Effect of Selected Mycorrhizal Inoculation on Phosphorus Sustainability in Sterile and Non-sterile Soils in the Harran Plain in South Anatolia

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ABSTRACT

The Southeastern Anatolian Project (SAP,Turkish acronym GAP)is the largest irrigation and development project of Turkey covering about two million ha cultivated land.A number of field experiments in the region with different crops including maize,wheat,and cotton,have repeatedly shown that increased applications of phosphorus (P)fertilizers (i.e.,from 0 k g P_2O_5 ha^{-1} up to 200 kg P_2O_5 ha^{-1})do not lead to any effects on crop yield in soils with low plant available P concentration.The aim of the research was to determine the potential effect of indigenous mycorrhiza and selected mycorrhiza species on plant growth and nutrient uptake under sterile and non-sterile soil conditions.The preliminary results led us to study the effect of indigenous mycorrhizae potential on the growth of plants and P nutrition in a representative soil from the GAP under

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greenhouse conditions. Using inoculation of three different mycorrhizae species (*Glomus caledonium*, *G. etunicatum*, and *G. mossea*) maize plants were grown with increasing P [0 (P1), 25 (P2), 125 (P3) mg P kg^{-1} soil] supply in soils with and without sterilization. At the lowest P supply, shoot dry matter production was significantly depressed. This decreasing effect of low P supply was particularly obvious when soils were sterilized and not inoculated with mycorrhizae. Inoculation of soil with mycorrhizae species significantly increased plant growth and P uptake of plants, especially under low P supply and soil sterilization. In all experiments, plants grown on non-sterile soil grew much better than on sterilized soils. However, mycorrhizal dependencies of plant grow in sterile soil is higher than that in non-sterile soil. Among the mycorrhizae species, *G. caledonium* was the most effective on plant growth, P uptake and mycorrhizal dependency. In low P application, plant roots were strongly infected and consequently increased plant growth, but in high P level application there was a slight reduction in root infection. The results show that mycorrhizal inoculation is an effective practice for improving crop production in P deficient soils. Also there was a potential effect of indigenous mycorrhizal fungi spores in the soil series of the Harran Plain that successfully infected the plant roots. It has been concluded that soil and crop management can help to get maximum benefit from indigenous mycorrhiza for sustainable P management.

Key Words: Please supply. Q1

INTRODUCTION

Many research projects were carried out between 1976 and 1992 in the Research Institute of Rural Services of Şanliurfa, which is located in the south of Turkey. The main objectives of these studies were to determine the optimal fertilizer amounts for cotton, tomato, alfalfa, lentils, and wheat in the Harran Plain which will be irrigated in the near future on the completion of the GAP project. After 20 years of research, scientists working in the area have reached the conclusion that there is no clear recommendation for phosphorus (P) fertilizer. Sometimes, a poor correlation between P fertilization and plant response was found. The results revealed that in most cases there was no suggestion for optimal use but in some years they found weak relationship between the cotton, tomato, alfalfa, lentil, and wheat yields and P fertilizer.[1–4] Since they were not well aware of indigenous mycorrhizal effect on P nutrition, they were not able to explain their findings in comparison with chemical analysis.

Arbuscular mycorrhizal (AM) fungi is able to infect most crop species, and depending on soil conditions and AM species, this infection can improve plant growth and nutrient uptake.[5] Low P uptake is caused either by low total P content in the soil or low P availability due to adverse soil chemical and biological properties.[6,7] Mycorrhizal inoculation increased other nutrient uptake such as zinc (Zn), copper (Cu), iron (Fe), manganese (Mn), but not as much as P.[8,9] Under such condition mycorrhizal inoculated roots have higher P absorption capacity compared to non-mycorrhizal roots.[10,11] It has been reported that maize plant with high growth rate and nutrient demand often benefits from mycorrhizal infection.[12]

The impact of mycorrhizal fungi is usually assessed by measuring plant growth and P uptake following the inoculation of the fungi to sterilized soils.[13] However, growth responses are erratic when arbuscular mycorrhizae fungi are added to non-sterile soil. In some cases, the external root colonization is less in plants in non-sterile soil than for plants in sterilized soil.[13] The effect of AM inoculation on plant growth are extensively documented, but little is known on the effect of different species of AM and re-inoculation of indigenous mycorrhiza on vegetative growth and mycorrhizal colonization.

MATERIALS AND METHODS

Soil samples were collected from a low P Harran soil series, which is widely distributed in the area and which is also poor in available P. The soil properties of the Harran series are given in Table 1. Wet sieving method[14] was used to count the number of mycorrhizal spores. T1

The soil to be studied was sterilized (autoclaving for 2 hours at 120°C) and kept in laboratory condition for two weeks before being repacked into the pots. Experiments were set up with various P levels. The soils were fertilized with 0 (P1), 25 (P2), and 125 (P3) mg P kg^{-1} soil as a mono-calcium phosphate $Ca(H_2PO_4)_2$, 200 mg N kg^{-1} soil [100 mg kg^{-1} soil, N-$(NH_4)_2SO_4$, 100 mg kg^{-1} soil, N-KNO_3], 5 mg kg^{-1} soil, Zn ($ZnSO_4$), 5 mg kg^{-1} soil, Fe (Fe-EDTA), and placed into the 3 L pots. Five maize seeds (*Zea mays* L. genotypes) were sown per pot and thinned to two seedlings after a week. Before the seeds were sown several arbuscular mycorrhizae *Glomus etunicatum* (Becker and Gerdemann) of Nutri-Link Isolate, USA, and *G. caledonium* (Nicolson and Gerdemann), as well as *G. mossea* (Nicolson and Gerdemann) were isolated from Rothamsted, UK, inocula which were used for both sterile and non-sterilized soils. Treatments received the same amount of mycorrhizae spore free inocula. Q2

Table 1. Selected physical, chemical, and biological properties of Harran soil series.

Sand (%)	19
Loam (%)	35
Clay (%)	46
pH (H_2O (1 : 2.5) ratio)	7.91
Salt (%)	0.08
Organic matter (%)	1.32
CEC ($Cmol_c\,kg^{-1}$	30.4
$CaCO_3$ (%)	26
P_2O_5[a] (kg/ha)	40.82
Exchangeable K[b] (mg/100 g soil)	62
N (%)	0.112
Zn[c] ($mg^{-1}\,kg$)	0.19
Fe[c] ($mg^{-1}\,kg$)	0.87
Cu[c] ($mg^{-1}\,kg$)	2.88
Mn[c] ($mg^{-1}\,kg$)	5.04
Number of mycorrhizal spores (10 g soil)	341

[a]0.5 N $NaHCO_3$ extractable.
[b]1 N HNO_3 extractable.
[c]DTPA extractable.

Distilled water was added daily to maintain moisture at field capacity. The plants were grown in greenhouse at 25–28°C and a relative humidity of 70–80%.

Harvest and Measurement

Plants were harvested following 45 days of growth. After drying at 75°C, the plant material was weighted. The dry material was ground using a Tema mill, 0.2 g of ground plant materials were ashed at 550°C followed by dissolution in 3.3% HCl. After the digestion of the plant material, the concentration of P was determined by spectrophotometry.[15] The concentration of Zn was determined by atomic absorption spectrophotometry.

Roots were separated from the soil by washing under 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 determination of root length and mycorrhizal infection. A small proportion

of preserved roots were stained according to Koske and Gemma,[16] and examined for the presence and degree of mycorrhizal infection.[17]

Statistical Analysis

The effects of soil sterilization, mycorrhizal inoculation, and P treatments on plant parameters were tested using analysis of variance (three-way ANOVA). Comparison of means was made by using the Duncan method ($P < 0.05$). All statistical analyses were performed using the Statistical Analysis System (SAS).

RESULTS AND DISCUSSION

In non-sterile and non-inoculated Harran soils, maize grew better than in sterile and non-inoculated plants with P1 and P2 rate P applications (Table 2). T2
In the P3 treatment, plant growth showed no difference between sterile and non-sterile treatments. As reported earlier by Abbott and Robson,[18] increases in plant growth, when plants were infected with mycorrhiza, could survive by increasing available soil P to a level where P did not limit growth of non-mycorrhizal plants. In both sterile and non-sterile treatments with increasing P application plant growth increased gradually with better growth in mycorrhizae inoculated plants. Irrespective of mycorrhizal inoculation plant dry matter was increased with increase in P levels. At low P supply in both soils, inoculated plant dry matter production was higher than non-inoculated. At both P1 and P2 levels and both sterilization treatments *G. mossea*, Q2
G. caledonium, and *G. etunicatum* inoculation significantly ($P > 0.001$) increased shoot and root dry weight at a greater rate than the control treatments. Mycorrhizal species differ with their effect on plant growth. *Glomus caledonium* was the best species that produced more dry weight than other species. Statistical variance analysis showed that mycorrhizal inoculation and P treatments were significantly effective ($P > 0.0001$) (Table 3). T3

Plant dry matter differences between mycorrhizal and non-mycorrhizal plants were considered to be a reflection of the benefit of the plants from the AM fungi-root association due to the majority of the mycorrhizal work was done on sterilized soils to demonstrate better effects of VAM on plant growth, but less was done on non-sterilized soils. Sieverding[19] and Hetrick et al.[13] statements on mycorrhizal inoculation of sterile soils is still questionable due

Table 2. The effect of different mycorrhizal species and P rate on shoot and root dry weight and shoot : root ratio.

Mycorrhizal species	P application (mg/kg soil)	Shoot dry weight (g/plant)	Root dry weight (g/plant)	Shoot : root dry weight ratio
		−Sterile		
Control	P0	2.21 ± 0.04hi	1.25 ± 0.53ef	1.76
	P1	3.25 ± 1.18gh	1.74 ± 0.60d–e	1.87
	P2	4.69 ± 0.93e–g	2.59 ± 1.01a–e	1.81
G. etunicatum	P0	3.52 ± 1.32f–h	1.99 ± 0.41d–e	1.76
	P1	5.31 ± 0.32c–g	1.83 ± 0.93d–e	2.90
	P2	7.28 ± 1.13a–d	3.54 ± 1.25a–e	2.06
G. caledonium	P0	4.19 ± 1.14f–h	2.47 ± 0.45a–e	1.70
	P1	7.07 ± 1.34b–d	3.72 ± 2.24a–e	1.90
	P2	8.71 ± 2.13ab	4.15 ± 1.52a–d	2.10
G.mossea	P0	3.15 ± 0.56gh	1.83 ± 0.84d–e	1.73
	P1	4.60 ± 0.23e–g	3.54 ± 0.47a–e	1.30
	P2	6.48 ± 1.40c–e	3.97 ± 0.72a–d	1.63

		+Sterile		
Control	P0	0.90 ± 0.91i	0.65 ± 1.00f	1.39
	P1	2.18 ± 0.06hi	1.13 ± 0.52ef	1.93
	P2	4.41 ± 0.54e–g	2.28 ± 0.69a–e	1.94
G. etunicatum	P0	4.74 ± 0.55e–g	3.53 ± 0.40a–e	1.34
	P1	5.16 ± 0.98d–g	2.23 ± 1.87c–e	2.31
	P2	5.58 ± 1.03c–f	4.87 ± 1.30ab	1.14
G. caledonium	P0	5.74 ± 1.81c–f	4.80 ± 0.20a–c	1.20
	P1	9.29 ± 1.83a	5.49 ± 4.00a	1.69
	P2	7.49 ± 2.17a–c	5.78 ± 1.34a	1.30
G.mossea	P0	4.65 ± 0.84e–g	3.94 ± 0.84a–d	1.18
	P1	5.53 ± 0.40c–f	4.17 ± 0.75a–d	1.33
	P2	7.11 ± 1.06b–d	4.71 ± 1.82a–c	1.51

Note: Means in the same column followed by the same letter are not significantly different at 0.5 level.

Table 3. Significance of *F*-values (probability) from analysis of variance for different plant biomass parameters and nutrient parameters (in shoot).

Treatments	SD	Shoot DW	Root DW	Root infection (%)	Root length	P concentration (% P)	mg P/ plant	Zn (mg kg^{-1} plant)
Sterilization	1	0.1594	0.0055	0.0001	0.0005	0.0001	0.8684	0.5617
Mycorrhizae	3	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Sterile × Mycor	3	0.0539	0.0616	0.0001	0.6166	0.1734	0.2269	0.2684
Phosphorus	2	0.0001	0.0018	0.0001	0.7735	0.1125	0.0001	0.0004
Sterile × Phosphor	2	0.0896	0.5818	0.0328	0.4410	0.1913	0.0001	0.3620
Myco phosphors	6	0.1896	0.6094	0.3109	0.0668	0.0016	0.0310	0.2412
Steril × Myco × Phos.	6	0.2306	0.9859	0.4378	0.7514	0.0103	0.0811	0.7626

Q3 ***, **, *, NS; 0.001, 0.01, 0.05, and >0.05 respectively.

to the concern on the effect of mycorrhizal inoculation on plant growth under the non-sterile soil condition.

Ortas et al.[20] recent data on the same soil revealed that under non-sterile soil conditions without inoculation plants were grown better than plants were grown in sterile soil. In another experiment, the effect of indigenous mycorrhizae on maize and soybean has been tested in sterile and non-sterile Harran soils and it was found that there was a potential indigenous mycorrhizal fungi in the Harran soil having a significant effect on plant growth.[20]

Plant root growth also increased with mycorrhizal inoculation and increasing P application enhanced root growth in both sterilization treatments (Table 2). In non-inoculated plants, the root growth was higher in non-sterile treatments, however, in mycorrhizal inoculated ones the root growth was higher in sterile treatments than non-sterile treatments. The root dry weight increased with increasing rates of P application in both soils. Despite shoot growth, *G. caledonum* increased root growth better than other mycorrhizal species. Statistically, mycorrhizal inoculation significantly increased root growth $P > 0.004$ (Table 3).

Shoot and root ratio in the mycorrhizal inoculated plant was higher than the non-inoculated plants (Table 2). In sterile soils mycorrhizal inoculated plants have higher ratios than in the non-sterile one, especially at *G. etunicatum* and P1 treatments (2.90).

In general, plants grown in non-sterile soil had more root length than the ones in sterile soils. Mycorrhizal inoculation significantly increased root length. Especially when plants inoculated with *G. etunicatum* and *G. caledonium* the root length was higher than the inoculate with *G. mossea.* In non-inoculated and sterile soils with increasing P addition (P1, P2, and P3) root lengths were 16, 79, and 93 m, respectively. But when plants were inoculated with *G. caledonium* with increasing P addition the root length differed from 234 to 200 and 201 m (Table 4). Statistically the effect of mycorrhizal inoculation and P addition significantly affected the root length ($P > 0.0001$). The plant root length increased with mycorrhizal inoculation when the soil P level was very low.[11] T4

Root infection was significantly affected by mycorrhizal inoculation. With P0 treatment in non-inoculated and non-sterile soils root infection was 41%, but in the *G. caledonium* inoculated plants it was 81% (Table 4), whereas in the sterile and non-inoculated plants it was 3%, but in the inoculated plants it was 84%. There are differences in root infection percentages between the mycorrhizal species. *Glomus caledonium* resulted higher root infection than other mycorrhizal species, though there were sufficient indigenous mycorrhizal spores, which seemed to be ineffective. Selected mycorrhizal inoculation has increased root infection from 2% to 84%.

Table 4. The effect of mycorrhizal inoculation and different level of P application on root length and root infection.

Mycorrhizal species	P application (mg/kg soil)	Root length (m)	Root infection (%)
		−Sterile	
Control	P0	25 ± 8e	41 ± 6h–i
	P1	97 ± 13de	47 ± 8g–i
	P2	115 ± 16cd	36 ± 4i
G. etunicatum	P0	272 ± 84ab	63 ± 6d–g
	P1	246 ± 55ab	56 ± 11c–f
	P2	246 ± 18ab	66 ± 10c–e
G. caledonium	P0	284 ± 31a	81 ± 7ab
	P1	247 ± 73ab	74 ± 6ab
	P2	259 ± 65ab	70 ± 16a–d
G. mossea	P0	236 ± 32ab	74 ± 6a–c
	P1	268 ± 34ab	71 ± 5a–c
	P2	233 ± 15ab	62 ± 7c–f
		+Sterile	
Control	P0	16 ± 5e	3 ± 2j
	P1	79 ± 11de	3 ± 1j
	P2	93 ± 13de	2 ± 1j
G. etunicatum	P0	251 ± 107ab	70 ± 7a–d
	P1	191 ± 56bc	67 ± 11b–d
	P2	199 ± 15ac	55 ± 10e–h
G. caledonium	P0	234 ± 26ab	84 ± 5a
	P1	200 ± 59ac	81 ± 7ab
	P2	201 ± 63ac	61 ± 9c–f
G. mossea	P0	197 ± 18ac	66 ± 11be
	P1	197 ± 50ac	66 ± 10be
	P2	189 ± 12bc	49 ± 6f–i

Note: Means in the same column followed by the same letter are not significantly different at 0.5 level.

The results demonstrate that in soils with low concentration of plant available P, inoculation of VAM species, *G. mossea*, *G. caledonium*, and *G. etunicatum*, with higher root colonization ability, could greatly contribute to the improvement of plant growth by providing P to the host plant. In general with P increase, plant root infection is gradually decreased.

Mycorrhizal inoculation has a positive effect on maize plant P uptake, which was exhibited even when P was high, however high P fertilization reduced the percentage of root colonization. Graham et al.[21] and Posta and Fuleky[22] showed that when soil P is high, the net exudation of roots was lower, and accordingly root colonization was reduced. Fries et al.[23] tested the effect of different level of P application on mycorrhizal formation and found that under low P levels, the mycorrhiza-inoculated plant accumulated a greater shoot dry weight and root P concentration than non-inoculated plants. In full agreement with those results, increasing P application with and without soil sterilization repressed mycorrhizal formation, especially at the P3 level. Decreased root infection with increasing P application or high level of soil P content was reported by Menge et al.,[24] Abbott and Robsen,[25] Smith et al.,[26] Ortas et al.,[11] Posta and Fuleky.[22] Insufficient uptake is caused either by low total P content in the soil or low P availability due to adverse soil chemical properties.[7]

The P concentration and uptake were increased with increasing P amendment at all of the treatments. The benefit of selected mycorrhizal inoculation (*G. mossea*, *G. caledonium*, and *G. etunicatum*) in both sterile and non-sterile treatments significantly increased plant P concentration and P uptake, but under sterilized soil conditions the effect was higher. Under such conditions mycorrhizal colonized roots are reported to have a higher P absorption capacity compared to non-mycorrhizal roots.[7,10,11,27–29] It has been reported that maize, with its high growth rate and nutrient demand, often benefits from mycorrhizal infection, and mycorrhizal inoculation during the early stages with an increased growth rate up to 82%.[12]

Plant P concentration increased with increasing P addition. In non-sterile Harran soils when treated with P1 and P2 addition, plant P% was over the critical level 0.20%, but in sterile soil this was less than 0.15–0.19% (Table 5). **T5**

In the sterile and non-sterile Harran soil, the plant Zn concentration increased with mycorrhizal inoculation. In the non-inoculated plant, Zn concentration was between 18–23 $mg\,kg^{-1}$ but with mycorrhizal inoculation this increased up to 35 $mg\,kg^{-1}$. There were no significant differences in Zn concentrations of mycorrhizal species. Liu et al.,[8,9] reported that the total Zn content in shoots was higher in mycorrhizal than non-mycorrhizal plants grown in soils with low P.

Mycorrhizal dependency has also been calculated, and it has been found that when soil has been sterilized, plants were much more dependent on mycorrhizal inoculation. Mycorrhizal dependency was also strongly affected by P addition as seen in Table 6. Mycorrhizal species are also different in terms of MD, thus *G. caledonium* species had higher mycorrhizal dependency than the other two species. In the sterile soil when *G. caledonium* was used as **T6**

Table 5. Effect of mycorrhizal inoculation and P and Zn application on P and Zn concentration and P uptake.

Mycorrhizal species	P application (mg/kg soil)	Zn (mg kg^{-1})	P (%)	P uptake (mg/g plant)
		−Sterile		
Control	P0	21.0 ± 1.7f–j	0.18 ± 0.02ij	5.0 ± 0.3ij
	P1	20.7 ± 1.2g–j	0.21 ± 0.01g–i	7.9 ± 3.1g–j
	P2	20.0 ± 1.7i–j	0.21 ± 0.01hi	11.7 ± 0.7f–j
G. etunicatum	P0	26.0 ± 2.6a–h	0.25 ± 0.01b–f	10.3 ± 3.7f–j
	P1	23.3 ± 2.1c–i	0.27 ± 0.02a–c	16.3 ± 2.5c–g
	P2	22.7 ± 1.5d–j	0.30 ± 0.01a	23.9 ± 2.9a
G. caledonium	P0	31.0 ± 1.0a	0.26 ± 0.01b–e	13.1 ± 3.3e–j
	P1	28.0 ± 9.6a–d	0.23 ± 0.02d–h	19.8 ± 4.0a–c
	P2	22.0 ± 2.6e–j	0.27 ± 0.01b–d	26.1 ± 6.3a
G.mossea	P0	31.7 ± 2.5a	0.24 ± 0.01c–f	8.8 ± 1.5g–j
	P1	28.3 ± 3.1a–d	0.28 ± 0.03ab	15.8 ± 1.0b–f
	P2	25.0 ± 1.0a–i	0.24 ± 0.01d–g	18.6 ± 3.7b–d

		+Sterile		
Control	P0	21.3 ± 1.5ij	0.16 ± 0.00kj	4.9 ± 2.6h–j
	P1	21.0 ± 4.0j	0.15 ± 0.01k	3.5 ± 2.1j
	P2	20.3 ± 6.0h–j	0.19 ± 0.02i	9.1 ± 3.9b–j
G. etunicatum	P0	27.5 ± 0.6a–e	0.23 ± 0.00e–h	12.8 ± 1.6d–f
	P1	26.8 ± 2.4a–f	0.24 ± 0.01d–g	15.4 ± 2.1c–g
	P2	23.8 ± 2.6c–i	0.26 ± 0.02b–f	19.0 ± 7.1a–d
G. caledonium	P0	28.7 ± 1.5a–c	0.23 ± 0.02f–h	15.7 ± 3.0cd
	P1	26.5 ± 2.0a–c	0.23 ± 0.01e–h	27.9 ± 10.8a–c
	P2	24.1 ± 0.9c–i	0.21 ± 0.01g–i	21.1 ± 5.8b–e
G.mossea	P0	30.7 ± 2.4ab	0.26 ± 0.02b–e	19.5 ± 2.4ab
	P1	31.1 ± 3.5a	0.24 ± 0.04d–g	17.5 ± 7.4b–f
	P2	28.8 ± 2.0ac	0.23 ± 0.02d–h	13.0 ± 9.5c–h

Note: Means in the same column followed by the same letter are not significantly different at 0.5 level.

Table 6. Effect of mycorrhizal species and P addition on mycorrhizal dependency (%).

Mycorrhizal Species	P Application (mg/kg Soil)	−Sterile	+Sterile
G. etunicatum	P0	37	81
	P1	39	58
	P2	36	21
G. caledonium	P0	47	84
	P1	54	77
	P2	46	41
G. mossea	P0	30	81
	P1	29	61
	P2	28	38

a mycorrhizal inoculum, the mycorrhizal dependency for P1, P2, and P3 levels was 84, 77, and 41%, but when the soil had not been sterilized mycorrhizal dependency was 47, 54, and 46%, respectively (Table 6).

Results revealed that indigenous mycorrhizae spores are functioning especially at low P addition. With increasing P addition mycorrhizae are not functioning due to the weakening effect of high P.[30]

CONCLUSIONS

Maize plants inoculated with AM fungi *G. caledonium*, *G. mossea*, and *G. etunicatum* grow better than indigenous mycorrhizal inoculation and non-inoculated control plants. The results show that selected mycorrhizal inoculation under sterilized and non-sterilized soil conditions significantly enhances plant growth.

The results revealed that there were potential effects of indigenous mycorrhizal fungi spores in the soil series of the Harran Plain, which successfully infect the plant roots. At low P application, plant roots were strongly infected and consequently increased plant growth, but in high P level application there is a slightly reduction in root infection, consequently in plant growth as well. Thus it can been concluded that, soil and crop management can get maximum benefit from indigenous mycorrhiza for sustainable P management, in spite of its highly variable potential in soils. It can be suggested that mycorrhizal inoculation is necessary for soils with low P contents in the semiarid regions. However, detailed studies are needed to test these findings under field experiments.

REFERENCES

1. Özer, M.S. *Requirement of Phosphorus Fertilizer of Cotton Harran Plain Condition in Harran Plain.* Research Institute of Rural Services: Şanliurfa, Turkey, 1992; Tech. Rep., 65.
2. Özer, M.S. *Requirement of Phosphorus Fertilizer of Wheat Dry and Irrigated in Conditions in Harran Plain.* Research Institute of Rural Services: Şanliurfa, Turkey, 1992; Tech. Rep., 56.
3. Özer, M.S.; Ünal, F. *Application Time and Requirement of Phosphorus Fertilizer for Alfalfa on Harran Plain.* Research Institute of Rural Services: Şanliurfa, Turkey, 1987; Tech. Rep., 70.
4. Dağdeviren, I.; Özer, M.S. *Requirements of Phosphorus Nitrogen Fertilizer of Tomato on Harran Plain.* Research Institute of Rural Services: Şanliurfa, Turkey, 1987; Tech. Rep., 67.
5. Smith, S.; Read, D.J. *Mycorrhizal Symbiosis*, 2nd Ed.; Academic Press: London, 1997; 605. Q4
6. Marschner, H. *Mineral Nutrition of High Plants*; Academic Press: London, 1995; 889. Q4
7. Marschner, H. Role of root growth, arbuscular mycorrhiza, and root exudates for the efficiency in nutrient acquisition. Field Crops Res. **1998**, *56*, 203–207.
8. Liu, A.; Hamel, C.; Hamilton, R.I.; Smith, D.L. Mycorrhizae formation and nutrient uptake of new corn (Zea *mays* L.) hybrids with extreme canopy and leaf architecture as influenced by soil N and P levels. Plant Soil **2000**, *22* (2), 157–166.
9. Liu, A.; Hamel, C.; Hamilton, R.I.; Ma, B.L; Smith, D.L. Acquisition of Cu, Zn, Mn and Fe by mycorrhizal maize (*Zea mays* L.) grown in soil at different P and micronutrient levels. Mycorrhiza **2000**, *9* (6), 331–336.
10. McArther, D.A.J.; Knowles, N.R. Influence of VAM and phosphorus nutrition on growth, development and mineral nutrition of potato. Plant Physiol. **1993**, *102*, 771–782.
11. Ortas, I.; Harris, P.J.; Rowell, D.R. Enhanced uptake of phosphorus by mycorrhizal sorghum plants as influenced by forms of nitrogen. Plant Soil **1996**, *184*, 255–264.
12. Khaliq, A.; Senders, F.E. Effects of phosphorus application and vesicular arbuscular mycorrhizal inoculation on the growth and phosphorus nutrition of maize. J. Plant Nutr. **1997**, *20*, 1607–1616.
13. Hetrick, A.B.D.; Kitt, D.G.; Wilson, T. The influence of phosphorus fertilization, drought, fungal species, and non-sterile soil on mycorrhizal growth response in tall grass praiser plants. J. Bot. **1986**, *64*, 1199–1203.

14. Gerdemann, J.W.; Nicolson, T.H. Spores of mycorrhizal endogeny species extracted from soil by wet sieving and decanting. transact. British Mycolog. Soc. **1963**, *46*, 235–244.
15. Murphy, Y.; Riley, J.P. A modified single solution method for determination of phosphate in natural waters. Anal. Chem. Acta **1962**, *27*, 31–36.
16. Koske, R.E.; Gemma, J.N. A modified procedure for staining roots to detect VAM. Mycolog. Res. **1989**, *92*, 486–505.
17. Gioannetti, M.; Mosse, B. An evaluation of techniques for measuring vesicular-arbuscular mycorrhiza in roots. New Phytol. **1980**, *84*, 489–500.
18. Abbott, L.K.; Robson, A.D. Growth stimulation of subterranean clover with vesicular-arbuscular mycorrhizas. Australian J. Agric. Res. **1977**, *28*, 639–649.
19. Sieverding, E. *Vesicular-Arbuscular Mycorrhize Management in Tropical Agrosystems*; Deutsche Gesellschaft für Technishe Zusammentarbeit (GTZ): Eschborn, Germany, 1991; 371.
20. Ortas, I.; Gök, M.; Kaya, Z.; Çoşkan, A.; Almaca, A.; Çakmak, I. The effect of indigenous and selected mycorrhizal inoculation on P sustainability in the upper part of Mesopotamia (in the Harran plain). In *Arbuscular Mycorrhiza (AM) in Plant Health and Revegetation and Restoration Processes*, Faro, Portugal, Nov. 30–Dec. 2, 2000.
21. Graham, J.H.; Leonard, R.T.; Menge, J.A. Membrane-mediated decrease in root exudation responsible for phosphorus inhibition of vesicular-arbuscular mycorrhiza formation. Plant Physiol. **1981**, *68*, 548–552.
22. Posta, K.; Fuleky, G. The effect of phosphorus on the mycorrhizal colonization of maize by *Glomus mosseae* (Nicol. Gerd). Novenytermeles **1997**, *46* (6), 573–582.
23. Fries, L.L.M.; Pacovsky, R.S.; Safir, G.R.; Kaminski, J. Phosphorus effect on phosphatase activity in endomycorrhizal maize. Physiol. Plant. **1998**, *103* (2), 162–171.
24. Menge, J.A.; Steirle, D.; Bagyaraj, D.J.; Jonson, E.L.V.; Leonard, R.T. Phosphorus concentrations in plants responsible for inhabitation of mycorrhizal infection. New Phytol. **1978**, *80*, 575–578.
25. Abbott, L.K.; Robson, A.D. The effect of VA mycorrhiza on plant growth. In *VA Mycorrhiza*; Powell, C.I., Bagyaraj, D.J., Eds.; Chemical Rubber Publ Co.: Boca Raton, FL, 1984; 113–130.
26. Smith, S.E.; Robson, A.; Abbott, L.K. The involvement of mycorrhizas in assessment of genetically dependent efficiency of nutrient uptake and use. Plant Soil **1992**, *146*, 169–179.
27. George, E.; Römheld, V.; Marschner, H. Contribution of mycorrhizal fungi to micronutrient uptake by plants. In *Biochemistry of Metal:*

Micronutrients in the Rhizosphere; Manthey, J.A., Crowley, D.E., Luster, D.G., Eds.; CRC Press: Boca Raton, FL, 1994; 93–109.
28. George, E.; Marschner, H.; Jakobsen, I. Role of arbuscular mycorrhizal fungi in uptake of phosphorus and nitrogen from soil. Critical Reviews in Biotechnology **1995**, *15* (3–4), 257–270.
29. Jakobsen, I. Transport of phosphorus and carbon in VA mycorrhizas. In *Mycorrhiza: Structure, Function, Molecular Biology and Biotechnology*; Varma, A., Hock, B., Eds.; Springer-Verlag: Berlin, Germany, 1995; 297–324.
30. Thompson, J.P. Soil sterilization methods to show VA-mycorrhizae aid P and Zn nutrition of wheat in vertisols. Soil Biol. Biochem. **1990**, *22*, 229–240.