Journal of Plant Breeding and Crop Science Vol. 1(5). pp. 217-222, July, 2009
Available online http://www.academicjournals.org/jpbcs

Full Length Research Paper

Interactive effects of P supply and drought on root growth of the mycorrhizal coriander (*Coriandrum sativum* L.)

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Accepted 26 June, 2009

Arbuscular mycorrhizal fungi (AMF) are among the most important plant root symbiosis fungi enhancing plant P uptake. This research was conducted in Iran during 2006. The experimental design was a split factorial on the basis of completely randomized block design with four replicates. The control and AM species, *Glomus hoi* were assigned to the main plots and the combination of P fertilizer including 0, 35 and 70 kg ha^{-1} of triple super phosphate and the drought treatment including control (30 mm evaporation) and 60 mm evaporation from the evaporation pan were factorially assigned to the subplots. AM and P fertilizer significantly increased the root yield, root length, primary root dry weight and primary root length of coriander. Although the non-drought stress treatment significantly increased the root of coriander, the longest root length was achieved under the drought stress. It can be stated that AM is able to enhance the growth of coriander under drought stress through enhancing P uptake. This can have very important environmental impact through decreasing the amount of P fertilizer under control and drought stress conditions and also through enhancing the coriander resistance when subjected to the drought stress. Findings may interest farmers and agricultural researches to consider carefully on huge amount of soil phosphorus with interaction to water restriction as a challenge in environmental issues.

Key words: AM fungi, drought stress, phosphorus, root growth, coriander.

INTRODUCTION

Mycorrhizal fungi live in a 'symbiotic' relationship with plants. They grow in close association with the roots and play an important role in the concentration and transfer of soil nutrients to the plant. In exchange, the plant supplies the fungus with sugars. Although specific fungus-plant associations with respect to drought tolerance are of great interest (Ruiz-Lozano et al., 1995), the exact role of arbuscular mycorrhizal fungi (AFM) in drought resistance remains unclear (Auge et al., 1992a). More studies are therefore needed to determine the direct or indirect mechanisms which control plant-water relations in AMF-plant symbiosis. Although the effects of AM fungi on plant water status have been ascribed to the improved host nutrition (Graham and Syverten, 1987; Nelsen and Safir, 1982; Fitter, 1985), there are reports that drought resistance of AMF plants is somewhat independent of plant P nutrition status of plants (Sweatt and Davies, 1984; Auge et al., 1986a; Bethenfalvay et al., 1988; Khalvati et al., 2005). Although improved host nutrition has been ascribed to AM fungi effects on plant water status, there are reports that the drought resistance of AMF plants is somewhat independent of phosphorous levels. For example, Vivas (2003) reported that the increased metabolically active fungal biomass in inocu-lated plants was independent of phosphorous levels and was not related to phosphorous uptake from the poor nutrients soil (Khalvati, 2005). Baon et al. (1993) reported that extent of colonization of different barley cultivars was not consistently affected by *Glomus intraradices* and was only variably sensitive to the addition of phosphorous. Therefore, we examined the effects of *Glomus hoi* inocu-

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Table 1. The results of soil analysis.

Soil texture	Sand (%)	Silt (%)	Clay (%)	K mg/kg	P mg/kg	N mg/kg	Na Ds/m	EC 1: 2.5	pH	Depth of sampling cm
Sa	49	30	21	147.2	6.2	34.7	0.04	0.19	8.1	0-15cm
Sa.c.L	56	25	19	124.3	3.7	28.2	0.03	0.16	7.9	15-30cm

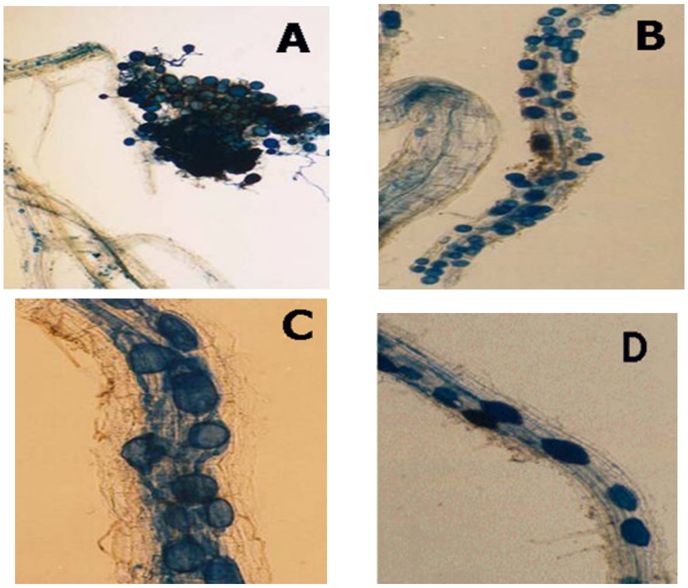

Figure 1. Symbiosis of AM fungi and coriander root. A) Spores of *Glomus hoi* B) Penetration of spores in coriander root C) Vesicles of *Glomus hoi* in main root D) Vesicles of *Glomus hoi* in lateral root.

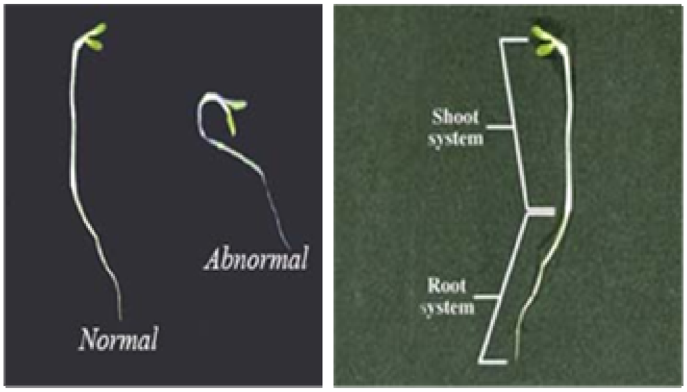

Figure 2. Normal and abnormal seedling (A) and seedling system (B).

lation of coriander on the underground organ components produced under different phosphorus availability. The objective of this investigation was to examine the degree of improvement in root growth of mycorrhizal plants in a soil with different P-content under simulated drought conditions.

MATERIALS AND METHODS

The experimental design was a split factorial on the basis of completely randomized block design with four replicates. The control and AM species, *G. hoi* were assigned to the main plots and the combination of P fertilizer including 0, 35 and 70 kg ha^{-1} of triple super phosphate and the drought treatment including control (30 mm evaporation) and 60 mm evaporation from the evaporation pan were factorially assigned to the subplots. The irrigation system was a piping system and determined water used in each irrigation period and amount of water for each irrigation treatments was 17.28 m^{-3} in each period and soil consisted of 48% clay, 30% silt and 21% sand (Table 1).

G. hoi was consisting of root fragments and adhering spores was mixed with soil (90 - 110 propgules per 10 g soil). A total number of 48 plots, each measuring 15 m^2 area (5 m × 3 m), were prepared in the field and a native variety named Shahabdolazimi was used in this experiment. Coriander seeds inoculated by inoculums in the planting time and the seeds were allowed to germinate, after which the seedlings were thinned to achieve 11 cm spacing within rows. Nitrogen fertilizer was added in two periods; 75 kg ha^{-1} urea in the beginning of steming stage and 75 kg ha^{-1} urea in beginning of flowering stage and also 150 kg ha^{-1} potash and phosphorus fertilizers were added in planting time. The degree of internal colonization produced by each entophyte in the roots of plants was rated by observation under a microscope. Root segments were clarified and stained with trypan blue. The extent of root colonization was estimated by comparison of root length between inoculated and non-inoculated plants as well as root length having hyphae. The results illustrated that coriander inoculated with *G. hoi* displayed 60 - 71% root colonization with *G. hoi* (Figure 1. A - D). At the end of growth, 100 plants were randomly collected from each plot for the study of plant characteristics and 100 seeds were collected from plants. Seeds of coriander were first sterilized in a 0.5% NaOCl solution for 15 min and then washed three times in sterile distilled water. Samples were placed in a germinator between two sheets of paper in Petri dishes. Seeds germinated after 21 days and we collected 10 normal seedlings (Figure 2). A and B) from each Petri dishes and determined radial dry matter and radial length (Abdul-Baki and Anderson, 1973).

Data were subjected to analysis of variance (ANOVA) using Statistical Analysis System and followed by Duncan's multiple range tests. Terms were considered significant at $P < 0.05$ (SAS institute Cary, USA, 1988).

RESULTS

The results showed that drought stress significantly affects root yield, primary root dry weight, root diameter, highest plant, number of branch and stem diameter ($\alpha = 1\%$), root length and primary root length ($\alpha = 5\%$) and the highest upon charactristics appeared under without stress but longest root length was achieved under the drought stress (Tables 2 and 3). The results also showed

Table 2. Variance analysis.

				Means Square					
Value Sources	**df**	**PRL**	**PRDW**	**Root diameter**	**Root length**	**Root yield**	**Number of branch**	**Stem diameter**	**Highest plant**
Replication	3	0.018	0.0001	0.036*	4.802	162755.694	4.347	0.023*	346.65
Mycorrhiza	1	0.505**	0.001*	0.001	136.603**	360317.291*	0.047	0.004	209.167
Error a	3	0.014	0.0001	0.004	3.792	17703.73	2.701	0.001	37.723
Phosphorus	2	0.136**	0.001**	0.003	36.91**	291690.374**	1.97	0.015	31.72
Mycorrhiza × phosphorus	2	0.033	0.0001	0.003	8.964	102190.046	2.183	0.001	17.671
Drought stress	1	0.158*	0.035**	0.694**	42.779*	14969087.337**	92.13**	0.715**	7874.563**
Mycorrhiza × drought stress	1	0.066	0.0001	0.0001	17.977	1736.263	3.05	0.002	5.88
Phosphorus × drought stress	2	0.008	0.0001	0.002	2.247	142939.147*	1.258	0.008	16.459
Mycorrhiza × phosphorus × drought stress	2	0.16	0.0001	0.0001	4.204	3072.814	4.421	0.004	4.107
Error bc	30	0.025	0.0001	0.009	6.745	39184.251	2.73	0.006	33.233
CV (%)		*14.05*	*9. 2*	*21.93*	*14.05*	*9.2*	*17.37*	*17.72*	*11.89*

PRDW= Primary root dry weight
PRL= Primary root length
* and ** : Significant at 5% and 1% levels respectively.

Table 3. Variance analysis.

Treatments		**Root yield (kg ha^{-1})**	**Root diameter (cm)**	**Root length (cm)**	**PRDW (g)**	**PRL (cm)**	**Highest plant (cm)**	**Stem diameter (cm)**	**Number of branch**
	Application	2693.7 a	0.75 a	20.02 a	0.1101 a	1.25 a	50.6 a	0.44 a	9.5 a
mycorrhiza									
	Non application	2008 b	0.73 a	16.13 b	0.1 b	0.94 b	46.4 a	0.42 a	9.5 a
	Non application	1915 c	0.69 b	15.93 c	0.1 c	0.95 c	46.9 a	0.39 a	9.1 a
Phosphorus	35 kg ha^{-1}	2153 b	0.71 a	18.27 b	0.106 b	1.2 b	49.2 a	0.44 a	9.8 a
	70 kg ha^{-1}	2203 a	0.72 a	20.56 a	0.1109 a	1.32 a	49.4 a	0.45 a	9.6 a
	Normal irrigation	2659 a	0.91 a	15.25 b	0.1362 a	1.12 a	61.3 a	0.55 a	11 a
Irrigation according									
	Drought stress	1510 b	0.47 b	18.89 a	0.947 b	0.73 b	35.7 b	0.31 b	8.1 b

PRDW= Primary root dry weight
PRL= Primary root length
Means within the same column and rows and factors, followed by the same letter are not significantly difference ($P < 0.05$) using Duncan's multiple range test.

that root yield, primary root dry weight (α = 5%), root length and primary root length (α=1%) among non-inoculated and *G. hoi*-inoculated coriander seedlings had significantly higher values for these characteristics among mycorrhizal plants (Tables 2 and 3). In addition, phosphorous application had a significant effect on root yield, primary root dry weight, root length and primary root length (α =1%) and highest values were appeared under 70 kg h^{-1} P fertilizer (Tables 2 and 3). Data of drought and interactive effect between P available and mycorrhizal plants on underground organs products demonstrated (Table 4) no significant difference between mycorrhizal plants treated with 35 and 70 kg h^{-1} P under sever water restriction (60 mm eva.). Therefore highest upon characteristics appeared under application of *G. hoi*, 70 kg ha^{-1} P and without drought stress conditions but longest root length was achieved under application of *G. hoi*, 35 kg ha^{-1} P and drought stress conditions (Table 4).

DISCUSSION

Plants colonized by mycorrhizal fungi have been shown to deplete soil water more thoroughly than non-mycorrhizal plants (Auge, 2001). One reason for this is the fact that the shoots of plants with AMF usually have a larger biomass (more evaporative leaf surface area) than non-AMF plants (Fitter, 1985; Nelsen, 1987). Also the root systems of plants with AMF are often more finely divided and thus have more absorptive surface area (Allen et al., 1981; Busse and Ellis, 1985; Ellis et al., 1985; Huang et al., 1985; Sharma and Srivastava, 1991; Osonubi et al., 1992; Osonubi et al, 1994; Okon et al., 1996). Furthermore, the roots of plants with AMF dry the soil more quickly than non-AMF plants of similar size (For example, Bryla and Duniway, 1997). In our experiment, mycorrhizal coriander significantly root dry matter throughout the improvement of plant water relations under drought conditions, corresponding of mycorrhiza's contribution in P uptake to AMF-plants and act to synthesis certain phytohormones such as ABA and cytokinin. In the present study, mycorrhizal (*G. hoi*) treatment of coriander significantly improved root dry matter through improvement of plant water relations under drought conditions. These improvements were likely achieved via the mycorrhizal contribution to phosphorous uptake and the ability of AM fungi to stimulate plant synthesis of certain phytohormones such as ABA and cytokinins. Consequently, plants with AMF had higher phosphorous content in shoots than non-AMF plants. In agreement with the observation of Labour et al. (2003) and Dhanda et al. (2004) our data also revealed that roots of AMF-inoculated coriander were longer with increasing fungal hyphae growth, similar to the findings of Ruiz-Lozano et al. (1995). In addition, we found longer root length among AMF-inoculated plants under drought conditions compared to well-watered plants. Drought stress causes increased root length due to restriction of water content in plant organs, which leads plants to make an effort to uptake water from further destinations (Mayaki et al., 1976). In fact, shoot growth is more restrained by drought than root growth and because drought causes a decrease in root dry matter and length, corresponding to a reduction of nutrient transfer to seeds. Therefore, in drought conditions, plants product lower strong seeds when compared to well-watered plants seeds. Importantly, seeds from plants grown under water stress in turn grow plants with low root dry matter. We have also observed that the highest root production under drought conditions occurred when plants were treated with 35 kg h^{-1} phosphorous, in agreement with Shubhra et al. (2004). However, increasing the phosphorous content to 70 kg h^{-1} did not significantly improve root production or phosphorous uptake. Therefore, mycorrhizal plants showed a low necessity of phosphorus fertilizer in terms of contribution of P uptake to plants by hyphae and produced a same amount of dry matter with 35 kg h^{-1} available phosphorus as compared to 70 kg h^{-1}. This observation has illustrated in the produced of root dry matter of mycorrhizal plants in the treated level by 35 kg h^{-1} phosphorus. It was no significant different with the plants which has treated by 70 kg h^{-1} phosphorus under drought conditions. However, similar produce of root dry matter in both 35 and 70 kg h^{-1} phosphorus correspond to the contribution of mycorrhizal fungi to uptake water and P for inoculated plants. In fact, under drought conditions, AMF-inoculated plants grown with 35 kg h^{-1} phosphorous produced root dry matter similar to that found among inoculated plants grown with 70 kg h^{-1} phosphorous, indicating the contribution of hyphea to phosphorous uptake regardless to soil phosphorus levels. Our findings indicate that AMF-inoculation improves root dry matter and root length decreases the phosphorous requirement for coriander plants subjected to water stress.

Conclusion

The investigation showed that AM is able to enhance the growth of coriander under water stress through enhanceing P uptake. This can have very important environmental implications through decreasing the amount of P fertilizer under control and water stress conditions and also through enhancing the coriander resistance when subjected to the water stress.

ACKNOWLEDGEMENTS

The authors are indebted to Dr. Sharifi-Ashoorabadi and Dr. Sefidkon for providing financial assistance and continuous encouragement to carry out in the investigation.

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Table 4. Means comparison.

Number of branch	Highest Plant (cm)	Stem Diameter (cm)	PRL (cm)	PRDW (g)	Root diameter (cm)	Root Length (cm)	Root yield (kg ha-1)		survey instance qualifications
9.2 a	44.7 b	0.4 a	0.9d	0.1 c	0.63 a	14.53d	1868 c	Non application of phosphorus	
10.2 a	46.2 ab	0.44 a	1 cd	0.102b	0.59 a	15.79cd	2058 d	35 (kg ha-1) phosphorus	**Non application**
9.3 a	48.4 ab	0.47 a	1.2b	0.11a	0.57 a	18.46 b	2201 a	70 (kg ha-1) phosphorus	
Mycorrhiza									
9.1 a	49.1 ab	0.39 a	1.1bc	0.103b	0.63 a	18.07bc	2062 b	Non application of phosphorus	
9.4 a	52.1 a	0.44 a	1.3a	0.11a	0.63 a	21.06a	2279 a	35 (kg ha-1) phosphorus	**Application**
10 a	50.4 ab	0.43 a	1.3a	0.11a	0.61 a	21.4 a	2239 a	70 (kg ha-1) phosphorus	
11.2 a	58.9 b	0.56 a	1.1b	0.11a	0.53 a	17.47b	2106 b	Non stress	
Non application									
8 b	34 c	0.32 b	0.9c	0.071c	0.27 b	15.25c	1416 d	Stress	
Mycorrhiza									
10.6 a	63.8 a	0.55 a	1.3 a	0.11a	0.56 a	20.51a	2190 a	Non stress	
Application									
8.4 b	37.4 c	0.29 b	1.2 b	0.08b	0.29 b	19.83a	1603 c	Stress	
10.8 a	58.6 a	0.51 a	1.15b	0.12 c	0.51 a	16.83bc	2319 c	Non application of phosphorus	
11.1 a	62.2 a	0.59 a	1.2 a	0.14 b	0.56 a	18.85ab	2760 b	35 (kg ha-1) phosphorus	**Non stress**
10.8 a	63.1 a	0.56 a	1.3 a	0.144a	0.56 a	20.99a	2908 a	70 (kg ha-1) phosphorus	
Drought stress									
7.4 b	35.2 b	0.28 b	1d	0.07 e	0.27 b	15.76c	1412 e	Non application of phosphorus	
8.5 b	36.3 b	0.3 b	1.1c	0.08 d	0.29 b	18bc	1577 d	35 (kg ha-1) phosphorus	**Stress**
8.5 b	35.7 b	0.35 b	1.1c	0.08 d	0.28 b	18.87ab	1542 d	70 (kg ha-1) phosphorus	
10.9 a	56.5 a	0.5 a	1.2bc	0.11 c	0.5 a	18.6abc	2216 c		
11.3 a	58.9 a	0.58 a	1.1 c	0.13 b	0.56 a	17.2bcd	2661 b	**Non stress**	
11.3 a	61.3 a	0.59 a	1.2 b	0.15 a	0.62 a	19.38ab	2890 a		
Non application									
7.4 b	32.9 b	0.3 b	0.9f	0.07 f	0.28 b	13.77d	1319 f		
7.1 b	33.5 b	0.31 b	0.95f	0.072ef	0.33 b	14.43cd	1454 ef	**Stress**	
7.3 b	35.6 b	0.36 b	1 ef	0.073ef	0.31 b	17.6bcd	1474 ef		
7.4 b	32.9 b	0.3 b	0.9f	0.07 f	0.28 b	13.77d	1319 f		

Table 4. Contd.

Mycorrhiza								
10.7 a	60.7 a	0.52 a	1.2 b	0.13 b	0.53 a	18.4abc	2621 b	**Non stress**
10.8 a	65.6 a	0.53 a	1.3 a	0.13 b	0.54 a	20.55ab	2558 a	
10.9 a	65.9 a	0.62 a	1.32 a	0.14 a	0.6 a	20.83 a	2927 a	
Application								
7.4 b	35.5 b	0.26 b	1.05de	0.075e	0.32 b	17.7bcd	1505 e	**Stress**
8 b	39.1 b	0.28 b	1.07d	0.08 d	0.25 b	20.8a	1699 d	
7.8 b	35.8 b	0.34 b	1.07d	0.08 d	0.33 b	20. 5a	1608 d	

PRDW= Primary root dry weight.
PRL= Primary root length.
Means within the same column and factors, followed by the same letter are not significantly difference ($P < 0.05$) using Duncan's multiple range test.

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