http://www.pjbs.org

PJBS

ISSN 1028-8880

Pakistan Journal of Biological Sciences

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Pakistan Journal of Biological Sciences 11 (15): 1909-1915, 2008
ISSN 1028-8880

Soil Salinity Affects Arbuscular Mycorrhizal Colonization of Halophytes

H.R. Asghari, M.R. Amerian and H. Gorbani
Faculty of Agriculture, Shahrood University of Technology, P.O. Box 3619995161-316, Shahrood, Iran

Abstract: In order to determine the effects of soil salinity on AM fungi colonization in halophytes, plants of semi-arid region of North-Eastern Iran were examined for their colonization in soils with different salinity levels. Roots of several halophytes were colonized and showed typical structure of AM fungi with different levels of colonization. *Haloxylon aphyllum*, *Kochia stellaris*, *Halocnemum strobilaceum*, *Seidlitzia rosmarinus* and *Salsola* sp. of the Chenopodiaceae and *Zygophyllum eurypterum* and *Peganum harmala* of the Zygophyllaceae were found to be colonized by AM fungi. In several species the mycorrhizal status is reported for the first time. The results of this study revealed that AM colonization in halophytes in soil with high salinity level (16 dS m^{-1}), but colonization was inhibited by very high salinity (45 dS m^{-1}). The AM fungi colonization was absent in halophytes in very high soil salinity conditions may was due to inability of AM fungi to survive such salinity conditions, which may limit the beneficial effects of AM fungi in halophytes.

Key words: Arbuscular mycorrhizal fungi, salt tolerance, semi-arid

INTRODUCTION

Mycorrhizal symbiosis is an association between fungi and plant roots. In this association the fungi provide a fundamental link between soil and plant roots which could increase transport and nutrient uptake in plants through the extension of fungal hyphae in soil. Mycorrhizal symbiosis is found in average on 80-90% of land plants in different soil conditions (Smith and Read, 1997). Absence of mycorrhizal fungi was reported in halophytes species mostly belonging to the Chenopodiaceae family in early studies (Hirrel *et al*., 1978).

Arbuscular mycorrhizal fungi occur in many stressful environments. Relatively large populations of AM fungi spores have been found in saline conditions (Aliasgharzadeh *et al*., 2001; Sengupta and Chaudhuri, 1990; Wang *et al*., 2004). The results of glasshouse studies have shown that AM fungi can increase plant salinity tolerance and yield in saline conditions (Al-Karaki, 2006; Asghari *et al*., 2005; Hirrel and Gerdemann, 1980; Ojala *et al*., 1983; Plenchette and Duponnois, 2005; Tian *et al*., 2004), but salinity may have negative effects on AM fungi growth and hyphal extension (Juniper and Abbott, 1993; Peat and Fitter, 1993).

The distribution of AM fungi in saline soils has been investigated in many studies (Aliasgharzadeh *et al*., 2001; Hildebrandt *et al*., 2001; Garcia and Mendoza, 2008; Landwehr *et al*., 2002; Sengupta and Chaudhuri, 1990; Wang *et al*., 2004). Aliasgharzadeh *et al*. (2001) reported that increasing soil salinity decreased the percentage of AM colonization in glycophytes. Garcia and Mendoza (2008) found high level of AM colonization in saline soils of a temperate grassland, which water content, salinity and sodicity in soil were positively associated with AM root colonization and arbuscule colonization in *Lotus tenuis*, but negatively so in the grasses The effects of soil salinity on spore germination of AM fungi and therefore hyphal production is one of the most important detrimental effects of salinity on mycorrhizal colonization (Juniper and Abbott, 2006).

Different levels of AM colonization in halophytes have been reported in many field studies in different locations, seasons and soil salinity levels, but AM colonization in halophytes along a salinity gradient has received less attention. The objectives of this study were to evaluate AM colonization of halophytes and also to investigate the effects of increased soil salinity along a transect on AM fungi colonization in halophytes of semi-arid region of North-Eastern Iran.

MATERIALS AND METHODS

Study site: This study was conducted in 2005 at Turan Biosphere Reserve (TBR), situated in north east of Iran (Fig. 1). The reserve includes 1.8 million hectares of flat, semi-arid desert plains which was set aside for conservation and research by the United Nations Development Program (UNDP) in 1972. The climate is

Corresponding Author: Hamid Reza Asghari, Shahrood University of Technology, Shahrood, Iran
Tel: 0098 273 3350570 Fax: 0098 273 3350570

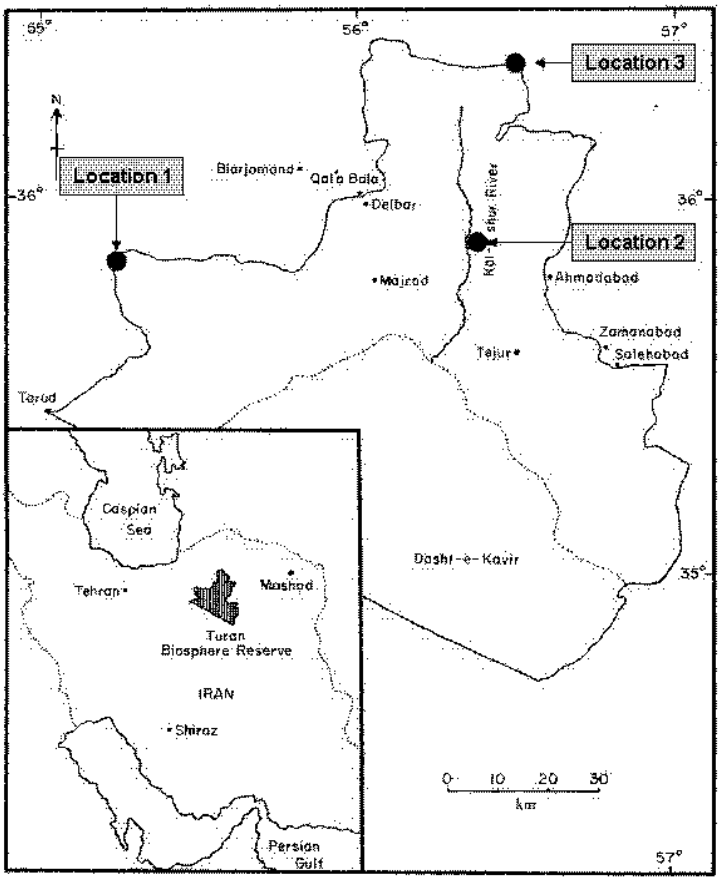

Fig. 1: Turan biosphere reserve of North-Eastern Iran, showing the three survey locations

semi-arid, with dry summers and cold winters. The 20-year mean annual rainfall is 110-170 mm. Rainfall varies across the TBR, decreasing from north to South.

Collection of plant specimens and soil: Two different sampling stages were carried out. At the first sampling event, three different locations in north, east and center of TBR (Fig. 1) were selected in June 2005 to study root AM colonization of different halophytes. The second sampling event was carried out along a 40 km north-south transect extending from a low soil salinity zone to a high soil salinity zone, in location 1 (Fig. 1) in April 2006 to study the effects of soil salinity on AM colonization in halophytes. At each location, soil and root samples were collected from 0-30 cm of three individual plants. Samples were taken from halophytes that had no immediately adjacent plants within approximately 1 m, to avoid contamination by roots of other plants. AM colonization is the pre-requisite for the interaction between AM fungi and plants and is therefore a better measure for the effect of AM on plants than spore counts. Therefore the percent of AM colonization of roots was estimated in this study and the density of spores in soil was not measured. AM colonization was assessed after clearing washed roots with 10% KOH for 3 days at room temperature and staining with trypan blue (Phillips and Hayman, 1970). Darkly pigmented roots were cleared with alkaline hydrogen peroxide (0.5% NH_4OH and 0.5% H_2O_2 v/v in water) (Brundrett *et al.*, 1996). After staining, AM colonization was determined in about 200-250 root segments by the gridline intersect method (Giovannetti and Mosse, 1980).

Air-dry soil was crushed and sieved through a 2 mm mesh for particle-size analysis using the hydrometer method. The Total Neutralizing Value (TNV) as calcium carbonate and magnesium carbonate was measured by back titration procedure. Soil pH and salinity of water extract of samples were determined by pH meter and electrical conductivity meter, respectively.

RESULTS

AM colonization in different locations: Of the plant species surveyed in first sampling event, 6 of 12

halophyte species (50%) showed some evidence of AM fungi colonization in at least one of the locations (Table 1). Members of Chenopodiaceae (*Haloxylon aphyllum*, *Kochia stellaris* and *Halocnemum strobilaceum*), Zygophyllaceae (*Zygophyllum eurypterum* and *Peganum harmala*) and Astraceae (*Artemisia herba-alba*) were all colonized. Except of Poaceae, AM fungi structures were found in all investigated plant families. The lowest percentages of AM colonization (10%) were observed in *Halocnemum strobilaceum* and the highest (60%) in *Haloxylon aphyllum* and *Zygophyllum eurypterum*. AM colonization in roots of halophytes was found in soil salinities range between 2.3-27.5 dS m^{-1}. The highest AM colonization occurred at the low salinity levels. The same plant species had different levels of AM colonization in different locations at nearly the same salinity levels (see *Haloxylon aphyllum* in location 2 and 3 in Table 1). At the same salinity level and location different plant species were not equally colonized. For example at nearly the same salinity levels

Table 1: Arbuscular mycorrhizal fungi colonization of the roots of halophytes collected from Turan biosphere reserve of North-Eastern Iran

Family	Plant name	Dominant plant cover	pH	EC (dS m^{-1})	TNV (%)	Sand (%)	Silt (%)	Clay (%)	Colonization (%)	Internal hyphae	Coil	Arbuscules	Vesicles
Location 1													
Tamaricaceae	*Tamarix brachystachys*	*Tamarix-Salsola*	7.75	61.9	35	57	43	0	0	-	-	-	-
	Tamarix brachystachys	*Tamarix-Salsola*	8.08	56.7	33	41	56	3	0	-	-	-	-
	Tamarix brachystachys	*Tamarix-Salsola*	7.93	73.2	36	43	56	1	0	-	-	-	-
Zygophyllaceae	*Zygophyllum eurypterum*	*Zygophyllum*	7.95	17.28	41	96	2	2	0	-	-	-	-
	Zygophyllum eurypterum	*Zygophyllum*	8.22	2.05	43	98	2	0	0	-	-	-	-
	Zygophyllum eurypterum	*Zygophyllum*	7.98	4.84	36	75	25	0	0	-	-	-	-
	Peganum harmala	*Zygophyllum*	7.50	5.5	28	70	20	10	30	+	-	+	+
Chenopodiaceae	*Kochia stellaris*	*Seidlitzia-Kochia*	7.91	4.02	37	84	12	4	0	-	-	-	-
	Kochia stellaris	*Seidlitzia-Kochia*	8.04	10.84	38	72	17	11	0	-	-	-	-
	Kochia stellaris	*Halostachys-Halocnemum*	7.47	103.0	26	69	25	6	0	-	-	-	-
	Kochia stellaris	*Seidlitzia-Kochia*	7.93	4.85	38	83	15	2	0	-	-	-	-
	Kochia stellaris	*Seidlitzia-Kochia*	8.11	3.76	43	79	16	5	15	+	+	-	+
	Seidlitzia rosmarinus	*Seidlitzia-Kochia*	7.88	5.7	17	91	1	8	0	-	-	-	-
	Seidlitzia rosmarinus	*Seidlitzia-Kochia*	7.63	14.63	26	70	20	10	0	-	-	-	-
	Halocnemum strobilaceum	*Halostachys-Halocnemum*	7.55	134.0	19	67	32	1	0	-	-	-	-
	Halocnemum strobilaceum	*Halostachys-Halocnemum*	7.17	128.0	25	58	41	1	0	-	-	-	-
	Halocnemum strobilaceum	*Halostachys-Halocnemum*	7.74	88.0	15	67	23	10	0	-	-	-	-
	Seidlitzia rosmarinus	*Halostachys-Halocnemum*	7.80	75.2	24	62	38	0	0	-	-	-	-
	Seidlitzia rosmarinus	*Halostachys-Halocnemum*	7.72	63.5	18	80	17	3	0	-	-	-	-
	Halostachys belangeriana	*Halostachys-Halocnemum*	7.92	85.1	30	82	17	1	0	-	-	-	-
	Halostachys belangeriana	*Halostachys-Halocnemum*	7.90	80.5	25	67	26	7	0	-	-	-	-
Astraceae	*Artemisia herba-alba*	*Zygophyllum-Artemisia*	7.50	5.0	25	65	22	13	15	+	-	+	+
Location 2													
Chenopodiaceae	*Atriplex* sp.	*Tamarix*	7.98	140	14	98	2	0	0	-	-	-	-
	Atriplex sp.	*Tamarix*	7.66	51.1	11	82	10	8	0	-	-	-	-
	Atriplex sp.	*Tamarix*	7.98	22.1	12	62	18	20	0	-	-	-	-
	Aeluropus littoralis	*Tamarix*	7.70	46.0	22	54	41	5	0	-	-	-	-
	Aeluropus littoralis	*Tamarix*	7.75	34.2	10	57	40	3	0	-	-	-	-
	Seidlitzia rosmarinus	*Halostachys-Seidlitzia*	7.71	52.7	11	90	9	1	0	-	-	-	-
	Seidlitzia rosmarinus	*Halostachys-Seidlitzia*	7.9	27.1	16	79	19	2	0	-	-	-	-
	Halostachys belangeriana	*Halostachys-Seidlitzia*	7.28	89.2	8.2	94	4	0	0	-	-	-	-
	Halostachys belangeriana	*Halostachys-Seidlitzia*	8.08	36.9	13	84	13	3	0	-	-	-	-
	Halostachis belangeriana	*Halostachys-Seidlitzia*	7.81	54.9	13	75	11	14	0	-	-	-	-
	Halocnemum strobilaceum	*Halostachys-Seidlitzia*	7.93	137.3	10	48	44	8	0	-	-	-	-
	Halocnemum strobilaceum	*Halostachys-Seidlitzia*	8.02	136.3	9.5	45	46	9	0	-	-	-	-
	Halocnemum strobilaceum	*Halostachys-Seidlitzia*	8.06	100.4	13.75	57	37	6	0	-	-	-	-
	Halocylon aphyllum	*Haloxylon-Zygophyllum*	8.1	15.99	18.75	69	16	15	40	+	+	+	+
	Halocylon aphyllum	*Haloxylon-Zygophyllum*	7.51	4.75	16.5	76	14	10	60	+	+	+	+
Zygophyllaceae	*Zygophyllum eurypterum*	*Haloxylon-Zygophyllum*	8.11	2.36	19.75	72	16	12	60	+	+	+	+
Poaceae	*Aeluropus littoralis*	*Tamarix*	7.7	46.0	22.0	54	41	5	0	-	-	-	-
	Aeluropus littoralis	*Tamarix*	7.75	34.2	10.0	57	40	3	0	-	-	-	-
Location 3													
Chenopodiaceae	*Halocnemum strobilaceum*	*Halocnemum*	7.93	30.0	20.0	76	16	8	0	-	-	-	-
	Halocnemum strobilaceum	*Halocnemum*	7.94	14.9	20.0	66	22	12	10	+	-	-	+
	Halocnemum strobilaceum	*Halocnemum*	7.6	27.5	22.5	46	37	17	20	+	-	-	+
	Seidlitzia rosmarinus	*Halocnemum*	7.99	21.6	23.25	45	40	15	0	-	-	-	-
	Seidlitzia rosmarinus	*Halocnemum*	8.32	20.8	23.25	36	40	15	0	-	-	-	-
	Halocylon aphyllum	*Halocnemum*	7.95	12.75	22.0	67	24	9	0	-	-	-	-
	Halocylon aphyllum	*Halocnemum*	7.86	12.8	20.5	50	36	14	0	-	-	-	-
	Halocylon aphyllum	*Halocnemum*	7.79	17.1	18.75	45	41	14	0	-	-	-	-
	Atriplex sp.	*Suaeda-Salsola*	7.91	14.05	19.5	40	38	22	0	-	-	-	-
	Atriplex sp.	*Suaeda-Salsola*	8.13	9.5	21.0	20	57	23	0	-	-	-	-
	Salsola sp.	*Salsola*	8.09	17.08	17.5	56	28	16	0	-	-	-	-
	Salsola sp.	*Salsola*	8.08	18.2	20.0	53	29	18	0	-	-	-	-
	Salsola sp.	*Salsola*	8.36	13.89	23.25	60	27	13	0	-	-	-	-
	Kochia stellaris	*Suaeda-Salsola*	8.03	11.35	22.25	67	18	15	0	-	-	-	-
	Suaeda arcuata	*Suaeda-Salsola*	8.11	24.7	22.5	50	33	17	0	-	-	-	-
	Suaeda arcuata	*Suaeda-Salsola*	7.56	28.2	25.5	48	36	16	0	-	-	-	-
	Salsola sp.	*Salsola*	8.12	20.9	26.0	37	42	21	0	-	-	-	-
	Salsola sp.	*Salsola*	7.99	11.25	19.75	56	29	15	0	-	-	-	-
Poaceae	*Aeluropus littoralis*	*Halocnemum*	8.11	9.76	20.75	65	25	10	0	-	-	-	-
	Aeluropus littoralis	*Halocnemum*	8.25	18.53	26.25	40	44	16	0	-	-	-	-

Table 2: Arbuscular mycorrhizal colonization of the roots of halophytes collected along a north-south transect in location 2 from turan biosphere reserve of North-Eastern Iran

Plant name	Dominant plant cover	Altitude (MSL)	pH	EC (d Sm^{-1})	TNV (%)	SAR	Colonization (%)	Internal hyphae	Coil	Arbuscules	Vesicles
Zygophyllum eurypterum	*Zygophyllum*	1320	7.6	2.5	25	2.0	15.0	+	-	+	+
Peganum harmala	*Zygophyllum*	1320	7.6	3.3	20	2.5	15.0	+	-	+	+
Ceratocarpus arenarius	*Zygophyllum*	1320	7.6	5.0	42	3.0	0.0	-	-	-	-
Zygophyllum eurypterum	*Zygophyllum-Artemisia*	1220	7.7	4.0	40	4.5	45.0	+	-	+	+
Artemisia herba-alba	*Zygophyllum-Artemisia*	1204	7.7	5.0	25	11.0	10.0	+	-	+	+
Zygophyllum eurypterum	*Zygophyllum-Artemisia*	1201	7.7	5.5	25	5.5	10.0	+	-	+	+
Londesia eriantha	*Zygophyllum-Artemisia*	1201	7.7	5.0	29	5.0	0.0	-	-	-	-
Peganum harmala	*Zygophyllum*	1108	7.5	4.0	28	11.0	15.0	+	-	+	+
Zygophyllum eurypterum	*Zygophyllum*	1106	7.6	6.0	18	14.0	65.0	+	-	+	+
Seidlitzia rosmarinus	*Zygophyllum*	1100	7.8	14.5	22	11.0	2.0	+	-	-	-
Seidlitzia rosmarinus	*Seidlitzia-Zygophyllum*	1100	7.5	16.0	21	24.0	10.0	+	-	-	+
Salsola sp.	*Seidlitzia-Zygophyllum*	1100	7.6	12.0	29	25.0	5.0	+	-	-	+
Zygophyllum eurypterum	*Seidlitzia-Zygophyllum*	1100	7.7	16.0	15	14.0	10.0	+	-	-	+
Zygophyllum eurypterum	*Seidlitzia-Zygophyllum*	1095	7.6	45.0	24	25.0	0.0	-	-	-	-
Seidlitzia rosmarinus	*Seidlitzia-Zygophyllum*	1095	7.4	45.0	25	25.0	0.0	-	-	-	-
Haloxylon aphyllum	*Haloxylon-Zygophyllum-Seidlitzia*	1092	7.8	62.0	25	38.0	0.0	-	-	-	-
Zygophyllum eurypterum	*Zygophyllum-Seidlitzia*	1090	7.5	67.0	29	42.0	0.0	-	-	-	-
Zygophyllum eurypterum	*Halocnemum-Zygophyllum*	1066	8.1	89.0	32	94.0	0.0	-	-	-	-
Seidlitzia rosmarinus	*Halocnemum*	1066	8.1	85.0	20	82.0	0.0	-	-	-	-
Artemisia herba-alba	*Halocnemum*	1066	8.1	94.0	19	90.0	0.0	-	-	-	-

Peganum harmala was colonized 30% and no AM colonization were found in *Zygophyllum eurypterum* in location 1 (Table 1). The roots of halophytes in high salinities contained internal hyphae and vesicles but no other mycorrhizal structures.

Effects of soil salinity on AM fungi colonization along a north-south transect: Altitude decreased from north to south, soil salinity, pH and Sodium Absorption Ratio (SAR) increased with decreasing altitude, but no significant changes were found in soil total neutralizing value (TNV) (Table 2). AM colonization was observed only between 2.5 to 16 dS m^{-1} and no AM fungi structure were found in very high salinity levels (45-94 dS m^{-1}) in all plant species investigated in this sampling. The percentage of AM colonization ranged from 2 to 65 in different plant species.

Zygophyllum eurypterum as a dominant plant along the transect, growing in different levels of soil salinity (2.5-89 dS m^{-1}), showed different levels of AM fungi colonization. The results showed that all mycorrhizal structures were found in *Zygophyllum eurypterum* roots at soil salinity levels up to 6 dS m^{-1}, but no arbuscules were found in soil salinities between 6 and 16 dS m^{-1} whereas no mycorrhizal structure were observed at 45 dS m^{-1}. The same trend towards AM absence in increased salinity level was found in *Artemisia herba-alba* and *Seidlitzia rosmarinus* (Table 2).

DISCUSSION

Occurrence of AM colonization of some halophytes has been reported by researchers in field and glasshouse conditions (Aldon, 1975; Hildebrandt *et al*., 2001; Sengupta and Chaudhuri, 1990; Wang *et al*., 2004). The results of this study showed different levels of AM colonization with different halophytes host plants (mostly from Chenopodiaceae family) which is in agreement with previous field studies. To our knowledge, the occurrence of AM fungi colonization in roots of *Zygophyllum eurypterum* and *Kochia stellaris* is reported for the first time in this study (Fig. 2).

The results of the first sampling showed that plant species from different family had different levels of AM fungi colonization. Different plant species growing at the same salinity level were colonized differently, which suggests that AM colonization is, at least partly, regulated by the plant species. Also finding different levels of AM colonization in the same plants species at the same salinity levels in different locations indicate that other factors such as soil moisture, soil layer and soil chemical and physical properties than salinity and plant species control AM colonization (McMillen *et al*., 1998; Nadian *et al*., 1998; Wang *et al*., 2004).

Overall the results of the first and second sampling stages showed that higher percentage of AM colonization occur at lower soil salinity levels and very high soil salinity was linked to the absence of AM fungi colonization in roots of halophytes. *Zygophyllum eurypterum* grew at different salinity levels (2.5 to 89 dS m^{-1}), but AM colonization did not occur at very high salinity levels (45 to 89 dS m^{-1}). This result showed the effects of edaphic properties to control AM fungi colonization in this halophytic plant. The same results were reported by other researchers in some other species and lower salinities.

Salinity could reduce AM colonization by directly reducing hyphal growth and/or decreasing plant growth (less carbohydrate). A recent report indicates that the most important effect of salinity on AM fungi is related to its detrimental effect on spore germination and hyphal production (Juniper and Abbott, 2006). On the other hand, in AM associations the fungus is completely depend on plant growth and carbohydrate nutrition production in

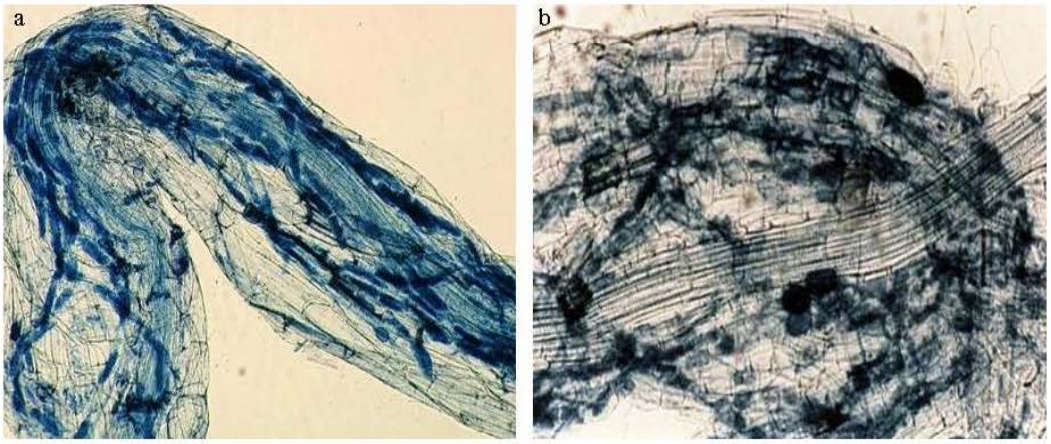

Fig. 2: Roots of halophytes with arbuscular fungi mycorrhizal structures, (a) *Zygophyllum eurypterum* and (b) *Kochia stellaris*

host plant, therefore every factor that effects the carbohydrate production and its translocation to the roots could effect the amount of mycorrhizal colonization (Thomson *et al*., 1990). Since salinity reduces plant growth and decreases carbohydrates concentration in host plant (Greenway and Munns, 1980), it could reduce mycorrhizal colonization. Poor growth of *Zygophyllum eurypterum* by increased soil salinity in location 1 has been observed, suggesting that the plant could not supply the AM fungi with enough carbohydrate.

In previous studies around the world, AM fungi colonization in roots of halophytes was found in different levels of soil salinity up to 185 dS m^{-1}. Different structures of AM colonization were found in some halophytes such as *Atriplex canescences* (Barrow *et al*., 1997), *Tamarix chinesis* and *Aeluropus littoralis* (Wang *et al*., 2004) and *Suaeda maritime* (Sengupta and Chaudhuri, 1990), but in this study no AM fungal structures were found in these genera of halophytes, even at relatively low salinity levels. However it is difficult to determine factors which actually control AM fungi colonization. Lack of root exudates (Nagahashi and Douds, 1999) or mycorrhizal helper microorganisms (Caroline and Bagyaraj, 1995) in the rhizosphere, presence of toxic compounds of root exudates (Peterson and Bradbury, 1995; Vierheilig *et al*., 1995) or intrinsic barrier of the root cortex or epidermis etc. Which have been reported previously for absence of AM colonization in plants in non saline conditions. Furthermore absence of salt tolerant AM fungi species could be the case in investigated soils with high salinity levels. The AM fungi which are isolated from saline soils which may have an ability to improve the survival of host plants (Copeman *et al*., 1996).

Moreover, different methods of root staining and times of investigation in a plant may cause different results. In this study some of halophytes species such as *Haloxylon aphyllum*, *Halostachys belangeriana* and *Seidlitzia rosmarinus* had dark roots, which did not clear completely making AM colonization difficult to observe. Different root clearing and staining methods is suggested in the future works.

The effects of AM fungi on plant salinity tolerance of a range of glycophytes have been shown previously. Furthermore AM fungi increased growth of halophytes in saline conditions in some glasshouse studies (Aldon, 1975; Asghari *et al*., 2005; Hirrel and Gerdemann, 1980; Plenchette and Duponnois, 2005). It is speculated that AM fungi improve plant growth in both glycophytes and halophytes in saline conditions. The results of this field study showed that high soil salinity lead to the absence of AM colonisation, which indicate halophytes can grow in higher soil salinity levels than AM fungi. This finding can show the limitation of AM fungi use in halophytes in very saline soils. These results may important in application of AM fungi in halophytes in revegetation of saline soils.

ACKNOWLEDGMENTS

Support for this research was provided by Shahrood University of Technology, Iranian Ministry of Science, Research and Technology. The author's thanks Mr. M.A. Hoseinpour, Mr. G.R. Shakeri, Ms. A. Hassani and Ms. S. Ahmadi for their excellent technical assistance and authors thanks members of faculty of Agriculture of Shahrood University of Technology for their helpful discussions.

REFERENCES

Al-Karaki, G.N., 2006. Nursery inoculation of tomato with arbuscular mycorrhizal fungi and subsequent performance under irrigation with saline water. Sci. Hortic., 109: 1-7.

Aldon, E.F., 1975. Endomycorrhizae enhance survival and growth of fourwing saltbush on coal mine spoils. United States Dept. of Agriculture Forest Service research note Pacific Southwest, RM-294

Aliasgharzadeh, N., N.S. Rastin, H. Towfighi and A. Alizadeh, 2001. Occurrence of arbuscular mycorrhizal fungi in saline soils of the Tabriz Plain of Iran in relation to some physical and chemical properties of soil. Mycorrhiza, 11: 119-122.

Asghari, H.A., P. Marschner, S.E. Smith and F.A. Smith, 2005. Growth response of *Atriplex nummularia* to mycorrhizal inoculation at different salinity levels. Plant Soil, 273: 245-256.

Barrow, J.R., K.M. Havstad and B.D. McCaslin, 1997. Fungal root endophytes in fourwing saltbush, *Atriplex canescens*, on arid rangelands of Southwestern USA. Arid Soil Res. Rehabil., 11: 177-185.

Brundrett, M., N. Bougher, B. Dell, T. Grove and N. Malajczuk, 1996. Working with Mycorrhizas in Forestry and Agriculture. 1st Edn., Australian Centre for International Agricultural Research, Canberra, Australia, ISBN: 1 86320 181 5.

Caroline, M. and D.J. Bagyaraj, 1995. Mycorrhization Helper Bacteria and Their Influence on Growth of Cowpea. In: Mycorrhizae: Biofertilizers for the Future. Adholeya, A. and S. Singh (Eds.) TERI, New Delhi, India pp: 192-196.

Copeman, R.H., C.A. Martin and J.C. Stutz, 1996. Tomato growth in response to salinity and mycorrhizal fungi from saline or non-saline soils. Hortscience, 31: 341-344.

Garcia, I.V. and R.E. Mendoza, 2008. Relationships among soil properties, plant nutrition and arbuscular mycorrhizal fungi-plant symbioses in a temperate grassland along hydrologic, saline and sodic gradients. FEMS Microbiol. Ecol., 63: 359-371.

Giovannetti, M. and B. Mosse, 1980. An evaluation of techniques for measuring vesicular-arbuscular mycorrhizal infection in roots. New Phytol., 84: 489-500.

Greenway, H. and R. Munns, 1980. Mechanisms of salt tolerance in nonhalophytes. Ann. Rev. Plant Physiol., 31: 149-190.

Hildebrandt, U., K. Janetta, F. Ouziad, B. Renne, K. Nawrath and H. Bothe, 2001. Arbuscular mycorrhizal colonization of halophytes in Central European salt marshes. Mycorrhiza, 10: 175-183.

Hirrel, M.C., H. Mehravaran and J.W. Gerdemann, 1978. Vesicular-arbuscular mycorrhiza in the Chenopodiaceae and Cruciferae: Do they occur? Can. J. Bot., 56: 2813-2817.

Hirrel, M.C. and J.W. Gerdemann, 1980. Improved growth of onion and bell pepper in saline soils by two vesicular-arbuscular mycorrhizal fungi. Soil Sci. Am. J., 44: 654-658.

Juniper, S. and L.K. Abbott, 1993. Vesicular-arbuscular mycorrhizas and soil salinity. Mycorrhiza, 4: 45-57.

Juniper, S. and L.K. Abbott, 2006. Soil salinity delays germination and limits growth of hyphae from propagules of arbuscular mycorrhizal fungi. Mycorrhiza, 16: 371-379.

Landwehr, M., U. Hildebrandt, P. Wilde, K. Nawrath, T. Toth, B. Biro and H. Bothe, 2002. The arbuscular mycorrhizal fungus *Glomus geosporum* in European saline, sodic and gypsum soils. Mycorrhiza, 12: 199-211.

McMillen, B.G., S. Juniper and L.K. Abbott, 1998. Inhibition of hyphal growth of a vesicular-arbuscular mycorrhizal fungus in soil containing sodium chloride limits the spread of infection from spores. Soil Biol. Biochem., 30: 1639-1646.

Nadian, H., S.E. Smith, A.M. Alston, R.S. Murray and B.D. Siebert, 1998. Effects of soil compaction on phosphorus uptake and growth of *Trifolium subterraneum* colonized by four species of vesicular-arbuscular mycorrhizal fungi. New Phytol., 140: 155-165.

Nagahashi, G. and D.D. Douds, 1999. Rapid and sensitive bioassay to study signals between root exudates and arbuscular mycorrhizal fungi. Biotechnol. Tech., 13: 893-897.

Ojala, J.C., W.M. Jarrell, J.A. Menge and E.L.V. Johnson, 1983. Influence of mycorrhizal fungi on the mineral nutrition and yield of onion in saline soil. Agron. J., 75: 255-259.

Peat, H.J. and A.H. Fitter, 1993. The distribution of arbuscular mycorrhizas in the British flora. New Phytol., 125: 845-854.

Peterson, R.L. and S.M. Bradbury, 1995. Use of Plant Mutants, Intraspecific Variants and Non-Hosts in Studying Mycorrhiza Formation and Function. In: Mycorrhiza, Structure, Function, Molecular Biology and Biotechnology. Hock, B. (Ed.). Springer Verlag, Berlin Heidelberg, ISBN: 978-3540639817, pp: 157-180.

Phillips, J.M. and D.S. Hayman, 1970. Improved procedures for clearing roots and staining parasitic and vesicular-arbuscular mycorrhizal fungi for rapid assessment of infection. Trans. Br. Mycol. Soc., 55: 158-161.

Plenchette, C. and R. Duponnois, 2005. Growth response of the saltbush *Atriplex nummularia* L. to inoculation with the arbuscular mycorrhizal fungus *Glomus intraradices*. J. Arid Environ., 61: 535-540.

Sengupta, A. and S. Chaudhuri, 1990. Vesicular arbuscular mycorrhiza (VAM) in pioneer salt marsh plants of the Ganges river delta in West Bengal (India). Plant Soil, 122: 111-113.

Smith, S.E. and D.J. Read, 1997. Mycorrhizal Symbiosis. 2nd Edn., Academic Press, London, ISBN 0-12-652840-3.

Thomson, B.D., A.D. Robson and L.K. Abbott, 1990. Mycorrhizas formed by *Gigaspora calospora* and *Glomus fasciculatum* on subterranean clover in relation to carbohydrate concentrations in roots. New Phytol., 114: 217-225.

Tian, C.Y., G. Feng, X.L. Li and F.S. Zhang, 2004. Different effects of arbuscular mycorrhizal fungal isolates from saline or non-saline soil on salinity tolerance of plants. Applied Soil Ecol., 26: 143-148.

Vierheilig, H., M. Alt, J. Lange, M. Gut-Rella, A. Wiemken and T. Boller, 1995. Colonization of transgenic tobacco constitutively expressing pathogenesis-related proteins by the vesicular-arbuscular mycorrhizal fungus *Glomus mosseae*. Applied Environ. Microbiol., 61: 3031-3034.

Wang, F.Y., R.J. Liu, X.G. Lin and J.M. Zhou, 2004. Arbuscular mycorrhizal status of wild plants in saline-alkaline soils of the Yellow River Delta. Mycorrhiza, 14: 133-137.