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Screening Mycorrhizae Species for Increased Growth and P and Zn Uptake in Eggplant (*Solanum melongena* L.) Grown under Greenhouse Conditions

I. Ortas[1)], N. Sari[2)], C. Akpinar[1)] and H. Yetisir[3)]
([1)]Department of Soil Science and Plant Nutrition, [2)]Department of Horticulture, Faculty of Agriculture, University of Çukurova, Adana, Turkey and [3)]Department of Horticulture, Faculty of Agriculture, University of Erciyes, Melikgazi-Kayseri, Turkey)

Summary

This study was undertaken to evaluate the effects of several mycorrhizal fungi species and their cocktail on eggplant (*Solanum melongena* L.) seedling growth, P and Zn uptake.

Three greenhouse experiments were continued consecutively for 3 years to evaluate the effects of several mycorrhizal species (*Glomus* species) on eggplant seedling production and growth before transplanting to field conditions. Arbuscular Mycorrhizae Fungi (AMF) used were *Glomus* mosseae, *G. clarum*, *G. caledonium, G. intraradices* and *G. etunicatum* and their mixture. In Experiment I, the plant was harvested once and there were two harvests in Experiment II and III.

The results of the three experiments revealed that mycorrhizal fungi significantly infected eggplant and all mycorrhizal inoculated plants showed better performance than non inoculated plants in terms of plant growth, P and Zn uptake. According to results of Experiment I, the better mycorrrizal species were *G. intraradices*, *G. etunicatum* and *G. clarum*. In Experiment II, *G. etunicatum* and cocktail mycorrhizae and in Experiment III, *G. caledonium* and *G. mosseae* inoculums were more effective species. The results show that mycorrhizal inoculation is necessary for healthy and vigorous seedling production. Seed and seedling stages mycorrhizal inoculation can be used for high quality seedling for field inoculation.

Key words. Eggplant – mycorrhizae – P uptake – Zn uptake – seedling growth

Introduction

The eggplant (*Solanum melongena* L.) is among the most valuable vegetables grown extensively for fresh-market production in the greenhouses of Turkey. The eggplant is known to be a medical plant and is said to be good for diabetics and an excellent remedy for those suffering from liver complaints (Lawande and Chavan 1998). Due to a combination of soil-borne pathogens, nematodes and weeds, soil fumigation with products such as methyl bromide (MeBr) has been essential for horticultural practice in this area. Since MeBr eliminates both desirable organisms, such as AMF and undesirable soil organisms, plant growth and nutrient uptake, especially P and Zn uptake has significantly declined (Haas et al. 1987; Bendavid-Val et al. 1997). Haas et al. (1987) have reported that pepper yield increased with P addition and mycorrhizal inoculation compared with non-inoculated ones. Mycorrhizae play a significant role in ion uptake, especially P, Zn and cupper (Cu), from soils (Ortas et al. 2002). The primary effect of AM on their host plant is an increase in plant growth and P uptake (Ortas et al. 1996; Ortas 2003). Also mycorrhizal inoculation reduces the quantity of P fertilizer normally required for non-inoculated plant conditions (Charron et al. 2001).

Since the eggplant remains for nearly 4 or 5 months in the field and is a heavy feeder, nutrient depletion from the soil occurs quickly; the plant prefers soils rich in nutrients and organic matter content. Since the soils along the coast of the Mediterranean are poor in nutrients and organic matter (Ortas et al. 2002), it is better to use natural plant mechanisms such as mycorrhizal fungi for better feeding. Mycorrhizal inoculation of eggplant seedlings prior to transplanting is economically feasible under semi-dry Mediterranean soil conditions (Ortas et al. 2003). Mycorrhizal inoculation play a key role in the physiology and ecology of horticultural plants affecting survival, shoot and root growth and nutrient uptake (Ortas 2010). Seedlings inoculated with the presence of mycorrhizae showed an increase in the plant phosphorus and zinc contents, as compared to seedlings in the absence of inoculation (Ortas 2010). As in plant growth parameters, the extent of increase in the plant phosphorus content varied among the fungi studied with pepper seedlings grown in the presence of mycorrhizae (Ortas et al. 2011). Early flowering is as also very important for early vegetable production. Sohn et al. (2003) reported that AMF-inoculation significantly shortened flowering time compared to non-AMF plants.

The notion that collaboration between plant mycologist, nutritionists, physiologists and breeders would lead to exploitation of these mycorrhizal species differences had considerable appeal. However, the advent of abundantly available, economically affordable mycorhizal inoculation was to relegate natural plant mechanisms, such as mycorrhizal hyphae, root hair and rhizosphere pH change, exploitation of nutritional differences, to a secondary concern for many decades (Ortas et al. 1996).

Mycorrhizae may also increase plant tolerance to stress conditions, such as transplanting shock, salinity, drought and to the attack of soil-borne pathogens (Scagel et al. 2003; Saggin-Junior and De Silva 2006) and Azcon-Aguilar and Barea (1997) reported that increasing the quantity of inoculum in the rooting substrate increased root growth during the early stages of rooting.

Different mycorrhizal fungal inocula produced differences in growth depending on the host species (Erica et al. 2000). Such screening experiments have not always provided an accurate indication of the performance of specific fungi in the field (Grove et al. 1991; Ortas et al. 2003). Mycorrhizae species need to be screened, which is effective under a wide range of growth conditions and hence able to adapt to the changing situation following out planting of fast-growing eggplants for semi-arid soil conditions. Douds and Reider (2003) and Saggin-Junior and De Silva (2006) reported proper selection of inoculum is essential for seedling growth.

Soils in Mediterranean region have high levels of clay and lime, which cause phosphorus (P), zinc (Zn) and iron (Fe) deficiency in several plant species (Ortas 2008). Thus, this study was designed to assess the effects of mycorrhizal species on seedling growth and nutrient uptake of eggplant seedling.

Materials and Methods

The arbuscular mycorrhizal fungi (AMF) isolates used in this study are 1) *Glomus etunicatum* (Becker and Gerdemann), 2) *G. clarum* (Nicolson and Schenck) supplied from Nutri-Link Isolate from USA, 3) *G. intraradices* (Schenck and Smith), 4) *G. caledonium* (Nicolson and Gerdemann), 5) *G. mosseae* (Nicolson and Gerdemann) supplied from Rothamsted, UK, and 6) a cocktail (a mixture of the five AMF species in equal portions). Non-inoculated plants were used as control. The AM fungal species used in this study were multiplied using sterilized Andezitic tuff, soil and a compost (7:2:1 v/v) mixture as the substrate and sudangrass [*Sorghum bicolor* (L.) Moench] as the host.

Production of eggplant seedlings

In a nursery trial, the experiments were carried out in greenhouse conditions for three successive years (1999–2001) at the Cukurova University Research Farm in Adana, Turkey. Mycorrhizal and non-mycorrhizal seedlings were produced under glasshouse conditions using a nested tray. The eggplant cultivar 'Pala' seeds were surface-sterilized with sodium hypochlorite solution (1 % available chlorine) for 10 min, rinsed three times and then soaked in distilled water several times. In seed inoculation stage, in each seedling tray (100 nests for each tray), two seeds per cell were sown with all selected mycorrhizae. The inoculum was calculated based on number of spores present in 10 g inoculum under 500 spores were mixed with the growing medium. In non mycorrhizal treatments, each tray filled with same amount of mycorrhizae free substrate (autoclaved growth medium).

Growth Medium

The experiment was performed in Andezitik tuff, soil and compost mixture (7:2:1 v/v) medium. Soil was collected from 0–20 cm depth in Canakcı soil series (*Typic Xerofluvents*) in the Cukurova Basin. Soil is clay loam, pH is 7.52 and Olsen extractable P is 3.8 mg kg^{-1} soil. Since growth medium have 10 % of compost material, no additional fertilizer was added. The growth medium was sterilized at 120 °C for two h to eliminate any microorganisms that could affect the function of the AM. Five AM fungi and their mixture were screened for their symbiotic response with eggplant seedlings in growth medium by comparing with non-inoculated plants.

Experimental Design

Three experiments were conducted during three successive years. For each year's experiment, plants were grown at different times in a glasshouse. In Experiment I, seeds were sown on 06 April 1999, plants were harvested on 10 July 1999. In Experiment II, seeds were sown on 14 March 2000, plants were harvested twice. 1st harvest was done on 1 June 2000 and 2nd harvest on 15 June 2000. In Experiment III, seeds were sown on 18 March 2001, 1st harvest was done on 13 June 2001, and 2nd harvest was done on 26 June 2001.

Five weeks after seed sowing, both inoculated and non inoculated uniform seedlings at 2 true-leaf stages with the AMF species were transplanted into 2 L plastic pots. In order to make clear the inoculum quantity and use of time, half of the seedlings were re-inoculated with the same mycorrhizal species by adding 500 spores from each mycorrhizae species to the growth medium 3 cm below the seedling roots before the seedlings were transplanted. Non-mycorrhizal seedlings were transplanted to equal amounts of mycorrhizae free growth medium.

The experiment was designed in a randomized complete block design for six mycorrhizae species, two inoculum stages and two harvests with six replications. The pots were periodically and manually watered with deionised water to keep the soil moisture at approximately field capacity. The plants were grown in greenhouse at 23–29 °C and a relative humidity of 70–85 %, with a 16 h day and 8 h dark photoperiod.

Plant Analysis and Mycorrhizal Colonization

At the harvest of each pot, shoots were separated from roots 0.5 cm above the soil surface. Plant materials, shoots and roots were washed thoroughly with distilled water and dried at 70 °C for 48 h for dry matter determination. Phosphorus and zinc content in shoot dry matter were analyzed. Washed, dried plant materials were ground for the chemical analysis. Tissue samples were dry-ashed at 500 °C overnight and P in the extracted solution was determined colorimetrically (Murphy and Riley 1962). An atomic absorption spectrophotometer was employed to determine the Zn contents of the plant

samples. Flowering time was recorded when 50 % of the plants in each experimental plot flowered.

Root samples were washed and sub-sampled first to determine mycorrhizal colonization. Mycorrhizal colonization was determined by KOSKE and GEMMA (1989) and calculated by the grid-line intersection method (GIOVANNETTI and MOSSE 1980).

Statistical analysis

Data were analyzed using analysis of variance procedures (ANOVA) and differences among treatments and means were compared using Duncan's Multiple Range Test at 5 % significance level by the SAS (1989) computer package program.

Results

Experiment I (Year 1999)

The effect of different mycorrhizal species inoculated to seed and seedling stages on eggplant growth was investigated and the results indicated that the development of plant was strongly affected by the mycorrhizal inoculation. Mycorrhizal species significantly ($P<0.008$) increased shoot dry weight (SDW), but inoculation time did not have any significant contribution. The effects of AM fungus species were insignificant for root dry matter (Table 1). The mycorrhizal inoculated seedlings produced more dry shoot and root weight than the non-inoculated one. *G. intraradices, G. etunicatum* and *G. clarum* were the more effective species (Table 2). In seed inoculation, *G. intraradices* produced 24.3 g plant^{-1} SDW, while non- inoculated plant produced 14.2 g plant^{-1}. Cocktail of the mycorrhizae species also produced less SDW. In seedling stages, *G. clarum*, *G. etunicatum* and cocktail mycorrhizal inoculation significantly increased the SDW (Table 2).

Flowering times were also affected by mycorrhizal inoculation. In seed inoculation, *G. caledonium*, *G. intraradices*, *G. etunicatum* and cocktail inoculation were the more effective species for each inoculation time (Table 3). However, in seedling inoculation, *G. caledonium* was the most effective one (Table 3). Mycorrhizae inoculated eggplant plants flowered 1–8 d earlier than the non–inoculated plants. Although there is a small difference between seed and seedling inoculation stages, seed inoculation seemed to flower earlier than seedling inoculation stage.

Plant P concentration was higher in all mycorrhizal inoculated seedlings than in the non-inoculated one. In general mycorrhizal inoculated plant's P concentration is over critical (>0.20 %) levels (Table 4).

The plant's Zn concentration was also considerably higher in mycorrhizal inoculated seedlings than the non-inoculated seedlings ($P<0.05$). In both inoculation stages, control plants had lower Zn concentration than the expected critical level. In both inoculation stages, *G. intraradcies* mycorrhizae inoculated plant resulted in higher Zn concentration than the other species.

Mycorrhizal inoculation significantly affected root infection. Statistically there were significant differences between seed and seedling inoculation. In both inoculum

Table 1. Significance of P-values (probability) from analysis of variance for the parameters shoot and root DW, Phosphorus (P) and Zinc (Zn) concentration and root colonization for experiments (years 1999, 2000 and 2001).

Years	Treatment	DF	Shoot DW	Root DW	P (%)	Zn (mg kg^{-1})	Colonization (%)
1999	T	1	0.508	0.569	0.782	0.977	0.009
	M	6	0.008	0.051	0.038	0.001	0.001
	T × M	6	0.911	0.228	0.278	0.259	0.388
2000	H	1	0.001	0.001	0.128	0.001	0.047
	T	1	0.001	0.001	0.044	0.176	0.508
	M	6	0.001	0.001	0.005	0.001	0.001
	H × T	1	0.126	0.001	0.001	0.001	0.702
	H × M	6	0.784	0.229	0.619	0.030	0.038
	T × M	6	0.499	0.024	0.634	0.636	0.054
	H × T × M	6	0.606	0.166	0.692	0.172	0.887
2001	H	1	0.001	0.054	0.580	0.198	0.257
	T	1	0.535	0.001	0.580	0.675	0.923
	M	6	0.001	0.001	0.285	0.001	0.001
	H × T	1	0.001	0.611	0.001	0.089	0.081
	H × M	6	0.622	0.312	0.585	0.103	0.162
	T × M	6	0.279	0.626	0.998	0.051	0.007
	H × T × M	6	0.972	0.296	0.992	0.343	0.116

DF: Degree of Freedom,
Application Time = T, Mycorrhiza Species = M, Harvest = H

Table 2. Effect of mycorrhizal species and inoculation time (seed and seedling stages) on eggplant shoot and root dry weight (g plant^{-1}).

Years	Harvests	Inoculation methods	Mycorrhizal Species						
			Control	*G. mosseae*	*G. etunicatum*	*G. intraradices*	*G. clarum*	*G.caledonium*	Cocktail
Shoot									
1999		Seed#	14.2 ± 4.8 b	18.6 ± 9.5 ab	17.6 ± 9.3 ab	24.3 ± 13.0 a	17.6 ± 3.2 ab	19.5 ± 10.4 ab	18.3 ± 3.7 ab
		Seedling	14.1 ± 2.6 b	22.8 ± 8.5 a	21.0 ± 8.9 ab	20.4 ± 8.1 ab	23.8 ± 5.5 a	19.2 ± 7.5 ab	20.4 ± 7.4 ab
2000	1th	Seed	1.0 ± 0.4 c	1.7 ± 0.4 bc	3.2 ± 1.0 a	1.1 ± 0.1 bc	2.1 ± 0.2 b	1.7 ± 0.6 bc	3.8 ± 0.8 a
		Seedling	1.2 ± 0.6 c	4.0 ± 0.6 b	6.5 ± 0.2 a	4.1 ± 1.0 b	5.6 ± 1.5 ab	3.5 ± 2.0 b	5.1 ± 1.2 ab
	2nd	Seed	11.0 ± 1.5 ab	11.7 ± 3.8 ab	13.5 ± 1.1 ab	13.0 ± 1.4 ab	14.1 ± 0.3 a	12.1 ± 2.0 ab	13.0 ± 0.6 ab
		Seedling	11.5 ± 0.6 c	13.6 ± 2.7 a-c	15.1 ± 1.4 ab	14.4 ± 0.3 ab	14.7 ± 1.1 ab	12.3 ± 2.4 bc	15.6 ± 1.4 a
2001	1th	Seed	5.8 ± 0.6 d	11.0 ± 0.2 a	8.3 ± 1.4 bc	7.2 ± 2.2 cd	10.1 ± 0.5 ab	11.5 ± 1.2 a	9.5 ± 1.8 a-c
		Seedling	5.7 ± 0.9 c	10.6 ± 1.3 a	9.6 ± 2.1 ab	9.2 ± 3.9 ab	7.2 ± 1.4 bc	12.1 ± 1.1 a	9.2 ± 0.7 ab
	2nd	Seed	6.6 ± 0.5 c	12.7 ± 0.6 ab	11.4 ± 2.1 ab	9.5 ± 1.5 bc	9.8 ± 4.0 bc	13.5 ± 0.7 a	10.1 ± 1.6 b
		Seedling	6.5 ± 1.3 c	13.9 ± 2.0 a	12.3 ± 2.9 a	10.7 ± 1.8 ab	8.4 ± 1.3 bc	14.1 ± 0.9 a	10.7 ± 2.8 ab
Root									
1999		Seed	2.3 ± 0.9 b	4.0 ± 1.4 a	4.7 ± 2.8 a	3.3 ± 1.1 ab	3.1 ± 0.8 ab	3.7 ± 0.9 ab	3.4 ± 0.7 ab
		Seedling	2.9 ± 1.1 c	4.8 ± 1.8 a	3.3 ± 1.8 ac	3.1 ± 1.3 bc	4.6 ± 1.0 a	3.1 ± 1.0 bc	3.8 ± 1.2 ac
2000	1th	Seed	0.1 ± 0.1b	0.4 ± 0.2 b	0.8 ± 0.2 a	0.2 ± 0.1 b	0.4 ± 0.1 b	0.3 ± 0.1 b	0.7 ± 0.3a
		Seedling	0.2 ± 0.1 c	0.8 ± 0.0 bc	1.4 ± 0.2 ab	1.0 ± 0.4 ab	1.3 ± 0.5 ab	0.9 ± 0.3 ab	1.5 ± 0.5 a
	2nd	Seed	4.0 ± 0.9 ab	2.9 ± 0.6 b	4.6 ± 0.7 a	3.8 ± 0.8 ab	4.5 ± 0.7 a	4.0 ± 0.5 ab	4.6 ± 0.7 a
		Seedling	4.6 ± 0.8 c	5.5 ± 0.8 bc	5.9 ± 1.1 a-c	7.4 ± 1.4 a	6.0 ± 0.3 a-c	5.3 ± 0.8b-e	6.8 ± 1.2 ab
2001	1th	Seed	2.6 ± 0.4 c	4.6 ± 0.9 ab	3.0 ± 1.2 bc	2.9 ± 1.1 bc	4.0 ± 1.5 a-c	4.8 ± 1.1 a	2.9 ± 0.5 bc
		Seedling	1.8 ± 0.1 c	2.5 ± 0.1 b	2.2 ± 0.3 ab	1.8 ± 0.7 c	1.9 ± 0.5 ab	3.6 ± 0.6 a	2.5 ± 0.2 ab
	2nd	Seed	2.9 ± 0.3 a	2.8 ± 0.4 a	2.9 ± 0.6 a	2.3 ± 1.1 a	2.2 ± 0.5 a	3.2 ± 0.9 a	2.4 ± 0.7 a
		Seedling	1.8 ± 0.2 b	2.5 ± 0.8 b	2.5 ± 0.2 b	2.7 ± 0.8 ab	2.3 ± 0.3 b	3.8 ± 1.4 a	2.3 ± 0.2 b

Mean of six replicates ± standard deviation. Means in the same row followed by the same letter represent significant differences ($P \leq 0.05$) among treatments.
Comparison of means of LSD were calculated for each year separately

times, *G. mosseae* species resulted in more than 50 % of root infection (Table 5).

Experiment II (Year 2000)

In Experiment II, eggplant plant gave a high response to the mycorrhizal inoculation. In harvest I, it was found that *G. etunicatum* and cocktail was the most effective mycorrhizal species. In harvest II, *G. etunicatum*, *G. clarum* and cocktail were the more effective mycorrhizae species. In both harvest and inoculation times, shoot growth was promoted by all mycorrhizal species and root growth also showed similar trends between mycorrhizal species (Table 2). Inoculation time, harvest time and mycorrhizal species affected shoot and root growth significantly ($P<0.01$) (Table 1).

Flowering times in mycorrhizal plants were 3 to 6 days earlier than non-inoculated ones (Table 3). Inoculated plants shoots had significantly higher amount of P than the non-inoculated plants (Table 4). In harvest I, the highest P concentration was determined in seed inoculated plant with *G. clarum*, followed by *G. intraradices*. But in seedling inoculated plant *G. etunicatum, G. clarum* and *G. mosseae* resulted in higher P concentration, respectively. In harvest II, the highest P concentration in seed inoculated plant was observed in plant inoculated with *G. clarum*, and cocktail, but in seedling inoculation the highest P concentration was recorded in plants inoculated with *G. intraradices* (Table 4).

Mycorrhizal inoculation in both harvests increased plant Zn concentration. In both harvests and inoculation times, control plant had Zn concentration below the critical level <20 mg Zn kg^{-1} DW (Table 4).

The roots of inoculated plants were well colonized. In both harvests in seed inoculation, there was no infection in non-inoculated control plants but in seedling inoculation there was a small contamination in non-inoculated plants (Table 5).

Table 3. Effect of mycorrhizal species and inoculation time (seed and seedling stages) on eggplant flowering time and earliness compared to control (ECC) in Experiment I (1999), II (2000) and III (2001).

Mycorrhizal	Seed Inoculation		Seedling Inoculation	
Species	Flowering Period	EFCC*	Flowering Period	EFCC
Experiment I (1999)				
Control	01 July 1999		28 June 1999	
G. mosseae	30 June 1999	1	29 June 1999	1
G. etunicatum	28 June 1999	3	28 June 1999	0
G. intraradices	26 June 1999	5	27 June 1999	1
G. clarum	04 July 1999	–3	27 June 1999	1
G. caledonium	23 June 1999	8	23 June 1999	5
Cocktail	24 June 1999	6	24 June 1999	4
Experiment II (2000)				
Control	26 June 2000		24 June 2000	
G. mosseae	20 June 2000	6	20 June 2000	4
G. etunicatum	20 June 2000	6	20 June 2000	4
G. intraradices	20 June 2000	6	18 June 2000	6
G. clarum	21 June 2000	5	21 June 2000	3
G. caledonium	23 June 2000	3	19 June 2000	5
Cocktail	22 June 2000	4	18 June 2000	6
Experiment III (2001)				
Control	28 June 2001		25 June 2001	
G. mosseae	22 June 2001	6	19 June 2001	6
G. etunicatum	18 June 2001	10	19 June 2001	6
G. intraradices	19 June 2001	9	17 June 2001	8
G. clarum	21 June 2001	7	18 June 2001	7
G. caledonium	20 June 2001	8	20 June 2001	5
Cocktail	19 June 2001	9	19 June 2001	6

Mean of six replicates, * ECC Early flowering days compared to control treatment

Experiment III (Year 2001)

In Experiment III, mycorrhizae inoculated eggplant plants also grew better than non-inoculated ones. In the first harvest, in seed inoculated plant with *G. mosseae* and *G. caledonium* produced the highest shoot dry weight and followed by *G. clarum*. In seedling inoculated plant, maximum SDW were produced by *G. caledonium* and followed by *G. mosseae*. In the second harvest, the general trend was similar to the first harvest. In general in both harvests and inoculation stages, *G. mosseae*, *G. caledonium* and *G. etunicatum* were the high responsive inoculum (Table 2). Shoot and root dry weight showed identical trends between mycorrhizal species. For both harvests mycorrhizal inoculation was statistically not significant (Table 1).

In seed and seedling stages, 6–10 and 5–8 d earlier flowering with *G. etunicatum* and *G. intraradices* inoculation respectively than control plants was determined (Table 3).

Plant P concentration was found that control plants were in critical stages but mycorrhizal inoculated plants accumulated more P over the critical level of 0.20 % P (Table 4).

In the first harvest at seed inoculation, control plants had a critical level of Zn concentration, around 20.0 mg Zn kg^{-1} DW, but *G. clarum* inoculated plants had 43.4 mg Zn kg^{-1} DW (Table 4). A similar situation was observed for seedling stages inoculation. In the second harvest, effects of mycorrhizal inoculation on Zn concentration were statistically significant. Although in both harvests control plants Zn content was higher than the critical level 20 mg Zn kg^{-1} DW (Jones 1998) but, inoculated plants had over the critical level. It is expected mycorrhizal inoculation has significant effects on Zn uptake.

Mycorrhizal inoculation significantly influenced plant root colonization. Non-inoculated plants had smaller root infection percentages, from 6.7 to 14.5 %. However, mycorhizal inoculated plants with *G. mosseae* had up to 68.7 %. Also there were great differences between mycorrhizal species. The root AM infection in AM-amended plants differed over time, ranging from 43.7 to 68.7 % at both harvest times (Table 5). In the third year experiment, *G. mosseae* inoculated plants had higher root colonization.

Table 4. Effect of mycorrhizal species and inoculation time (seed and seedling stages) on eggplant P (%) and Zn (mg Zn kg^{-1} DW) concentration.

Years	Harvests	Inoculation methods	Mycorrhizal Species						
			Control	*G. mosseae*	*G. etunicatum*	*G. intraradices*	*G. clarum*	*G.caledonium*	Cocktail
P concentration (%)									
1999		Seed#	0.19 ±0.08 b	0.26 ± 0.05 a	0.24 ±0.05 ab	0.29 ± 0.03 a	0.26 ± 0.02 a	0.24 ±0.04 ab	0.27 ±0.04 a
		Seedling	0.21 ±0.05 b	0.26 ± 0.05 a	0.25 ±0.04 a	0.23 ± 0.04 a	0.25 ± 0.04 a	0.26 ±0.06 a	0.26 ±0.02 a
2000	1st	Seed	0.15 ±0.06 b	0.20 ± 0.03ab	0.22 ±0.08 ab	0.23 ± 0.02ab	0.25 ± 0.03 a-	0.20 ±0.06 ab	0.18 ±0.00 ab
		Seedling	0.23 ±0.02 b	0.31 ± 0.08ab	0.32 ±0.02 a	0.24 ± 0.02ab	0.31 ± 0.07ab	0.28 ±0.06 ab	0.29 ±0.04 ab
	2nd	Seed	0.14 ±0.03 b	0.26 ± 0.08ab	0.20 ±0.06 ab	0.27 ± 0.08ab	0.30 ± 0.03 a	0.23 ±0.09 ab	0.31 ±0.01 a
		Seedling	0.12 ±0.08 b	0.23 ± 0.07 a	0.24 ±0.04 a	0.29 ± 0.01 a	0.23 ± 0.08 a	0.24 ±0.05 a	0.23 ±0.10 a
2001	1st	Seed	0.19 ±0.0 a	0.20 ± 0.0 a	0.19 ±0.0 a	0.20 ± 0.0 a	0.21 ± 0.0 a	0.20 ±0.0 a	0.23 ±0.0 a
		Seedling	0.17 ±0.0 c	0.27 ± 0.0 a	0.23 ±0.0 a-c	0.23 ± 0.0 a-c	0.20 ± 0.0 bc	0.24 ±0.0 ab	0.20 ±0.0 bc
	2nd	Seed	0.17 ±0.0 ab	0.20 ± 0.0 b	0.20 ±0.0 a	0.25 ± 0.0 a	0.25 ± 0.0 a	0.25 ±0.0 a	0.24 ±0.0 a
		Seedling	0.15 ±0.0 b	0.21 ± 0.0 ab	0.21 ±0.0 ab	0.21 ± 0.0 ab	0.21 ± 0.1 ab	0.23 ±0.0 a	0.18 ±0.0 b
Zn concentration (mg Zn kg^{-1} DW)									
1999		Seed	16.6 ±2.8 d	35.9 ± 8.1 a	26.7 ±5.9 bc	37.1 ± 5.6 a	32.7 ± 7.0 ab	24.2 ±5.6 c	30.3 ±8.6 ac
		Seedling	19.2 ±5.2 b	32.1 ±10.5 a	29.4 ±3.6 a	33.7 ± 6.8 a	28.8 ± 7.7 a	32.0 ±8.7 a	28.5 ±3.8 a
2000	1st	Seed	20.2 ±3.4 d	39.6 ± 0.3 c	49.0 ±5.8 a	43.9 ± 2.9 ac	43.2 ± 2.9 ac	43.9 ±4.2 ac	47.7 ±0.6 ab
		Seedling	19.4 ±2.0 c	38.1 ± 2.1 b	39.3 ±0.2 b	34.1 ± 4.5 b	42.2 ± 6.7 ab	48.1 ±8.7 a	41.3 ±0.7 ab
	2nd	Seed	18.5 ±1.9 b	33.4 ± 8.5 a	29.2 ±1.1 a	28.5 ± 4.8 a	31.0 ± 6.7 a	30.7 ±9.7 a	30.3 ±6.7 a
		Seedling	18.8 ±1.4 b	36.8 ± 1.0 a	32.7 ±2.0 ab	31.2 ± 2.8 ab	32.0 ± 3.6 ab	31.0 ±4.2 ab	32.2 ±2.4 ab
2001	1st	Seed	20.0 ±4.0 c	33.5 ± 1.1 b	30.6 ±9.7 bc	23.5 ± 3.3 c	43.4 ± 1.0 a	33.1 ±7.7 b	35.0 ±1.6 ab
		Seedling	19.3 ±1.1 c	34.0 ± 4.3 b	33.1 ±0.4 b	36.5 ± 4.3 ab	42.1 ± 6.8 a	37.8 ±3.2 ab	31.3 ±5.0 bc
	2nd	Seed	21.1 ±2.7 c	33.7 ± 5.0 bc	25.2 ±1.8 c	40.3 ±10.7 ab	46.7 ±10.8 a	36.7 ±9.0 bc	39.4 ±1.0 ab
		Seedling	20.6 ±2.4 c	30.1 ± 1.0 b	34.1 ±5.5 ab	38.5 ± 4.5 a	37.8 ± 3.3 a	38.4 ±4.4 a	34.2 ±3.2 ab

Mean of six replicates ± standard deviation. Means in the same row followed by the same letter represent significant differences ($P \leq 0.05$) among treatments.
Comparison of means of LSD were calculated for each year separately

Discussion

Since eggplants are not a commonly consumed vegetable, little research has been conducted on this plant in comparison to the other vegetables. Al-Raddad (1987) also grow eggplant inoculated with several mycorrhizal species under greenhouse conditions and found that the dry weight of eggplant increased significantly. In Japan, under greenhouse conditions, the effects of mycorrhizal fungus inoculation on seedlings of 17 species of vegetable crops were investigated and it was reported that plant growth was noticeably enhanced by AMF inoculation (Matsubara et al. 1994).

This study was conducted from 1999 to 2001, to examine the effect of inoculation with several AMF species at the seed and seedling stage on the growth of eggplants. AMF species significantly increased dry weight and total P and Zn content of eggplant seedlings inoculated in seed and seedling stages.

In the first year experiment, *G. intraradices*, *G. etunicatum* and *G. clarum* were the efficient mycorrhizae species in terms of plant growth. *G. caledonium* inoculated plant flowered earlier than the other mycorrhizae species.

In the second year experiment, although eggplants had less response to mycorrhizal inoculation, *G. etunicatum* produced higher shoot dry weight than the other mycorrhizae in both seed and seedling stages of mycorrhizal inoculation. *G. etunicatum*, *G. clarum* and cocktail inoculated plants produced more dry weight, P-Zn uptake and root infection.

According to the three years of experiments, it seemed significantly that mycorrhizal inoculated seedling increased shoot and root dry weight and nutrient uptake. There was a significant difference between mycorrhizae species in terms of flowering times as well. Mycorrhizal plants produce higher dry matter and flowered from one to 10 d earlier. Especially for fresh market vegetable production, 10 d of early production is quite important. In some cases price doubles. Ortas et al. (2011) observed that mycorrhizae inoculated pepper plants have early flowering than non inoculated plants. Scagel (2004) reported that the rhizosphere organisms associated with the AMF inocu-

Table 5. Effect of mycorrhizal species and inoculation time (seed and seedling stages) on eggplant root infection (%).

Years	Harvests	Inoculation methods	Mycorrhizal Species						
			Control	*G. mosseae*	*G. etunicatum*	*G. intraradices*	*G. clarum*	*G.caledonium*	Cocktail
1999		Seed#	5 ± 2 c	55 ± 8 a	53 ± 5 ab	52 ±12 ab	43 ±12 b	44 ±11 b	52 ±10 ab
		Seedling	12 ± 2 d	54 ± 8 a	48 ±10 ab	39 ± 7 c	33 ± 4 c	42 ±12 bc	41 ± 8 bc
2000	1st	Seed	0 ± 0 e	31 ±10 cd	37 ± 4 bc	43 ± 3 ab	49 ±10 a	36 ± 7 bc	23 ± 4 d
		Seedling	5 ± 2 b	32 ± 8 a	43 ±17 a	39 ± 1 a	50 ± 9 a	32 ± 2 a	37 ±17 a
	2nd	Seed	0 ± 0 b	26 ± 1 a	33 ± 9 a	27 ±13 a	39 ±21 a	44 ± 5 a	30 ±10 a
		Seedling	9 ± 8 c	25 ± 2 bc	39 ±23 ab	22 ± 7 bc	28 ± 4 bc	28 ± 6 bc	53 ±21 a
2001	1st	Seed	6.7 ± 2.4 d	68.7 ± 9.3 a	43.7 ± 3.5 c	46.3 ± 5.7 c	61.7 ± 3.2bc	52.0 ± 4.0ab	48.7 ± 8.0 c
		Seedling	14.5 ± 5.8 b	58.7 ±13.3 a	60.7 ± 0.6 a	59.7 ±12.4 a	58.7 ±25.0 a	48.4 ± 8.0 a	50.0 ± 7.2 a
	2nd	Seed	7.8 ± 3.4 d	66.3 ± 4.0 a	44.3 ± 1.5cb	62.0 ± 2.6ab	65.0 ± 9.5 a	55.7 ± 5.1 b	61.7 ± 2.1ab
		Seedling	6.7 ± 5.0 d	64.3 ± 9.3 a	53.7 ± 5.1 bc	59.0 ± 6.2ab	46.7 ± 1.5 c	65.7 ± 2.1 a	46.3 ± 8.5 c

Mean of six replicates ± standard deviation. Means in the same row followed by the same letter represent significant differences ($P \leq 0.05$) among treatments.
Comparison of means of LSD were calculated for each year separately

lum influenced several measures of plant development, growth and flower production of harlequin flower. Similarly Sohn et al. (2003) found that AMF-inoculation significantly shortened flowering time compared to non-AMF plants. Aminifard et al. (2010) observed that nitrogen fertilizer affected eggplant flowering factors. In the present experiment, N concentration was not measured however P and Zn concentration of plant tissue is higher than non-inoculated one.

AM fungal species show different affinities and effects on fitness across different host species. Mycorrhizal fungal communities have the potential to influence the diversity and distribution of the associated host plants (Bever et al. 1997). Also it has been reported that the complexity of the AM fungal community can influence host diversity (Van Der Heijden et al. 1998).

Since plant critical Zn concentration was 20 mg Zn kg^{-1} DW (Jones 1998), the results obtained in seedling stages are very important for plant Zn nutrition. Since the Zn concentration for mycorrhizae inoculated plants is over the critical level, it does make more sense for practical application. AMF significantly increased the dry weight and total P content of seedlings (endangered plant species) of growing on native soil (Fisher and Jayachandran 2002).

The effect mycorrhizaes in horticulture are almost exclusively beneficial. So far, several other research results have shown that in horticultural production systems mycorrhizal symbiosis have many benefits, such as, enhanced nutrient uptake, resistance to water and salt stress, resilience to heavy metal and other pollutant toxicity, reduction of transplant shock and time of flowering and incidence of disease. Especially in coastal Mediterranean, there are several root diseases and problems of nematodes damage. It appears that there are some other benefits of mycorrhizae on horticultural plants, such as controlling disease and increasing plant resistance (Ortas 2010).

Conclusions

This study documents that the successful inoculation of eggplant roots with mycorrhizae species increased plant growth parameters and nutrient uptake. Eggplant shoot dry matter accumulation and P and Zn uptake during the growing period for both harvests and inoculation times consistently enhanced under AM environments. Compare to the non-inoculated control, increase in shoots and roots dry weight occurred as a result of AM fungal symbiosis. Our future experiment will be focused on using mycorrhizal inoculated eggplant seedlings in a field experiment.

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Addresses of authors: I. Ortas (corresponding author) and C. Akpinar, Department of Soil Science and Plant Nutrition, N. Sari, Department of Horticulture, Faculty of Agriculture, University of Çukurova, Adana, 01330 Turkey and H. Yetisir, Department of Horticulture, Faculty of Agriculture, University of Erciyes 38039 Melikgazi-Kayseri, Turkey, e-mail (corresponding author): iortas@cu.edu.tr.