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Effect of Arbuscular Mycorrhizal Fungi on the Tolerance to Sodium Chloride Levels, and on Growth and Yield of Lentil (*Lens culinaris*)

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Abstract

A pot experiment was carried out in the nethouse of Soil Science Division, Bangladesh Agricultural Research Institute, Joydebpur, Gazipur during 2014-2015 through 2015-2016. The design of the experiment was factorial randomized completely block design with 4 replications. The objectives of the study were to evaluate the potential of Arbuscular mycorrhization (AM) on the germination, yield and yield attributes of lentil treated with different concentration of sodium chloride (NaCl). Five NaCl treatments (0, 1, 2, 3 and 4%) possessed NaCl level as the first factor that were treated with soils before sowing of lentil seeds overriding or pivotal pulse crop in Bangladesh. The second factor consists of mycorrhizal and non-mycorrhizal treatments. Mycorrhizal plants showed better performance in terms of germination %, yield and yield contributing characters than non-mycorrhizal plants. With increasing NaCl concentration germination %, yield and yield contributing characters in the rhizosphere soil, decreased significantly ($p<0.01$). Interaction effects of mycorrhizal inoculation and NaCl on germination %, growth and yield of lentil were appeared to be statistically non-significant. The highest germination (96.25% in 2014-2015 and 92.50% in 2015-2016), seed yield (6.45 g pot^{-1} in 2014-2015 and 5.89 g pot^{-1} in 2015-2016), and stover yield (9.55 g pot^{-1} in 2014-2015 and 8.58 g pot^{-1} in 2015-2016) was found in NaCl 0% + AM treatment. The lowest germination %, seed yield and stover yield was found in NaCl 4% treatment. Mycorrhizal inoculation increased seed yield on an average by 31.85% during 2014-2015 and 63.71% during 2015-2016, and increased stover yield on an average by 48.56% during 2014-2015 and 63.55% during 2015-2016 over non-mycorrhizal inoculation. Therefore, it can be concluded that mycorrhizal inoculation increases germination %, growth and yield of lentil over non-mycorrhizal inoculation.

Keywords: Mycorrhizal inoculation, germination, lentil, sodium chloride, yield.

1. Introduction

Soil salinity is one of the major environmental hazards of the present world including Bangladesh greatly affecting agricultural production as well as food security. Abiotic and biotic stresses hamper the production of our cultivated land at an alarming rate. Among the abiotic stresses salt stress has a greater impact on farmlands worldwide. It is reported that about 7% of the total land on earth and 20% of the total arable land are affected by high salt content (Mali *et al.*, 2012). In view of another projection, 2.1% of the global dry land agriculture is affected by salinity. Over 30% of the cultivable area of Bangladesh lies in the coastal and offshore zones. Out of 2.86 million hectares of coastal and offshore lands, about 1.06 million hectares are affected by varying degrees of salinity (SRDI, 2010). The area under salinity is increasing with time (from 0.83 m ha to 1.06 m ha in 36 years; SRDI, 2010) due to rise in sea water level with increased global temperature. The other main three causes are tidal flooding, salinity intrusion and capillary rise of saline water.

In the world associated agricultural production losses were estimated to be close to $12 billion per year due to soil salinization. Furthermore, the salinized areas are increasing at a rate of 10% annually for various reasons. It has been estimated that more than 50% of the arable land would be salinized by the year 2050 (Jamil *et al*., 2011). On the other hand the human race is increasing and is believed to reach 8.3 billion by 2030. It is difficult to feed this increasing population as the productive land is decreasing day by day. Agriculture is the most important sector of Bangladesh economy. Usually 30-50% yield losses occur depending on the level of soil salinity.

Researchers are trying to their level best to find out suitable techniques to combat these concerning problems ie. looking for an alternative to bring the uncultivated land under cultivation. But these techniques seem to be very costly and unaffordable to underdeveloped countries, whereas microorganisms specially arbuscular mycorrhiza (AM) have the potential to reduce the sodium and chloride toxicity in crops which could be a cost effective environmental friendly option that is available in a shorter time frame. Arbuscular mycorrhizas (AM) are pervasive and they are found in 80% of vascular plant families in existence today and fungi belonging to the order glomeromycota. AM have been shown to promote plant growth (Hameed *et al*., 2014), enhance nutrient uptake such as nitrogen, phosphorus, magnesium, and micronutrients from the soil (Evelin *et al*., 2012), improve soil structure, and also able to enhance plant tolerance under different stresses such as drought and salinity (Wu *et al*., 2014). Plants treated with AM fungi have shown to have enhanced the growth and yield, and maintains the osmotic and ionic balance to a normal level so that plants will thrive well under these stress conditions (Hameed *et al*., 2014).

Lentil (*Lens culinaris)* var. BARI Masur-5 belongs to the family Fabaceae and is commonly used as an important pulse crop in Bangladesh. In 2013-2014, about 136,695 ha of land are under lentil cultivation and the total production is about 157,422 metric tons and in 2014-2015, about 145,493 ha of land is under lentil cultivation and the total production is about 167,261 metric tons (BBS, 2015). An ideal sustainable agricultural system is one which maintains and improves human health, benefits producers and consumers both economically and spiritually, protects the environment, conserve ecosystem, sustain soil health and produces enough food for an increasing world population. Plant associated microorganisms ie. arbuscular mycorrhiza can play an important role in conferring resistance to alleviating salinity stresses in plants. Taking the current leads available, concerted future research is needed to have an appraisal or summing-up of the present state of land areas affected by salinity. Therefore, the overall aim of the investigation was to evaluate the potential of arbuscular mycorrhizal inoculation on seed germination (%), growth and yield of lentil treated with different concentration of NaCl.

2. Materials and Methods

2.1 Seed collection and Soil preparation

The during rabi season from December, 2014 through March, 2015 and December, 2015 through experiment was carried out March, 2016 in the net house of Soil Science Division, BARI, Joydebpur, Gazipur (23^0 59'38" N latitude, 90^0 24'89" E longitude and 8.4 m elevation). Seeds of lentil (BARI Masur-5) were collected from Pulse Research Centre, BARI, Gazipur. The silted (sandy clay loam) soils were collected from the bank of Turag river at Kodda, Gazipur mixed with cowdung at 5:1 ratio and was used as the potting media. Each pot (28 cm in diameter and 23 cm in height) was filled with approximately 8-kg soil leaving upper 3 inches of pot vacant to facilitate watering. The pH of cowdung was 6.7 and the nutrient contents were: organic matter 14.1%, N 0.8%, P 1.26%, K 0.88%, Ca 1.55%, Mg 0.82%, S 0.62%, Fe 0.25% and Mn 0.112%. The physical and chemical properties of the soil were presented in Table 1. The soil contained 12 AM (100^{-1} g soil) spores of indigenous mixed AM fungal species and the experiment was conducted under unsterilized soil condition.

2.2 Soil analysis

Soil pH was measured by a combined glass calomel electrode. Organic carbon was determined by Wet Oxidation Method. Total N was determined by modified Kjeldahl method. Calcium, K and Mg were determined by NH_4OAc extraction method. Copper, Fe, Mn and Zn were determined by DTPA extraction followed by AAS reading. Boron was determined by $CaCl_2$ extraction method. Phosphorus was determined by Modified Olsen method (Neutral + Calcareous soils). Sulphur was determined by $CaH_4(PO_4)_2.H_2O$ extraction followed by turbidimetric method with $BaCl_2$.

2.3 Fertilizer application

Chemical fertilizers @ 11.53 mg N: 9.9 mg P: 11.55 mg K: 6.18 mg S: 0.60 mg Zn: 0.37 mg B: 0.17 mg Mo kg^{-1} soil was applied (BARC, 2012). Urea, TSP, MoP, Gypsum, $ZnSO_4$, Boric acid and Na_2MoO_4 were used as a source of N, P, K, S, Zn, B and Mo, respectively. Total amount of TSP, MoP, Gypsum, $ZnSO_4$, Boric acid, Na_2MoO_4 and half of N was broadcast and incorporated during final pot preparation and remaining N was applied in two equal splits at 15 and 35 days after sowing.

2.4 Preparation of NaCl solution and Mycorrhizal inoculum

Different concentrations of NaCl solution was prepared according to experimental design and 250 mL of each NaCl solution was applied in each pot with irrigation water before sowing of lentil seed. The developed soil salinity was within the range of 1.04 to 3.75 dSm^{-1}.

The AM inoculum was prepared from the roots and rhizosphere soils of sorghum. Mycorrhizal species was originally isolated from different AEZs, using the wet sieving and decanting method (Gerdemann and Nicolson, 1963). The spores were left to multiply for 6 months on sorghum plants using unsterilized soil, collected from the same site, in the net house of Soil Science Division, BARI. Plants were irrigated with tap water as needed. A mixture of infected sorghum root and soil which contained spores was used as mycorrhizal inoculum. The soil based AM fungal inoculum containing 150 g of rhizosphere soil (approximate 209.67 ± 5.5 spores/100 g soil) and infected sorghum root fragments with a minimum infection level was inoculated to each mycorrhizal pot. Figure 1 represents different mycorrhizal spore identified in the Soil Microbiology Laboratory, Soil Science Division, BARI and used for the experiment. The mycorrhizal inoculum were first placed in each pot at 3-5 cm depth and was covered with a thin soil layer of 1 cm immediately prior to the seed sowing of lentil to facilitate fungal colonization of plant roots.

2.5 Design of experiment and treatments

The experiment was designed in factorial RCBD with 10 treatments combination and 4 replications. Twenty seeds were sown in each pot at 1 cm soil depth. The treatment was sustained with 11-14 vigorous seedlings in mycorrhizal and non-mycorrhizal pot and the other seedlings were removed from the pot. The 10 treatment combinations were: T_1: NaCl 0%, T_2: NaCl 0% + AM, T_3: NaCl 1%, T_4: NaCl 1% + AM, T_5: NaCl 2%, T_6: NaCl 2% + AM, T_7: NaCl 3%, T_8: NaCl 3% + AM, T_9: NaCl 4% and T_{10}: NaCl 4% + AM.

2.6 Determination of germination percentage

The germination test was carried out according to International Seed Testing Association (ISTA) rules. For each treatment, 100 seeds were put into Petridishes. The Petridishes were put on a laboratory table at room temperature (25 ± 2°C). After 8 days, normal, abnormal and diseased seeds were counted. Germination of lentil seed in the laboratory table was 85%. Twenty seeds were sown in each pot. After 24 days germinated seeds were observed and counted. Germination percentage was calculated by the following formula:

$$\text{Germination (\%)} = \frac{\text{Number of germinated seeds in each pot}}{\text{Total number of seeds sown in each pot}} \times 100$$

2.7 Crop harvest

Lentil was harvested after 90 days of sowing. After harvesting root parts were cleaned under running tap water and allow for drying at room temperature. Different growth parameters like root length, shoot length and plant height were measured by using centimeter scale. Plant dry weight, total seed weight, 1000-seed weight, seed yield and stover yield were measured by using digital weight balance and pods plant^{-1} were counted by using hand.

2.8 Statistical analysis

Data were statistically analyzed using Analysis of Variance (ANOVA) following CropStat package while the all pair comparisons were done by Statistix 10.

3. Results and Discussion

3.1 Effect of AM inoculation

The effect of mycorrhizal inoculation on seed germination at 24 DAS, root length (cm), shoot length (cm), root + shoot length (cm), plant dry weight (g plant^{-1}), pods plant^{-1}, total seed weight (g plant^{-1}), 1000-seed weight (g), seed yield (g pot^{-1}) and stover yield (g pot^{-1}) at harvest have been presented in Table 2 and Table 3 and Figure 2 and Figure 3.

Table 1. Initial fertility status of the soil samples

Soil Properties	Texture	pH	OM (%)	Ca	Mg	K	Total N (%)	P	S	B	Cu	Fe	Mn	Zn
				meq 100 g^{-1}				µg g^{-1}						
Result	Sandy clay loam	7.6	0.32	6.6	2.3	0.09	0.017	12	25	0.10	1.0	14	1.3	0.85
Critical level	-	-	-	2.0	0.5	0.12	-	10	10	0.20	0.2	4.0	1.0	0.60

Table 2. Effect of AM on germination (%), root length, shoot length and root + shoot length of lentil

Effect of AM	Germination (%) after 24 DAS		Root length		Shoot length		Root + shoot length	
			(cm at harvest)					
	2014-2015	2015-2016	2014-2015	2015-2016	2014-2015	2015-2016	2014-2015	2014-2015
Without AM	72.00b	77.25b	4.45a	5.39b	16.36b	14.83b	20.81b	20.22b
With AM	78.25a	85.50a	5.12a	5.88a	17.19a	17.10a	22.31a	22.98a
SE (±)	1.34	1.44	0.11	0.14	0.27	0.36	0.31	0.45
F test	**	**	**	*	*	**	**	**

AM: Arbuscular mycorrhiza. The values represent means of 04 replicates. Different letters within each column indicate significant differences between treatments. Test CropStat and Statistix 10. **Significant P≤0.01, *significant P≤0.05

Table 3. Effect of AM on plant dry weight, number of pods, total seed weight and 1000-seed weight of lentil

Effect of AM	Plant dry weight (g $plant^{-1}$)		Number of pods $plant^{-1}$		Total seed weight (g $plant^{-1}$)		1000-seed weight (g)	
	2014-2015	2015-2016	2014-2015	2015-2016	2014-2015	2015-2016	2014-2015	2015-2016
Without AM	0.73b	0.55b	15.82b	11.08b	0.34b	0.26b	15.71b	15.21b
With AM	0.95a	0.74a	17.00a	15.09a	0.39a	0.33a	17.73a	16.87a
SE (±)	0.23	0.15	0.40	0.29	0.82	0.76	0.39	0.28
F test	**	**	*	**	**	**	**	**

AM: Arbuscular mycorrhiza. The values represent means of 04 replicates. Different letters within each column indicate significant differences between treatments. Test CropStat and Statistix 10. **Significant P≤0.01, *significant P≤0.05

Table 4. Effect of NaCl on germination (%), root length, shoot length and root + shoot length of lentil

Effect of NaCl	Germination (%) after 24 DAS		Root length (cm at harvest)		Shoot length (cm at harvest)		Root + shoot length (cm at harvest)	
	2014-2015	2015-2016	2014-2015	2015-2016	2014-2015	2015-2016	2014-2015	2015-2016
NaCl 0%	94.38a	90.63a	5.92a	6.53a	17.76a	17.99a	23.68a	24.52a
NaCl 1%	84.38b	85.00ab	5.27b	6.12ab	17.18ab	16.66ab	22.45ab	22.78ab
NaCl 2%	75.63c	81.88bc	4.78bc	5.66bc	16.74abc	15.86bc	21.52bc	21.52bc
NaCl 3%	65.00d	76.88cd	4.31c	5.18cd	16.32bc	14.88c	20.62cd	20.06cd
NaCl 4%	56.25e	72.50d	3.65d	4.70d	15.88c	14.43c	19.53d	19.13d
SE (±)	2.12	2.28	0.17	0.22	0.42	0.56	0.49	0.71
F test	**	**	**	**	*	**	**	**

The values represent means of 04 replicates. Different letters within each column indicate significant differences between treatments. Test CropStat and Statistix 10. **Significant P≤0.01, *significant P≤0.05

Table 5. Effect of NaCl on plant dry weight, no. of pods, total seed weight, and1000-seed weight of lentil

Effect of NaCl	Plant dry weight (g $plant^{-1}$)		Number of pods $plant^{-1}$		Total seed weight (g $plant^{-1}$)		1000-seed weight (g)	
	2014-2015	2015-2016	2014-2015	2015-2016	2014-2015	2015-2016	2014-2015	2015-2016
NaCl 0%	1.04a	0.83a	19.20a	16.98a	0.46a	0.40a	20.18a	17.48a
NaCl 1%	0.92b	0.73b	17.73ab	15.30b	0.42b	0.34b	18.00b	16.95ab
NaCl 2%	0.85bc	0.66c	16.45bc	13.15c	0.37c	0.29c	16.65bc	16.15bc
NaCl 3%	0.76c	0.55d	15.11cd	11.03d	0.32d	0.25d	15.25cd	15.35cd
NaCl 4%	0.65d	0.46e	13.55d	8.98e	0.27e	0.19e	13.53d	14.28d
SE (±)	0.37	0.24	0.63	0.47	0.13	0.12	0.62	0.45
F test	**	**	**	**	**	**	**	**

The values represent means of 04 replicates. Different letters within each column indicate significant differences between treatments. Test CropStat and Statistix 10. **Significant P≤0.01

Table 6. Interaction effect of AM and NaCl on germination (%), root length, shoot length and root + shoot length of lentil

Effect of AM	Germination (%) after 24 DAS	Root length	Shoot length	Root + shoot length
		(cm at harvest)		
2014-2015				
NaCl 0%	92.50	5.48	16.95	22.43
NaCl 0% + AM	96.25	6.35	18.58	24.93
NaCl 1%	83.75	5.00	16.79	21.79
NaCl 1% + AM	85.00	5.55	17.75	23.12
NaCl 2%	71.25	4.49	16.38	20.87
NaCl 2% + AM	80.00	5.07	17.10	22.17
NaCl 3%	58.75	4.01	16.05	20.06
NaCl 3% + AM	71.25	4.60	16.59	21.19
NaCl 4%	53.75	3.25	15.65	18.90
NaCl 4% + AM	58.75	4.05	16.11	20.16
SE (±)	3.00	0.25	0.59	0.70
F test	NS	NS	NS	NS
CV (%)	8.0	10.3	7.1	6.5
2015-2016				
NaCl 0%	88.75	6.29	16.78	23.06
NaCl 0% + AM	92.50	6.78	19.20	25.98
NaCl 1%	81.25	5.90	15.76	21.66
NaCl 1% + AM	88.75	6.35	17.57	23.91
NaCl 2%	77.50	5.54	14.72	20.26
NaCl 2% + AM	86.25	5.78	17.00	22.78
NaCl 3%	71.25	4.92	13.85	18.77
NaCl 3% + AM	82.50	5.44	15.90	21.34
NaCl 4%	67.50	4.33	13.03	17.36
NaCl 4% + AM	77.50	5.08	15.83	20.90
SE (±)	3.23	0.31	0.80	1.00
F test	NS	NS	NS	NS
CV (%)	7.94	10.8	10.0	9.3

AM: Arbuscular mycorrhiza. The values represent means of 04 replicates. Different letters within each column indicate significant differences between treatments. Test CropStat and Statistix 10. NS non significant

Mycorrhizal inoculation significantly increased germination (78.25%) at 24 DAS, root length (5.12 cm), shoot length (17.19 cm), root + shoot length (22.31 cm), plant dry weight (0.95 g plant^{-1}), pods (17 plant^{-1}), total seed weight (0.39 g plant^{-1}), 1000-seed weight (17.73 g), seed yield (4.95 g pot^{-1}) and stover yield (6.87 g pot^{-1}) at harvest in 2014-2015 and germination (85.50%) at 24 DAS, root length (5.88 cm), shoot length (17.10 cm), root + shoot length (22.98 cm), plant dry weight (0.74 g plant^{-1}), pods (15 plant^{-1}), total seed weight (0.33 g plant^{-1}), 1000-seed weight (16.87 g), seed yield (4.30 g pot^{-1}) and stover yield (5.45 g pot^{-1}) at harvest in 2015-2016 (Table 2 and Table 3 and Figure 2 and Figure 3).

3.2 Effect of NaCl

Effects of different concentration of NaCl on lentil have been presented in Table 4 and Table 5 and Figure 4 and Figure 5. Significant differences were found in case of germination

(%) at 24 DAS, root length (cm), shoot length (cm), root + shoot length (cm), plant dry weight (g plant^{-1}), pods plant^{-1}, total seed weight (g plant^{-1}), 1000-seed weight (g), seed yield (g pot^{-1}) and stover yield (g pot^{-1}).

The highest germination (94.38%) at 24 DAS, root length (5.92 cm), shoot length (17.76 cm), root + shoot length (23.68 cm), plant dry weight (1.04 g plant^{-1}), pods (19.20 plant^{-1}), total seed weight (0.46 g plant^{-1}), 1000-seed weight (20.18 g), seed yield (6.62 g pot^{-1}) and stover yield (8.26 g pot^{-1}) in 2014-2015 and germination (90.63%) at 24 DAS, root length (6.53 cm), shoot length (17.99 cm), root + shoot length (24.52 cm), plant dry weight (0.83 g plant^{-1}), pods (16.98 plant^{-1}), total seed weight (0.40 g plant^{-1}), 1000-seed weight (17.48 g), seed yield (5.00 g pot^{-1}) and stover yield (7.03 g pot^{-1}) in 2015-2016 were observed in NaCl 0% treatment (Table 4 and Table 5 and Figure 4 and Figure 5). The lowest germination (56.25%) at 24 DAS, root length (3.65 cm), shoot length (15.88 cm), root + shoot length (19.53 cm), plant dry weight (0.65 g plant^{-1}), pods (13.55 plant^{-1}), total seed weight (0.27 g plant^{-1}), 1000-seed weight (13.53 g), seed yield (2.76 g pot^{-1}) and stover yield (3.67 g pot^{-1}) in 2014-2015 and germination (72.50%) at 24 DAS, root length (4.70 cm), shoot length (14.43 cm), root + shoot length (19.13 cm), plant dry weight (0.46 g plant^{-1}), pods (8.98 plant^{-1}), total seed weight (0.19 g plant^{-1}), 1000-seed weight (14.28 g), seed yield (2.20 g pot^{-1}), and stover yield (2.64 g pot^{-1}) in 2015-2016 were observed in NaCl 4% treatment (Tables 4-5 and Figures 3-4). The highest germination (%) at 24 DAS, root length at harvest, plant dry weight (g plant^{-1}), total seed weight (g plant^{-1}), 1000-seed weight (g), seed yield (g pot^{-1}) and stover yield (g pot^{-1}) in 2014-2015 were found in NaCl 0% level which was significantly higher over all other NaCl levels. In contrast, the highest germination (%) at 24 DAS, root length at harvest (cm), shoot length at harvest (cm), root + shoot length at harvest (cm) and 1000-seed weight (g) in 2015-2016 were found in NaCl 0% level which was significantly higher than NaCl 2%, NaCl 3% and NaCl 4% level but identical to NaCl 1% level. The highest shoot length (cm) in 2014-2015 was found in NaCl 0% level which was significantly higher than NaCl 3% and NaCl 4% level but identical to NaCl 1% and NaCl 2% level and root + shoot length (cm) was found in NaCl 0% level which was significantly higher than NaCl 2%, NaCl 3% and NaCl 4% level but identical to NaCl 1% level. On the other hand, the highest plant dry weight (g plant^{-1}), pod plant^{-1}, total seed weight (g plant^{-1}), seed yield (g pot^{-1}) and stover yield (g pot^{-1}) in 2015-2016 were found in NaCl 0% level which was significantly higher than all other NaCl levels.

3.3 Interaction effects of mycorrhizal inoculation and NaCl

Interaction effects of mycorrhizal inoculation and NaCl on germination (%) at 24 DAS, root length (cm), shoot length (cm), root + shoot length (cm), plant dry weight (g plant^{-1}), pods plant^{-1}, total seed weight (g plant^{-1}), 1000-seed weight (g), seed yield (g pot^{-1}), and stover yield (g pot^{-1}) were appeared to be statistically non-significant (Table 6 and Table 7). This result suggests that mycorrhizal inoculation and NaCl acted independently. Nevertheless, NaCl 0% + AM combinations resulted in higher germination %, growth and yield of lentil. The highest germination (96.25% in 2014-2015 and 92.50% in 2015-2016), seed yield (6.45 g pot^{-1} in 2014-2015 and 5.89 g pot^{-1} in 2015-2016), and stover yield (9.55 g pot^{-1} in 2014-2015 and 8.58 g pot^{-1} in 2015-2016) was found in NaCl 0% + AM treatment. The lowest germination %, seed yield and stover yield was found in NaCl 4% treatment. Mycorrhizal inoculation increased seed yield on an average by 31.85% during 2014-2015 and 63.71% during 2015-2016, and increased stover yield on an average by 48.56% during 2014-2015 and 63.55% during 2015-2016 over non-mycorrhizal inoculation. A non-significant result does not mean that there is no effect of mycorrhizal inoculation and NaCl but it means that there is not sufficient evidence in my dataset to conclude that there is an effect of mycorrhizal inoculation and NaCl.

Table 7. Interaction effect of AM and NaCl on plant dry weight, no. of pods, total seed weight, 1000-seed weight, seed yield and stover yield of lentil

Treatments	Plant dry weight (g plant^{-1})	Number of pods plant^{-1}	Total seed weight (g plant^{-1})	1000-seed weight (g)	Seed yield (g pot^{-1})	Stover yield (g pot^{-1})
2014-2015						
NaCl 0%	0.94	18.35	0.44	18.70	6.19	6.97
NaCl 0% + AM	1.14	20.05	0.48	21.65	6.45	9.55
NaCl 1%	0.82	17.00	0.40	16.70	4.66	5.56
NaCl 1% + AM	1.02	18.45	0.44	19.30	6.01	7.97
NaCl 2%	0.74	15.85	0.35	15.60	3.74	4.61
NaCl 2% + AM	0.96	17.05	0.40	17.70	4.78	6.87
NaCl 3%	0.65	14.85	0.28	14.45	2.70	3.87
NaCl 3% + AM	0.86	15.38	0.36	16.05	4.20	5.24
NaCl 4%	0.51	13.05	0.25	13.1	2.27	2.64
NaCl 4% + AM	0.78	14.05	0.29	13.95	3.24	4.70
SE (±)	0.52	0.89	0.18	0.88	0.29	0.34
F test	NS	NS	NS	NS	NS	NS
CV (%)	12.3	10.8	9.9	10.5	13.2	11.9
2015-2016						
NaCl 0%	0.70	15.15	0.36	16.60	4.12	5.49
NaCl 0% + AM	0.96	18.80	0.44	18.35	5.89	8.58
NaCl 1%	0.64	13.50	0.30	15.95	3.72	4.56
NaCl 1% + AM	0.83	17.10	0.37	17.95	5.15	6.16
NaCl 2%	0.59	10.80	0.27	14.95	2.82	3.36
NaCl 2% + AM	0.74	15.50	0.31	17.35	3.94	4.78
NaCl 3%	0.47	8.55	0.21	14.65	1.98	2.13
NaCl 3% + AM	0.63	13.50	0.29	16.05	3.49	4.35
NaCl 4%	0.35	7.40	0.16	13.90	1.37	1.89
NaCl 4% + AM	0.57	10.55	0.23	14.65	3.03	3.40
SE (±)	0.35	0.66	0.17	0.63	0.19	0.25
F test	NS	NS	NS	NS	NS	NS
CV (%)	10.7	10.1	11.6	7.9	10.6	11.4

AM: Arbuscular mycorrhiza. The values represent means of 04 replicates. Different letters within each column indicate significant differences between treatments. Test CropStat and Statistix 10. NS non significant.

The length of shoot and root decreased with the increasing concentration of NaCl and the results are in accordance with Rohanipoor *et al*. (2013) who also reported decrease in shoot length under salt stress in maize. Ahmad *et al*. (2014) also observed decrease in shoot length with increasing concentration of salt in mulberry. In response to salt stress, reduction in root growth of tomato (Latef and Chaoxing, 2011) and Jatropha curcas (Kumar *et al.,* 2010) has been reported even when the plants were inoculated with the AM fungi. Similar results were also reported by Hajbagheri and Enteshari (2011). In this study, root dry weight increased due to enhance salinity and root fresh weight decreased due to reduced osmotic potential of soil and also due to its low water absorption capacity (Hajbagheri and Enteshari, 2011). Mycorrhizal fungal fibers entering the plants increase cytokinin content resulting in higher water absorption and formation of extensive root system in plants. Other group of fibers presented outside the root system produces organic acids solubilizing phosphorus like malic acid, thereby enhancing phosphorus absorption and hence plant dry matter. Phosphorus plays a crucial role in cellular division by regulating the activity of growth hormones. Growth and biomass inhibition under salt stress is reported by Siddiqui *et al*. (2009) due to high accumulation of NaCl salt. Our results of decreasing plant dry weight correspond to the findings of Ahmad *et al*. (2012) on different cultivars of *Brassica juncea*. Colla *et al.* (2008) reported improved growth, yield, water status, nutrient content and quality of fruits of *Cucurbita pepo* plants colonized by *Glomus intraradices* when exposed to salinity stress. Therefore, enhanced growth of arbuscular mycorrhizal plants has been partly attributed to mycorrhizae mediated nutrient acquisition, especially better P nutrition within the soil plant system.

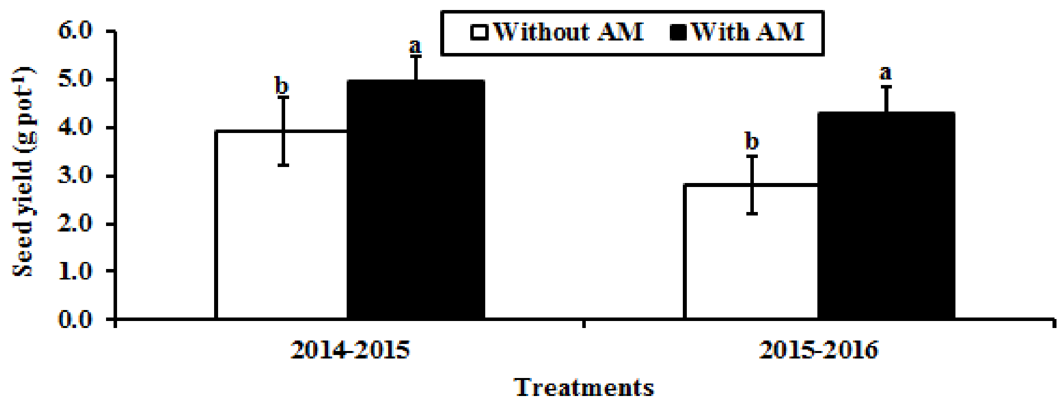

Figure 2. Effect of AM on seed yield (g pot^{-1}) of lentil

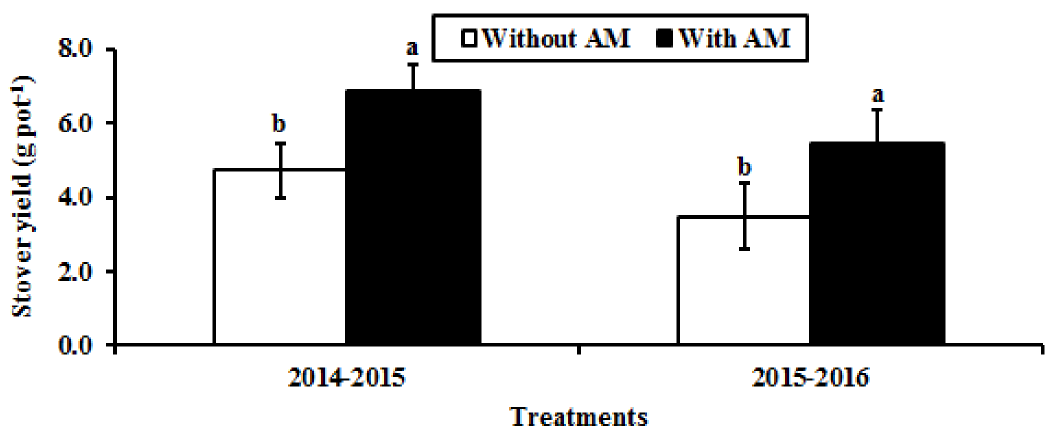

Figure 3. Effect of AM on stover yield (g pot^{-1}) of lentil

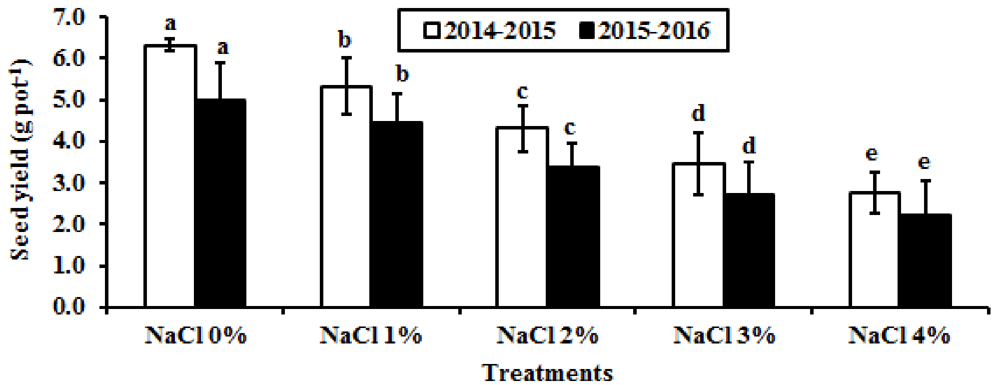

Figure 4. Effect of NaCl on seed yield (g pot^{-1}) of lentil

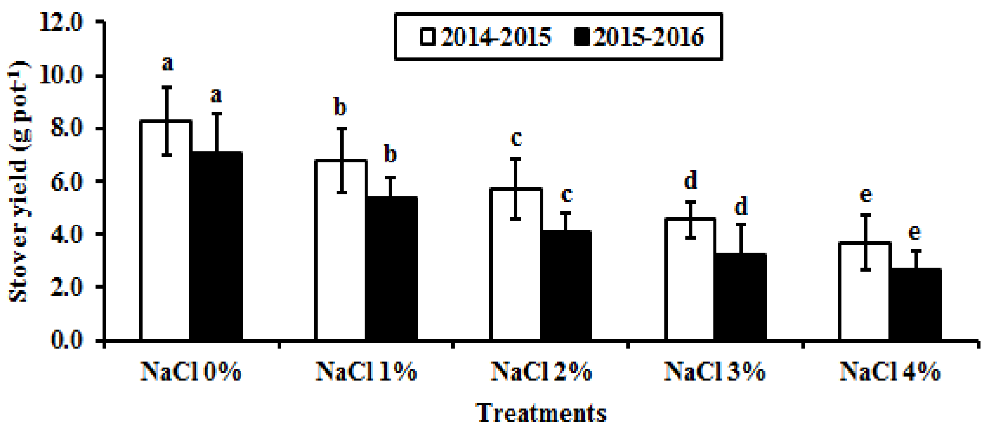

Figure 5. Effect of NaCl on stover yield (g pot^{-1}) of lentil

Plants inoculated with AM have been reported to improve plant growth and yield even under stress conditions (Wu *et al*., 2010; Alqarawi *et al*., 2014). Past research showed the higher growth of mycorrhizal plants under salt stress (Zuccarini and Okurowska, 2008). Hajbagheri and Enteshari (2011) reported maximum plant growth and biomass under salt stress. Ashoori *et al*. (2015) observed that mycorrhizal *Ocimum basilicum* plants in saline conditions showed better growth than non-inoculated plants. The results of Hashem *et al*. (2015) confirmed that NaCl imposes threat to the survival of tomato plants and application of AM mitigates the negative effect to an appreciable level. Phosphorus limits plant growth due to its poor mobility in the soil. However, its increased availability due to AM fungi symbiosis with the host plant has been reported to enhance plant growth and biomass. Ying-Ning *et al*. (2013) observed that citrus plants inoculated with AM overcome the adverse effects of NaCl stress.

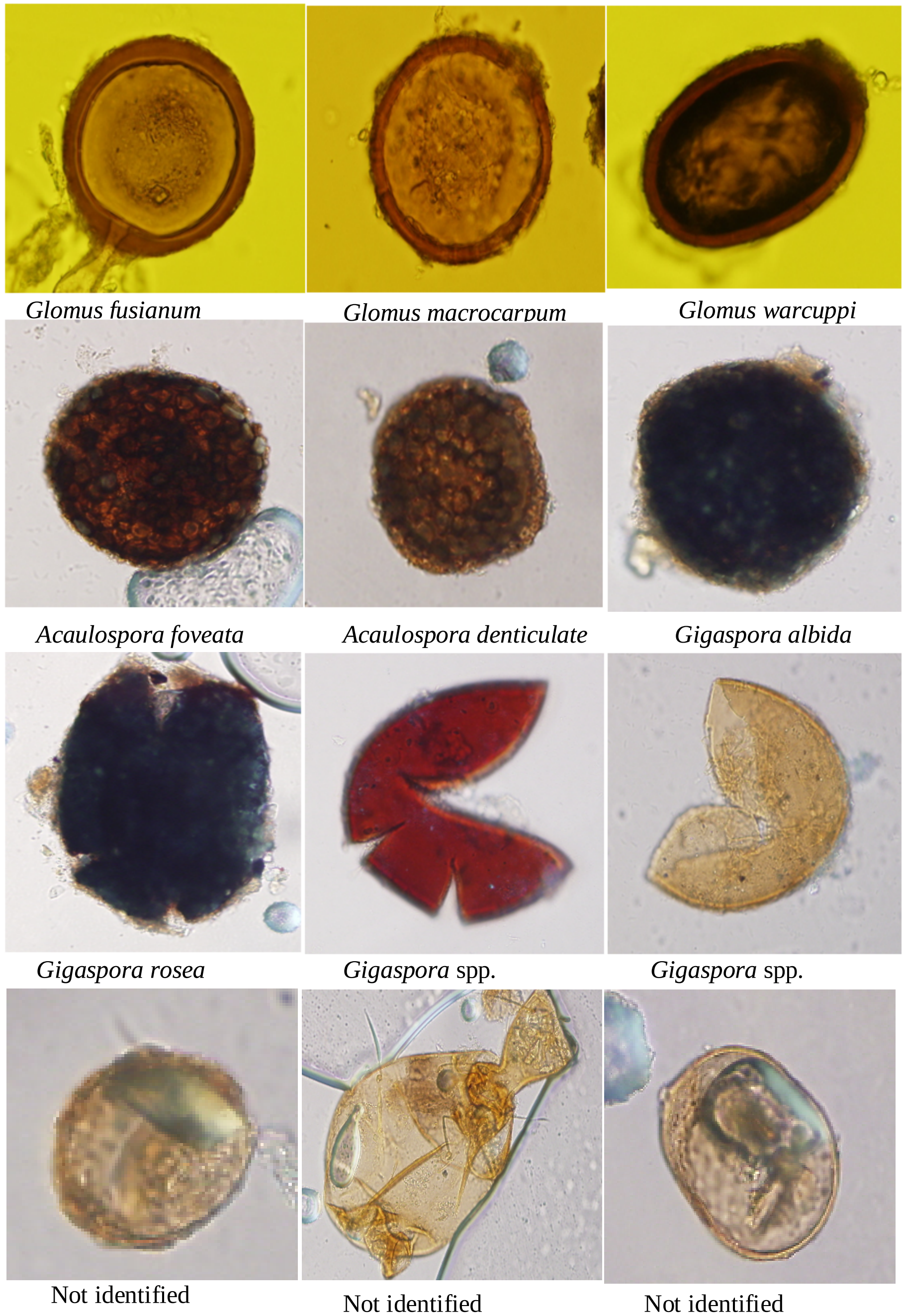

Figure 1. Different mycorrhizal spore identified in the Soil Microbiology Laboratory, Soil Science Division, BARI and used for the experiment

The work of Yamato *et al*., 2008 and those of Daei *et al*., 2009 showed that AM fungi can grow naturally in various saline environments where they can improve plant growth. Application of NaCl significantly reduced growth responses, flower parameters, mineral contents, and levels of mycorrhizal colonization of mycorrhizal and non-mycorrhizal kalanchoe plants comparing to control plants, mainly at high concentrations (Abdul-Wasea *et al*., 2014). Several researchers have reported that AM inoculated plants grow better than non-inoculated plants under salt stress (Zuccarini and Okurowska, 2008). Therefore, the enhanced growth of AM fungi treated plants is due to adequate supply of mineral nutrients, particularly phosphorous, increase in surface area for absorption which is mediated by profound branching of mycorrhizal hyphae and help uptake of water from soil with low water potential.

4. Conclusions

Results of the experiment revealed that mycorrhizal plants showed better performance in terms of lentil seed germination (%) at 24 DAS, growth parameters as well as seed and stover yield (g pot^{-1}). With the increase of NaCl concentration, germination (%) at 24 DAS, growth parameters as well as seed and stover yield (g pot^{-1}) decreased significantly. Interaction effects of mycorrhizal inoculation and NaCl on germination %, growth and yield of lentil were appeared to be statistically non-significant. The highest germination (96.25% in 2014-2015 and 92.50% in 2015-2016), seed yield (6.45 g pot^{-1} in 2014-2015 and 5.89 g pot^{-1} in 2015-2016), and stover yield (9.55 g pot^{-1} in 2014-2015 and 8.58 g pot^{-1} in 2015-2016) was found in NaCl 0% + AM treatment. The lowest germination %, seed yield and stover yield was found in NaCl 4% treatment. Mycorrhizal inoculation increased seed yield on an average by 31.85% during 2014-2015 and 63.71% during 2015-2016, and increased stover yield on an average by 48.56% during 2014-2015 and 63.55% during 2015-2016 over non-mycorrhizal inoculation. Although, NaCl uptake and chemical transformation by seedlings were not tested in this study, these findings gave an indication that the use of effective AM inoculants may help the host plants in increasing overall above ground productivity and plant establishment. Further, research efforts should be oriented to know the direct or indirect relationship of AM and NaCl with belowground and above-ground community via plants. Conclusively, efforts should be made in such a way for improving the quality of AM as a complete commercial supplement for lentil in saline areas which have the potential to reclaim a saline soil owing to enhancement of productivity for a sustainable agriculture as well as a green, safe and food secure world.

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