menendez, J.M. Scervino, A.M. Godeas, Arbuscular mycorrhizal populations associated with natural and cultivated vegetation on a site of Buenos Aires province, Argentina, Biol. Fertil. Soils 33 (2001) 373–381.
[32] C. Wagg, J. Jansa, M. Stadler, B. Schmid, M.G.A. van der Heijden, Mycorrhizal fungal identity and diversity relaxes plant-plant competition, Ecology 92 (2011) 1303–1313.
[33] E. Pellegrino, S. Bedini, L. Avio, E. Bonari, M. Giovannetti, Field inoculation effectiveness of native and exotic arbuscular mycorrhizal fungi in a Mediterranean agricultural soil, Soil Biol. Biochem. 43 (2011) 367–376.
[34] A. Williams, D.A. Norton, H.J. Ridgway, Different arbuscular mycorrhizal inoculants affect the growth and survival of *Podocarpus cunninghamii* restoration plantings in the Mackenzie Basin, New Zealand, N. Z. J. Bot. 50 (2012) 473–479.
[35] I. Ortas, O. Ustuner, Determination of different growth media and various mycorrhizae species on citrus growth and nutrient uptake, Sci. Hortic. 166 (2014) 84–90.
[36] M.M. Alguacil, M.P. Torres, E. Torrecillas, G. Diaz, A. Roldan, Plant type differently promote the arbuscular mycorrhizal fungi biodiversity in the rhizosphere after revegetation of a degraded, semiarid land, Soil Biol. Biochem. 43 (2011) 167–173.
[37] R. Mendoza, M. Cabello, J. Anchorena, I. Garcia, L. Marban, Soil parameters and host plants associated with arbuscular mycorrhizae in the grazed Magellanic steppe of Tierra del Fuego, Agric. Ecosyst. Environ. 140 (2011) 411–418.
[38] B.A.D. Hetrick, D.G. Kitt, G.T. Wilson, The influence of phosphorus fertilization, drought, fungal species, and nonsterile soil on mycorrhizal growth-response in tall grass prairie plants, Can. J. Bot. Rev. Can. Bot. 64 (1986) 1199–1203.
[39] N.S. Aggangan, H.K. Moon, The effects of soil sterilization, mycorrhizal inoculation, and rates of phosphorus on growth and survival of *Kalopanax*

*septemlobus* microplants during the acclimatization period, Plant Biotechnol. Rep. 7 (2013) 71–82.
[40] A. Almaca, I. Ortas, Growth response of maize plants (*Zea mays* L.) to wheat and lentil pre-cropping and to indigenous mycorrhizae in field soil, Span. J. Agric. Res. 8 (2010) S131–S136.
[41] J.B. Jones, Plant Nutrition Manual, CRC Publisher, New York, 1998.
[42] J.O. Hill, R.J. Simpson, M.H. Ryan, D.F. Chapman, Root hair morphology and mycorrhizal colonisation of pasture species in response to phosphorus and nitrogen nutrition, Crop Pasture Sci. 61 (2010) 122–131.
[43] I. Ortas, The effect of mycorrhizal fungal inoculation on plant yield, nutrient uptake and inoculation effectiveness under long-term field conditions, Field Crops Res. 125 (2012) 35–48.
[44] S.M. Mickelson, S.M. Kaeppler, Evaluation of six mycorrhizal isolates for their ability to promote growth of maize genotypes under phosphorus deficiency, Maydica 50 (2005) 137–146.