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Studies on Nutrient Acquisition by Mycorrhizal Plants at Various Levels of Induced Sodicity

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Abstract

The role of AM (Arbuscular mycorrhizal) fungi in the rhizosphere of onion at induced salt stress was studied. A pot culture experiment was set up with three levels of salts and six treatments involving mycorrhizal inoculations with host crop as onion. The initial observations of the soil physico-chemical analysis on comparison with postharvest soil revealed that there was significant difference in nutrient availability as well as uptake by the plants. The percentage increase in nutrient contents over control was observed to be the highest in treatments with Glomus intraradices and Scutellospora calospora. Interestingly the native isolate from Trichy sodic soil was found to be on par with the standard isolates which made the study to render a valuable finding and the reasons are also discussed.

Keywords

Mycorrhiza, Glomus, Scutellospora, Onion, Rhizosphere

Introduction

The beginning of twenty first century is marked by environmental pollution and increased salinization of soil and water. Crops grown on saline soils suffer due to high osmotic stress, nutritional disorders and toxicities, poor soil physical conditions and reduced crop productivity. The direct effects of salt on plant growth may involve physiological drought, toxicity of excessive Na⁺ and Cl⁻ ions and nutrient imbalance of soil solution as well as in the plant caused by nutrient uptake and/or transport to the shoot leading to ion deficiencies (Marschner, 1995).

Arbuscular mycorrhziae
development frequently leads to increased plant uptake of P and several micro nutrients through an increased exploitation of the soil volume. An increased exploitation is especially important for the uptake of less mobile nutrients like P, Zn and Cu. In mycorrhizal plants, the uptake rate of P per unit root length is two to three times higher than in non-mycorrhizal plants (McGonigle and Fitter, 1988). AM fungi, by their adequate supply of P enables the plants to thrive under stress conditions (Barea et al., 1992). Improved salt tolerance due to inoculation of *Glomus mosseae* (AM fungi) in tomato was proved by Al-karaki (2000) along with better mineral nutrition, particularly phosphorus at various levels of salt stress than the non-mycorrhizal tomatoes. Aliasgharzadeh et al., (2001) evaluated the distribution of arbuscular mycorrhizal fungi in the Tabriz plain, where soil salinity levels ranged from 7.3 – 9.2 dSm⁻¹ and observed a close correlation lied between root colonization, and spore density with available P in soil. The concentration of nutrients (P, Zn, and Cu) decreased with the increasing levels of salinity, but were higher than those of the non-mycorrhizal plants. Also, in mycorrhizal plants Na concentration were found to get lowered as salinity levels increased (Giri et al., 2007). Turkmen et al., (2008) studied the effect of two mycorrhizal genus *G. intraradices* and *Gigaspora margarita* on growth and nutrient contents of pepper seedlings grown under moderate salt stress (7.5 ppm NaCl) and observed that plant growth parameters and nutrient contents (P, K, Ca and Na) had positive effects in tolerating salinity and on comparison, the performance of *G. intraradices* was found to be better than that of *G. margarita*. Mycorrhizal inoculations have shown to reduce the Na uptake and increased the K uptake in leaves of lettuce, increasing the salinity tolerance of the plants (Kohler et al., 2010).

Among various environmental stresses, soil salinity is one of the most devastating, which causes major reductions in cultivated land area, crop productivity and quality (Shahbaz and Ashraf, 2013). However, the need for enhancing the crop productivity is inevitable to feed the fast growing population.

This paper deals with the augmentation of nutrient uptake in plants under salt stress conditions by colonization of the AM fungi in the rhizosphere of onion. The use of biofertilizers can mitigate salinity effects on vegetables and reduce soil salinization by enhancing the nutrient status, growth and yield of the plants by either replacing soil nutrients, by making nutrients more available to plants, and/or by increasing plant access to nutrients. For e.g. the endomycorrhizal fungi Arbuscular mycorrhiza, improve plant growth and nutrient uptake (*viz.*, Phosphorus, Nitrogen, Zinc, and Copper) in plants and are beneficial in the biological management of biotic and abiotic stress (Sanjoy kumar et al., 2011).

Also they aggregate soil particles (due to production of Glomalin protein through their hyphae) which is another lag in saline soil and thereby impart tolerance to salt stress. Biofertilizers can reduce soil salinization by reducing application of fertilizers, improving soil fertility by fixing atmospheric N, both in association with plant roots and independent of roots, solubilizing insoluble soil phosphates and producing plant growth substances in the soil (Machado and Serralheiro, 2017). Here comes the need of the study, to understand better about the salinity tolerance of AM plants.

With this background, a study was taken up with the objective to evaluate the effect of AM fungal isolates at various levels of salinity in onion through a pot culture experiment.
Materials and Methods

A pot culture study was taken up to analyze the influence of AM inoculation in salinity tolerance in Onion. Pots of 12 Kg capacity were filled with sterilized pot mix soil followed by AM inoculation @ 50 g -1 pot. Screened isolates of AM (TRY 1, TRY 2, TRY 3 and TFS 1) along with two standard cultures (G. intraradices and S. calospora) were used as inoculants while control was maintained without AM inoculation with salt treatment alone. Onion bulbs were planted (4-5 bulbs pot -1) and then subjected to three levels of salinity (1.5, 3.0 and 4.5 dSm -1) by addition of NaCl through irrigation water twice in a week. All the treatments were replicated three times in a completely randomized design.

Treatments

Inoculants:

T1 -  Glomus intraradices
T2 -  Scutellospora calospora
T3 -  TRY 1 (Acaulospora sp.)
T4 -  TRY 2 (Scutellospora sp.)
T5 -  TRY 3 (Glomus sp.)
T6 -  TFS 1 (Glomus sp.)
T7 -  Control (NaCl alone)

Salinity Levels

L 1 - 1.5 dSm -1
L 2 - 3.0 dSm -1
L 3 - 4.5 dSm -1

Observations

Analysis of plant nutrients

The plant samples were collected at 45 DAS as well as at harvest and analysed for the nutrient contents in the plants. The methodologies followed are represented in table below. Standard methodologies for the analysis of plant samples

| S. No. | Parameter | Unit | Method | Reference |
|-------|-----------|------|--------|-----------|
| 1.    | Total nitrogen | per cent | Diacid extract (prepared by mixing H2SO4: HClO4 @ 5:2) - semi automatic Kjeldahl distillation | Humphries (1956) |
| 2.    | Total phosphorous | per cent | Triacid extract - Vanadomolybdate colorimetric method | Jackson (1973) |
| 3.    | Total potassium | per cent | Triacid extract - Flame photometer | Jackson (1973) |
| 4.    | Micronutrients | ppm | Triacid extract – Atomic Absorption Spectroscopy | USEPA (1979) |
| 5.    | Sodium | per cent | Triacid extract - Flame photometer | Jackson (1973) |

Computation of nutrient uptake

Dry matter productions at different stages were recorded for each plant. The quantity of element taken by the plant was obtained by multiplying the dry weight with that of nutrient content.

Statistical analysis

The data were subjected to statistical analysis by variance (P=0.05) with mean separation by Least significant difference (LSD) as per the methods detailed by the Panse and Sukhatme (1978). The analysis for microbial population
count was based on the log and arcsine transformed values.

Results and Discussion

Nutrient uptake

The status of nutrients in this study revealed that, uptake of nutrients significantly increased in mycorrhizal treatments but the uptake was found to decrease with increase in salt levels in all the treatments (Table 1). As like nitrogen uptake, phosphorus uptake was also found to be higher at harvest. At harvest, there was an overall increase in uptake of phosphorus and the highest was in *G. intraradices* followed by *S. calospora* inoculation (Table 2). Table 3 shows the uptake of potassium with gradual decrease on salt increments, still with a steady increase with respect to growth stage where, the maximum was at harvest in *G. intraradices* followed by *S. calospora* (Fig. 1).

Micronutrient uptake

The micronutrient content was read in plant samples at 45 DAS and harvest while the uptake was higher at harvest. Mycorrhizal treatments influenced the uptake of iron, copper and zinc, among which, same significant difference was observed between the treatments. The uptake was maximum at L1 (1.5 dSm\(^{-1}\)) in all the treatments. *G. intraradices* showed the maximum of 14.51, 1.63 and 3.71 mg plant\(^{-1}\) of iron, copper and zinc respectively (Table 4a, 4b, 4c) but the latter was not significant within the interactions. With the increase in salt levels, all the nutrients were found to be decreased recording the least at L3 (4.5 dSm\(^{-1}\)).

Sodium

Treatments with AM fungal inoculation showed comparatively reduced uptake of sodium than the control. The uptake of sodium was maximum at harvest and was found to be increased with increments in salt levels. All the treatments showed reduced uptake when compared to the control plants. Treatment with *G. intraradices* marked the least (17.26, 20.12 and 21.07 mg plant\(^{-1}\) at L1, L2 and L3 respectively) followed by *S. calospora* (18.26, 20.35 and 21.33 mg plant\(^{-1}\) at L1, L2 and L3 respectively) (Table 5).

Available nutrient status on soil

The available nitrogen content in soil was analysed at two stages of crop growth and the treatments showed significant increase at both stages when compared to control. At L1 (1.5 dSm\(^{-1}\)), treatments inoculated with *S. calospora* and *G. intraradices* recorded the highest of 249.0 and 248.0 kg ha\(^{-1}\) (Table 6). The availability of phosphorus was significantly influenced by AM fungal inoculation in each level of salt than in control. Treatments with *G. intraradices* and *S. calospora* showed availability of 17.30 and 16.40 kg P ha\(^{-1}\) (with 63.8 and 61.0 per cent increase over control respectively) (Table 7). Mycorrhizal inoculation significantly influenced the availability of potassium but it was not significant with respect the salt levels and interactions. Among the treatments, *G. intraradices* ranked high with 165.0 kg K ha\(^{-1}\) followed by *S. calospora* with 164.0 kg K ha\(^{-1}\) at L1 (1.5 dSm\(^{-1}\)) (Table 8).

Available micronutrient contents

The soil micronutrient contents were found to be decreased with increase in salt levels as well as with stages of plant growth and the nutrient availability were statistically non significant under the interaction between the treatments and salt levels. Among the three salt levels, soils with L1 (1.5 dSm\(^{-1}\)) accumulated higher micronutrients both at 45 DAS and at harvest.
Table 1 Effect of AM fungal isolates on nitrogen uptake in Onion against various levels of salinity

| S.No | Treatments       | Nitrogen uptake (mg plant⁻¹) | 45 DAS | Mean     | Per cent increase over control | At harvest | Mean     | Per cent increase over control |
|------|------------------|-----------------------------|--------|----------|--------------------------------|------------|----------|--------------------------------|
|      |                  |                             | L1     | L2       | L3                             | L1         | L2       | L3                             |
| 1.   | *G. intraradices*|                             |        |          |                                |            |          |                                |
|      |                  |                             | 20.13  | 15.78    | 13.48                          | 16.46      | 230.6    | 56.31                          | 50.15      | 43.48    | 49.98                          | 178.3      |
|      |                  |                             | (178)  | (222.0)  | (378.0)                        |            | (160.45)| (178.3)                        | (205.5)    | (203.3)  | (178.3)                        |            |
| 2.   | *S. calospora*   |                             | 20.03  | 15.68    | 12.01                          | 15.91      | 219.4    | 53.96                          | 46.35      | 43.16    | 47.82                          | 166.3      |
|      |                  |                             | (177.4)| (220.0)  | (325.8)                        |            | (149.5)| (157.2)                        | (203.3)    | (176.0)  | (157.2)                        |            |
| 3.   | TRY 1            |                             | 12.50  | 9.76     | 6.52                           | 9.59       | 92.6     | 37.91                          | 34.26      | 29.77    | 33.98                          | 89.2       |
| 4.   | TRY 2            |                             | 11.83  | 8.11     | 7.30                           | 9.08       | 82.3     | 42.93                          | 39.43      | 32.58    | 38.31                          | 113.3      |
| 5.   | TRY 3            |                             | 15.82  | 12.62    | 10.87                          | 13.10      | 163.1    | 47.80                          | 43.8       | 39.28    | 43.62                          | 142.9      |
|      |                  |                             | (119.1)| (157.5)  | (285.4)                        |            | (121.0)| (143.0)                        | (176.0)    | (176.0)  | (157.2)                        |            |
| 6.   | TFS 1            |                             | 11.42  | 8.90     | 7.10                           | 9.14       | 83.5     | 40.57                          | 37.58      | 30.65    | 36.27                          | 101.9      |
| 7.   | Control          |                             | 7.22   | 4.90     | 2.82                           | 4.98       | -        | 21.62                          | 18.02      | 14.23    | 17.96                          | -          |
|      |                  |                             | Mean   | 14.14    | 10.82                          | 8.59       | 11.18    | 43.01                          | 38.51      | 33.31    | 38.28                          |            |
|      |                  | SEd                         | 0.23   | 0.15     | 0.41                           | 0.48       | 0.31     | 0.83                           | 0.57       | 0.37     | 0.98                           | 1.15       |
|      |                  | CD (0.05)                   |        |          |                                |            |          |                                |            |          |                                |            |

Values represent mean of three replicates L1 – 1.5 dSm⁻¹; L2 - 3.0 dSm⁻¹; L3 – 4.5 dSm⁻¹

DAS – Days after sowing.

*G. intraradices* - *Glomus intraradices*
*S. calospora* - *Scutellospora calospora*
TRY 1 - *Acaulospora* sp
TRY 3 - *Glomus mosseae*
TRY 2 - *Scutellospora* sp
TFS 1 - *Glomus aggregatum*
Table 2: Effect of AM fungal isolates on phosphorus uptake in Onion against various levels of salinity

| S.No | Treatments       | 45 DAS | Mean | Per cent increase over control | At harvest | Mean | Per cent increase over control |
|------|------------------|--------|------|--------------------------------|------------|------|--------------------------------|
|      |                  | L1     | L2   | L3                             | L1         | L2   | L3                             | L1        | L2              | L3        |
| 1.   | *G. intraradices*| 7.24   | 6.27 | 6.04                           | 6.52       | 144.1| 19.70                         | (128.4)   | 18.94           | 17.88     | 18.84          | 101.2     |
| 2.   | *S. calospora*   | 6.85   | 6.34 | 5.16                           | 6.12       | 129.1| 17.11                         | (116.1)   | 17.25           | 16.85     | 17.07          | 82.4      |
| 3.   | TRY 1            | 4.52   | 4.15 | 3.48                           | 4.05       | 51.7 | 15.01                         | (49.2)    | 13.33           | 11.27     | 13.20          | 41.1      |
| 4    | TRY 2            | 3.51   | 3.15 | 3.92                           | 3.53       | 32.1 | 13.56                         | (3.9)     | 11.71           | 10.92     | 12.06          | 28.9      |
| 5.   | TRY 3            | 4.73   | 4.58 | 4.18                           | 4.50       | 68.4 | 14.27                         | (92.6)    | 13.82           | 11.48     | 13.19          | 40.9      |
| 6.   | TFS 1            | 4.19   | 3.13 | 2.93                           | 3.42       | 28.0 | 13.28                         | (3.96)    | 12.6            | 10.84     | 12.24          | 30.8      |
| 7.   | Control          | 3.17   | 2.68 | 2.17                           | 2.67       | -    | 10.85                         | (4.09)    | 9.4             | 7.83      | 9.36           | -         |
| Mean |                  | 4.89   | 4.33 | 3.98                           | 4.40       | 14.82| 13.86                         |          | 12.44           | 13.70     |                |           |

Values represent mean of three replicates; L1 – 1.5 dSm⁻¹; L2 - 3.0 dSm⁻¹; L3 – 4.5 dSm⁻¹

DAS – Days after sowing; Value in paranthesis indicate per cent increase over control

*G. intraradices* - *Glomus intraradices*
*S. calospora* - *Scutellospora calospora*
TRY 1- *Acaulospora* sp
TRY 2- *Glomus mosseae*
TRY 2- *Scutellospora* sp.
TFS 1- *Glomus aggregatum*
### Table 3: Effect of AM fungal isolates on potassium uptake in Onion against various levels of salinity

| S.No | Treatments       | Potassium uptake (mg plant⁻¹) | 45 DAS Mean | Per cent increase over control | At harvest Mean | Per cent increase over control |
|------|------------------|--------------------------------|-------------|--------------------------------|-----------------|--------------------------------|
|      |                  |                                | L1          | L2                            | L3              |                                |
| 1.   | *G. intraradices*|                                | 43.95 (207.1)| 34.81 (246.7)                | 29.8 (398.3)    | 36.19                          | 257.9 | 88.12 (405.3) | 78.32 (471.2) | 68.48 (434.1) | 78.31 | 434.2 |
| 2.   | *S. calospora*   |                                | 39.31 (174.7)| 32.97 (228.4)                | 25.21 (321.6)   | 32.50                          | 221.4 | 84.86 (386.6) | 74.38 (442.5) | 64.33 (401.8) | 74.52 | 408.3 |
| 3.   | TRY 1            |                                | 23.24        | 18.17                         | 12.4            | 17.94                          | 77.4  | 50.22         | 46.67          | 40.85          | 45.91 | 213.2 |
| 4.   | TRY 2            |                                | 22.02        | 15.6                          | 14.25           | 17.29                          | 71.0  | 53.66         | 49.78          | 41.35          | 48.26 | 229.2 |
| 5.   | TRY 3            |                                | 28.73 (100.7)| 24.31 (142.1)                | 21.32 (256.5)   | 24.79                          | 145.2 | 60.02 (244.1) | 54.85 (300.0)  | 48.07 (275.0)  | 54.31 | 270.5 |
| 6.   | TFS 1            |                                | 19.38        | 15.64                         | 13.06           | 16.03                          | 58.5  | 50.51         | 35.38          | 23.17          | 36.35 | 148.0 |
| 7.   | Control          |                                | 14.31        | 10.04                         | 5.98            | 10.11                          | -     | 17.44         | 13.71          | 12.82          | 14.66 | -     |
|      | **Mean**         |                                | 27.28        | 21.65                         | 17.43           | 22.12                          | -     | 57.83         | 50.44          | 42.72          | 50.33 | -     |

|       | SEd              | CD (0.05)                      | SEd          | CD (0.05)                      |
|-------|------------------|--------------------------------|--------------|--------------------------------|
| T     | 0.51             | 1.04                           | 1.13         | 2.29                           |
| L     | 0.33             | 0.68                           | 0.74         | 1.50                           |
| T x L | 0.89             | 1.80                           | 1.96         | 3.97                           |

Values represent mean of three replicates; L1 – 1.5 dSm⁻¹; L2 – 3.0 dSm⁻¹; L3 – 4.5 dSm⁻¹

DAS – Days after sowing; Value in paranthesis indicate per cent increase over control

*G. intraradices* - *Glomus intraradices*

*S. calospora* - *Scutellospora calospora*

TRY 1 - *Acaulospora* sp

TRY 3 - *Glomus mosseae*

TRY 2 - *Scutellospora* sp.

TFS 1 - *Glomus aggregatum*
### Table 4a Effect of AM fungal isolates on iron uptake in Onion against various levels of salinity

| S.No | Treatments         | Iron uptake (mg plant⁻¹) |   |   |   |   |   |   |
|------|--------------------|--------------------------|---|---|---|---|---|---|
|      |                    | 45 DAS                   | Mean | At harvest | Mean |   |   |   |
|      |                    | L1 | L2 | L3 | L1 | L2 | L3 |   |   |
| 1.   | G. intraradices    | 11.90 | 8.84 | 5.70 | 8.81 | 14.51 | 12.24 | 8.33 | 11.70 |
| 2.   | S. calospora       | 11.91 | 7.68 | 5.30 | 8.30 | 13.70 | 10.87 | 8.40 | 11.00 |
| 3.   | TRY 1              | 10.17 | 7.22 | 4.48 | 7.29 | 10.94 | 7.52 | 6.24 | 8.23 |
| 4.   | TRY 2              | 10.23 | 7.25 | 4.57 | 7.35 | 12.59 | 7.47 | 6.15 | 8.74 |
| 5.   | TRY 3              | 10.50 | 7.64 | 4.77 | 7.64 | 14.83 | 9.35 | 6.58 | 10.25 |
| 6.   | TFS 1              | 9.42 | 6.94 | 4.38 | 6.91 | 12.09 | 7.90 | 5.54 | 8.51 |
| 7.   | Control            | 9.11 | 5.68 | 4.08 | 6.29 | 10.68 | 7.92 | 5.07 | 7.89 |
|      | Mean               | 10.46 | 7.32 | 4.75 | 7.51 | 12.76 | 9.04 | 6.62 | 9.47 |
|      | SEd                | 0.127 | 0.083 | 0.220 | 0.256 | 0.168 | 0.444 | 0.160 | 0.277 | 0.323 | 0.560 |
|      | CD (0.05)          | 0.323 | 0.211 | 0.560 |

L1 – 1.5 dSm⁻¹; L2 - 3.0 dSm⁻¹; L3 – 4.5 dSm⁻¹; DAS – Days after sowing Values represent mean of three replicates; Value in paranthesis indicate per cent increase over control

*G. intraradices* - *Glomus intraradices*
*S. calospora* - *Scutellospora calospora*
TRY 1 - *Acaulospora* sp
TRY 3 - *Glomus mosseae*
TRY 2 - *Scutellospora* sp.
TFS 1 - *Glomus aggregatum*
**Table 4b** Effect of AM fungal isolates on copper uptake in Onion against various levels of salinity

| S.No. | Treatments      | Copper uptake (mg plant^-1) | 45 DAS          | Mean      | At harvest | Mean |
|-------|-----------------|----------------------------|------------------|-----------|------------|------|
|       |                 |                            | L1   | L2   | L3   | L1   | L2   | L3   | Mean |
| 1.    | G. intraradices |                            | 0.68 | 0.48 | 0.23 | 0.46 | 1.63 | 1.10 | 0.43 | 1.05 |
| 2.    | S. calospora    |                            | 0.64 | 0.45 | 0.24 | 0.44 | 1.51 | 1.05 | 0.43 | 1.00 |
| 3.    | TRY 1           |                            | 0.34 | 0.39 | 0.20 | 0.31 | 1.54 | 0.93 | 0.30 | 0.92 |
| 4.    | TRY 2           |                            | 0.33 | 0.38 | 0.21 | 0.31 | 1.54 | 0.98 | 0.30 | 0.94 |
| 5.    | TRY 3           |                            | 0.42 | 0.38 | 0.19 | 0.33 | 1.54 | 0.98 | 0.38 | 0.97 |
| 6.    | TFS 1           |                            | 0.38 | 0.30 | 0.17 | 0.28 | 1.59 | 1.05 | 0.28 | 0.97 |
| 7.    | Control         |                            | 0.34 | 0.30 | 0.17 | 0.27 | 1.45 | 0.85 | 0.22 | 0.84 |
| Mean  |                 |                            | 0.45 | 0.38 | 0.20 | 0.34 | 1.54 | 0.99 | 0.33 | 0.96 |

|                | SEd  | CD (0.05)  | SEd   | CD (0.05) |
|----------------|------|------------|-------|-----------|
| T      | 0.006| 0.012      | 0.018 | 0.036     |
| L      | 0.004| 0.008      | 0.011 | 0.023     |
| T x L  | 0.011| 0.022      | 0.031 | 0.063     |

Values represent mean of three replicates; L1 – 1.5 dSm^-1; L2 – 3.0 dSm^-1; L3 – 4.5 dSm^-1; DAS – Days after sowing
Value in paranthesis indicate per cent increase over control
G. intraradices - Glomus intraradices
S. calospora - Scutellospora calospora
TRY 1- Acaulospora sp
TRY 3- Glomus mosseae
TRY 2- Scutellospora sp.
TFS 1- Glomus aggregatum
Table 4c Effect of AM fungal isolates on zinc uptake in Onion against various levels of salinity

| S.No. | Treatments | Zinc uptake (mg plant⁻¹) | 45 DAS | Mean | At harvest | Mean |
|-------|------------|--------------------------|--------|-------|------------|-------|
|       |            |                          | L1     | L2    | L3         | L1    | L2    | L3    |       |
| 1.    | G. intraradices | 1.26 | 0.71 | 0.35 | 0.77 | 3.71 | 1.8 | 0.91 | 2.14 |
| 2.    | S. calospora  | 1.22 | 0.67 | 0.33 | 0.74 | 3.57 | 1.6 | 0.98 | 2.05 |
| 3.    | TRY 1       | 1.2  | 0.65 | 0.3  | 0.72 | 2.44 | 1.31 | 0.58 | 1.44 |
| 4.    | TRY 2       | 1.15 | 0.63 | 0.3  | 0.69 | 2.68 | 1.37 | 0.55 | 1.53 |
| 5.    | TRY 3       | 1.2  | 0.65 | 0.31 | 0.72 | 3.13 | 1.57 | 0.82 | 1.84 |
| 6.    | TFS 1       | 1.22 | 0.66 | 0.32 | 0.73 | 2.69 | 1.38 | 0.68 | 1.58 |
| 7.    | Control     | 1.2  | 0.6  | 0.25 | 0.68 | 1.12 | 0.5  | 0.32 | 0.65 |
|       | Mean        | 1.21 | 0.65 | 0.31 | 0.72 | 2.76 | 1.36 | 0.69 | 1.61 |
|       | SEd         |       |       |       |       | 0.031 |       |       |
|       | CD (0.05)   |       |       |       |       | 0.063 |       |       |

L1 – 1.5 dSm⁻¹; L2 - 3.0 dSm⁻¹; L3 – 4.5 dSm⁻¹; DAS – Days after sowing
Values represent mean of three replicates; Value in parenthesis indicate per cent increase over control

G. intraradices - Glomus intraradices
S. calospora - Scutellospora calospora
TRY 1- Acaulospora sp
TRY 3- Glomus mosseae
TRY 2- Scutellospora sp.
TFS 1- Glomus aggregatum
Table 5 Effect of AM fungal isolates on sodium uptake in Onion against various levels of salinity

| S.No. | Treatments   | Sodium uptake (mg plant⁻¹) | 45 DAS | Mean | At harvest | Mean |
|-------|--------------|-----------------------------|--------|------|------------|------|
|       |              | L1  | L2  | L3  | L1  | L2  | L3  | Mean | L1  | L2  | L3  | Mean |
| 1.    | G. intraradices | 12.02 | 13.47 | 17.18 | 14.22 | 17.26 | 20.12 | 21.07 | 19.48 |
| 2.    | S. calospora | 12.31 | 15.20 | 17.72 | 15.08 | 18.26 | 20.35 | 21.33 | 19.98 |
| 3.    | TRY 1 | 13.54 | 14.34 | 17.25 | 15.04 | 16.02 | 21.67 | 23.16 | 20.28 |
| 4.    | TRY 2 | 14.31 | 15.16 | 18.06 | 15.84 | 18.71 | 21.70 | 23.35 | 21.25 |
| 5.    | TRY 3 | 13.15 | 14.71 | 17.21 | 15.02 | 17.02 | 20.03 | 21.68 | 19.66 |
| 6.    | TFS 1 | 15.74 | 17.18 | 18.40 | 16.99 | 19.32 | 22.37 | 23.85 | 21.85 |
| 7.    | Control | 17.33 | 18.14 | 19.90 | 18.45 | 20.54 | 22.71 | 25.52 | 22.92 |
| Mean | 14.00 | 16.00 | 17.96 | 15.81 | 18.16 | 21.28 | 23.11 | 20.85 |

| SEd | CD (0.05) | SEd | CD (0.05) |
|-----|-----------|-----|-----------|
| T  | 0.115     | 0.233 | 0.125 | 0.253 |
| L  | 0.075     | 0.152 | 0.082 | 0.165 |
| T x L | 0.199 | 0.403 | 0.216 | 0.438 |

L1 – 1.5 dSm⁻¹; L2 – 3.0 dSm⁻¹; L3 – 4.5 dSm⁻¹ DAS – Days after sowing
Values represent mean of three replicates; Value in paranthesis indicate per cent increase over control
G. intraradices - Glomus intraradices
S. calospora - Scutellospora calospora
TRY 1- Acaulospora sp
TRY 3- Glomus mosseae
TRY 2- Scutellospora sp.
TFS 1- Glomus aggregatum
Table 6: Effect of AM fungal isolates on available nitrogen in Onion rhizosphere against various levels of salinity

| S.No | Treatments       | Available Nitrogen (kg ha⁻¹) | 45 DAS | Mean | Per cent increase over control | At harvest | Mean | Per cent increase over control |
|------|------------------|------------------------------|--------|------|--------------------------------|------------|------|--------------------------------|
|      |                  |                              | L1     | L2   | L3                            | L1         | L2   | L3                            | L1         | L2   | L3                            | L1   | L2   | L3                            |
| 1.   | *G. intraradices*| 248.0                        | 243.0  | 240.0| 243.7                         | 235.0      | 231.0| 226.0                         | 230.7      | 5.2  |
| 2.   | *Scutellospora* sp.| 249.0                        | 244.0  | 241.0| 244.7                         | 238.0      | 232.0| 227.0                         | 232.3      | 5.9  |
| 3.   | TRY 1            | 245.0                        | 240.0  | 235.0| 240.0                         | 227.0      | 223.0| 220.0                         | 223.3      | 1.8  |
| 4.   | TRY 2            | 240.0                        | 236.0  | 232.0| 236.0                         | 228.0      | 223.0| 221.0                         | 224.0      | 2.1  |
| 5.   | TRY 3            | 242.0                        | 241.0  | 236.0| 239.7                         | 233.0      | 228.0| 225.0                         | 228.7      | 4.3  |
| 6.   | TFS 1            | 240.0                        | 238.0  | 233.0| 237.0                         | 226.0      | 222.0| 218.0                         | 222.0      | 1.2  |
| 7.   | Control          | 239.0                        | 232.0  | 230.0| 233.7                         | 223.0      | 220.0| 215.0                         | 219.3      | 5.2  |
| Mean |                  | 243.3                        | 239.1  | 235.3| 239.2                         | 230.0      | 225.6| 221.7                         | 225.8      |      |

|                  | SEd               | CD (0.05) | SEd | CD (0.05) |
|------------------|-------------------|-----------|-----|-----------|
| T                | 0.266             | 0.539     |     |           |
| L                | 0.174             | 0.353     |     |           |
| T x L            | 0.462             | 0.934     |     |           |

L1 – 1.5 dSm⁻¹; L2 – 3.0 dSm⁻¹; L3 – 4.5 dSm⁻¹, DAS – Days after sowing
Values represent mean of three replicates; Value in parenthesis indicate per cent increase over control

*G. intraradices* - *Glomus intraradices*
*S. calospora* - *Scutellospora calospora*
TRY 1 - *Acaulospora* sp
TRY 3 - *Glomus mosseae*
TRY 2 - *Scutellospora* sp.
TFS 1 - *Glomus aggregatum*
Table 7: Effect of AM fungal isolates on available phosphorus in Onion rhizosphere against various levels of salinity

| S.No. | Treatments      | Available Phosphorus (kg ha⁻¹) | 45 DAS | Mean   | Per cent increase over control | At harvest | Mean   | Per cent increase over control |
|-------|----------------|--------------------------------|--------|-------|--------------------------------|------------|-------|--------------------------------|
|       |                | L1                          | L2     | L3    |                                | L1         | L2    | L3                                |
| 1.    | *G. intraradices* | 17.30 (73.0) | 15.50 (58.1) | 13.40 (57.6) | 15.40 | 63.8 | 16.10 (96.3) | 13.60 (70.0) | 12.60 (75.0) | 14.10 | 80.8 |
| 2.    | *S. calospora* | 16.40 (64.0) | 15.00 (53.0) | 14.00 (64.7) | 15.13 | 61.0 | 15.80 (92.6) | 13.60 (70.0) | 11.80 (63.9) | 13.73 | 76.1 |
| 3.    | TRY 1 | 12.30 | 11.10 | 10.60 | 11.33 | 20.6 | 10.40 | 10.00 | 15.60 | 12.00 | 53.8 |
| 4.    | TRY 2 | 12.30 | 11.80 | 11.10 | 11.73 | 24.8 | 10.50 | 10.00 | 9.80 | 10.10 | 29.5 |
| 5.    | TRY 3 | 13.70 (37.0) | 12.00 (22.45) | 11.10 (30.6) | 12.26 | 30.5 | 11.50 (40.2) | 11.00 (37.5) | 10.20 (41.6) | 10.90 | 39.7 |
| 6.    | TFS 1 | 11.90 | 10.20 | 9.80 | 10.63 | 13.1 | 9.50 | 8.20 | 7.50 | 8.40 | 7.7 |
| 7.    | Control | 10.00 | 9.80 | 8.50 | 9.43 | - | 8.20 | 8.00 | 7.20 | 7.80 | - |
| Mean |                 | 13.41 | 12.20 | 11.21 | 12.27 | - | 11.71 | 10.63 | 10.67 | 11.00 | - |

|          | SEd   | CD (0.05) |          | SEd   | CD (0.05) |
|----------|-------|-----------|----------|-------|-----------|
| T        | 0.12  | 0.24      |          | 0.14  | 0.28      |
| L        | 0.07  | 0.16      |          | 0.09  | 0.18      |
| T x L    | 0.20  | 0.42      |          | 0.24  | 0.49      |

L1 – 1.5 dSm⁻¹; L2 - 3.0 dSm⁻¹; L3 – 4.5 dSm⁻¹, DAS – Days after sowing
Values represent mean of three replicates; Value in paranthesis indicate per cent increase over control
Table 8 Effect of AM fungal isolates on available potassium content in Onion against various levels of salinity

| S.No. | Treatments       | Available Potassium (kg ha⁻¹) | 45 DAS Mean | Per cent Increase over control | At harvest Mean | Per cent increase over control |
|-------|------------------|-------------------------------|-------------|--------------------------------|----------------|--------------------------------|
|       |                  |                               | L1 | L2 | L3 | L1 | L2 | L3 | L1 | L2 | L3 | L1 | L2 | L3 |
| 1.    | *G. intraradices*|                               | 165.0 | 161.0 | 156.0 | 160.7 | 5.0 | 155.0 | 151.0 | 146.0 | 150.7 | 3.7 |
| 2.    | *S. calospora*   |                               | 164.0 | 161.0 | 155.0 | 160.0 | 4.6 | 153.0 | 152.0 | 145.0 | 150.0 | 3.2 |
| 3.    | TRY 1            |                               | 161.0 | 158.0 | 152.0 | 157.0 | 2.6 | 152.0 | 149.0 | 143.0 | 148.0 | 1.9 |
| 4.    | TRY 2            |                               | 162.0 | 156.0 | 152.0 | 156.7 | 2.4 | 153.0 | 149.0 | 142.0 | 148.0 | 1.9 |
| 5.    | TRY 3            |                               | 162.0 | 158.0 | 155.0 | 158.3 | 3.5 | 154.0 | 150.0 | 143.0 | 149.0 | 2.5 |
| 6.    | TFS 1            |                               | 159.0 | 156.0 | 153.0 | 156.0 | 2.0 | 151.0 | 150.0 | 143.0 | 148.0 | 1.9 |
| 7.    | Control          |                               | 157.0 | 152.0 | 150.0 | 153.0 | 5.0 | 150.0 | 146.0 | 140.0 | 145.0 | 3.7 |
|       | Mean             |                               | 161.4 | 157.4 | 153.3 | 157.4 | 5.0 | 152.6 | 149.6 | 143.1 | 148.4 |

SEd CD (0.05)

| T    | 2.60 | 5.27 |
| L    | 1.70 | NS   |
| T x L| 4.52 | NS   |

L1 – 1.5 dSm⁻¹; L2 – 3.0 dSm⁻¹; L3 – 4.5 dSm⁻¹, DAS – Days after sowing
Values represent mean of three replicates; Value in paranthesis indicate per cent increase over control, NS – not significant

*G. intraradices* - *Glomus intraradices*
*S. calospora* - *Scutellospora calospora*
TRY 1- *Acaulospora* sp
TRY 3- *Glomus mosseae*
TRY 2- *Scutellospora* sp.
TFS 1- *Glomus aggregatum*
**Table 9a** Effect of AM fungal isolates on micronutrient (iron) availability in rhizosphere soil of Onion against various levels of salinity

| S. No. | Treatments               | 45 DAS | At harvest |
|--------|--------------------------|--------|------------|
|        |                          | L1     | L2 | L3 | Mean | L1 | L2 | L3 | Mean |
| 1.     | *G. intraradices*        | 6.10   | 5.45 | 5.12 | 5.56 (25.7) | 6.00 | 5.24 | 4.85 | 5.36 |
| 2.     | *S. calospora*           | 6.17   | 5.34 | 5.21 | 5.57 (26.1) | 5.98 | 5.14 | 5.01 | 5.38 |
| 3.     | TRY 1                    | 5.64   | 5.20 | 4.84 | 5.23 (18.3) | 5.50 | 5.04 | 4.55 | 5.03 |
| 4.     | TRY 2                    | 5.75   | 4.93 | 4.65 | 5.11 (15.6) | 5.68 | 5.10 | 4.63 | 5.14 |
| 5.     | TRY 3                    | 5.81   | 5.36 | 4.65 | 5.27 (19.3) | 5.72 | 5.16 | 4.50 | 5.13 |
| 6.     | TFS 1                    | 5.48   | 4.74 | 4.21 | 4.81 (8.8)  | 5.56 | 5.03 | 4.10 | 4.90 |
| 7.     | Control                  | 5.16   | 4.43 | 3.67 | 4.42         | 4.33 | 4.05 | 3.40 | 3.93 |
| **Mean** |                          | 5.73   | 5.06 | 4.62 | 5.14         | 5.54 | 4.97 | 4.43 | 4.98 |

|                  | SEd | CD (0.05) | SEd | CD (0.05) |
|------------------|-----|-----------|-----|-----------|
| T                | 0.03| 0.06      | 0.03| 0.07      |
| L                | 0.02| 0.04      | 0.02| 0.04      |
| TxL              | 0.05| NS        | 0.06| NS        |

L1 – 1.5 dSm\(^{-1}\); L2 - 3.0 dSm\(^{-1}\); L3 – 4.5 dSm\(^{-1}\); DAS – Days after sowing; Values represent mean of three replicates

Values in parenthesis represent per cent increase over control; NS – not significant

*G. intraradices* - *Glomus intraradices*

*S. calospora* - *Scutellospora calospora*

TRY 1 - *Acaulospora* sp

TRY 3 - *Glomus mosseae*

TRY 2 - *Scutellospora* sp.

TFS 1 - *Glomus aggregatum*
Table 9b Effect of AM fungal isolates on micronutrient (copper) availability in rhizosphere soil of Onion against various levels of salinity

| S.No. | Treatments  | 45 DAS | Copper content (ppm) | At harvest | Mean |
|-------|-------------|--------|----------------------|------------|------|
|       |             | L1     | L2     | L3     | Mean | L1     | L2     | L3     | Mean |
| 1.    | G. intraradices | 0.40   | 0.28   | 0.18   | 0.29 (43.3) | 0.36 | 0.25 | 0.13 | 0.25 (54.2) |
| 2.    | S. calospora | 0.40   | 0.30   | 0.19   | 0.30 (48.3) | 0.36 | 0.28 | 0.15 | 0.26 (64.6) |
| 3.    | TRY 1       | 0.30   | 0.22   | 0.15   | 0.22 (11.7) | 0.28 | 0.20 | 0.10 | 0.19 (20.8) |
| 4.    | TRY 2       | 0.30   | 0.22   | 0.16   | 0.23 (13.3) | 0.29 | 0.20 | 0.11 | 0.20 (25.0) |
| 5.    | TRY 3       | 0.31   | 0.24   | 0.16   | 0.24 (18.3) | 0.26 | 0.20 | 0.10 | 0.19 (16.7) |
| 6.    | TFS 1       | 0.28   | 0.22   | 0.15   | 0.22 (8.3) | 0.25 | 0.21 | 0.06 | 0.17 (8.3) |
| 7.    | Control     | Mean   | 0.32   | 0.24   | 0.16   | 0.24 | 0.29 | 0.22 | 0.10 | 0.20 |

|     | SEd         | CD (0.05) | SEd         | CD (0.05) |
|-----|-------------|------------|-------------|------------|
| T   | 0.003       |            | 0.006       |            |
| L   | 0.002       |            | 0.004       |            |
| T x L | 0.005   |            | NS          |            |

L1 – 1.5 dSm⁻¹; L2 - 3.0 dSm⁻¹; L3 – 4.5 dSm⁻¹; DAS – Days after sowing
Values represent mean of three replicates; Value in paranthesis indicate per cent increase over control; NS – not significant

G. intraradices - Glomus intraradices  S. calospora - Scutellospora calospora
TRY 1 - Acaulospora sp  TRY 3 - Glomus mosseae
TRY 2 - Scutellospora sp.  TFS 1 - Glomus aggregatum
| S.No | Treatments       | 45 DAS |            | Mean     |            | At harvest |            | Mean     |            |
|------|-----------------|--------|------------|----------|------------|------------|------------|----------|------------|
|      |                 | L1     | L2         | L3       | Mean       | L1         | L2         | L3       | Mean       |
| 1.   | G. intraradices | 2.68   | 2.55       | 2.35     | 2.53 (63.0)| 2.60       | 2.24       | 1.84     | 2.23 (72.6) |
| 2.   | S. calospora    | 2.66   | 2.34       | 2.20     | 2.40 (54.8)| 2.58       | 2.16       | 1.90     | 2.21 (71.6) |
| 3.   | TRY 1           | 2.48   | 2.20       | 2.01     | 2.23 (43.9)| 2.31       | 2.00       | 1.53     | 1.95 (50.9) |
| 4.   | TRY 2           | 2.60   | 2.22       | 1.95     | 2.26 (45.6)| 2.52       | 1.94       | 1.66     | 2.04 (58.1) |
| 5.   | TRY 3           | 2.64   | 2.35       | 1.95     | 2.31 (49.2)| 2.56       | 2.15       | 1.70     | 2.14 (65.6) |
| 6.   | TFS 1           | 2.40   | 2.11       | 1.74     | 2.08 (34.4)| 2.20       | 2.01       | 1.20     | 1.80 (39.8) |
| 7.   | Control         | 2.07   | 1.57       | 1.01     | 1.55       | 1.76       | 1.27       | 0.83     | 1.29       |
| Mean |                 | 2.50   | 2.19       | 1.89     | 2.19       | 2.36       | 1.97       | 1.52     | 1.95       |
|      | SEd             | 0.02   | 0.01       | 0.03     | 0.04       | 0.02       | 0.02       | 0.04     | 0.05       |

L1 – 1.5 dSm⁻¹; L2 – 3.0 dSm⁻¹; L3 – 4.5 dSm⁻¹; DAS – Days after sowing. Values represent mean of three replicates; Value in paranthesis indicate per cent increase over control; NS – not significant

G. intraradices - Glomus intraradices
S. calospora - Scutellospora calospora
TRY 1- Acaulospora sp
TRY 3- Glomus mosseae
TRY 2- Scutellospora sp.
TFS 1- Glomus aggregatum
Figure 1. Effect of AM fungal isolates on nutrient uptake in onion against various levels of salinity

Treatments

T1 - Glomus intraradices
T2 - Scutellospora calospora
T3 - TRY 1 (Acaulospora sp.)
T4 - TRY 2 (Scutellospora sp.)
T5 - TRY 3 (Glomus mosseae)
T6 - TFS 1 (Glomus aggregatum)
T7 - Control

Levels

L1 - 1.5 dSm⁻¹
L2 - 3.0 dSm⁻¹
L3 - 4.5 dSm⁻¹
Among the micronutrients analysed, iron was higher in soils than copper and zinc. Highest uptake of 6.17 ppm iron was observed in T2 (S. calospora) which was on par with T1 (G. intraradices). The content of copper was highest at L1 (1.5 dSm\(^{-1}\)) in G. intraradices showing 0.40 ppm and was on par with S. calospora inoculation while the zinc contents were maximum in treatments with G. intraradices and S. calospora (2.68 and 2.66 ppm) (Table 9 a,b,c).

In the present study, the mycorrhizal plants showed noticeable increase in uptake of nitrogen than the control. Similar increase in N uptake has been reported in various crops which may be attributed to the contribution of hyphal transport of N in the form of NO\(^3\) or NH\(^4\) (Taylor et al., 1995). The enhanced P status in mycorrhizal plants might have altered the activities of N assimilating enzymes such as nitrate reductase (NR) and nitrate reductase (NIR). Better nutrient acquisition in mycorrhizal lettuce plants has been reported by Azcon et al., (2003) who explained that soil nitrogen (N) and phosphorus (P) levels are considered the most important factors among those, affecting AM association efficiency.

In this study, the uptake was decreasing with respect to increments in salt levels while maximum was observed at L1 (1.5 dSm\(^{-1}\)). At L3 (4.5 dSm\(^{-1}\)), the N uptake was decreased, still where AM inoculated treatments showed better concentrations than the control. This is in agreement with a studies by Rabie and Almadini (2005), who reported that inoculation of faba (Vicia faba) with mycorrhiza caused slight amelioration of nitrogen content and was significantly influenced due to mycorrhizal inoculations at all salinity levels compared to control plant and was reduced by about 64% at high salinity level. Increase in phosphorus uptake was clearly observed at harvest in the present investigation in all the treatments except the control and this can be substantiated with the fact that increase in P uptake is attributed to the hyphal absorption and increased affinity towards ‘P’ due to the presence of PO\(_4\) transporter compounds in the AM colonized roots. Effect of Glomus sp. in enhancing nutrient uptake was reported in a study by Giri et al., (2007) where root and shoot tissues of mycorrhizal plants showed apparently higher concentrations of ‘P’ than non-mycorrhizal plants at all salinity levels. AM fungi have been shown to positively influence the composition of mineral nutrients of plants (especially poor mobility nutrients such as P) (Giri et al., 2003), by increasing tolerance as well as phosphorus availability under soil stress conditions (Sangeeta and Subodh, 2010) and they are directly involved in plant mineral nutrition (Uttam Tripura et al., 2016).

In this study, apart from the decrease in uptake of ‘P’ with increments in salt level, an increase in uptake at each level of salt in the treatments showed the inoculation effect of the AM fungal isolates. Except in the G. intraradices and S. calospora inoculated treatments, the ‘P’ uptake by other isolates was much less comparatively and still decreased at high salinity level (L3 – 4.5 dSm\(^{-1}\)), which may be caused by the toxic effect of Na ions on AM fungal development. A similar decrease in P concentration has been reported earlier (Al-Karaki et al., 2001). It has also been reported that high salt content inhibits the growth of the AM fungal hyphae, which in turn reduced transport of P into roots and its uptake by the plant. (Mc Millen et al., 1998),

The phosphorus uptake is not only related to increased nutrient contents in mycorrhizal plants, but also to maintain plant health. Garg
and Machanda (2009) explained that stress impeded the growth of plants, led to weight gain reductions in shoots as well as roots and nitrogen and phosphorus uptake, however, salt-stressed mycorrhizal plants produced greater root and shoot biomass, had higher phosphorus and nitrogen content than the corresponding uninoculated stressed plants. It is possible that improved plant nutrition by AM fungi allows cells to more effectively regulate and separate flowing ions. Ion pumps in the plasma membrane and tonoplast of root cells that bring about and maintain salt compartmentalization (Larcher, 1980) must be more efficient if the nutrition in the cell remains balanced. Reducing cell-membrane permeability by providing P via AM fungal hyphae to plant cells (particularly root cells) enhances cell structural organization. As cells are able to maintain membrane integrity under saline conditions, it is possible to avoid interference of excessive ions with metabolic processes (e.g., photosynthesis). These mechanisms strongly document that improved P nutrition by AM fungi under saline conditions reduced the negative effects of Na$^+$ and Cl$^-$ by maintaining vacuolar membrane integrity, which prevented these ions from interfering in growth metabolic pathways thereby influencing growth attributes (Cantrell and Lindermann, 2001).

In this study, potassium uptake was maximum at harvest in the G. intraradices and S. calospora treatments. K uptake was also mediated through the hyphal absorption. Increase in the concentration of K in mycorrhizal plants has also been reported previously (Mohammad et al., 2003; Giri et al., 2007) where mycorrhizal plants accumulated a higher concentration of K at all salinity levels. Higher water potentials, along with improved K nutrition by AM fungal in Onion, indicate mechanisms other than increased P nutrition may be important for plants growing under saline stress. These effects appear to be secondary to the effects of AM fungi on P uptake (Poss et al., 1985). It seems that higher K accumulation by mycorrhizal plants under salt stress conditions may help in maintaining a high K/Na ratio, by preventing the disruption of various enzymatic process and inhibition of protein synthesis and thus another important effect of AM fungi, which may be related to salinity tolerance.

In this study, all the treatments were found to enhance the uptake at each level of stress still a gradual decline along with increasing salinity was observed. This concept is supported by some with previous observations also (Shokri and Maadi, 2009). The mycorrhizal K response (MKR) in shoots of Trifolium sp. showed that mycorrhizal effects on K uptake were generally higher at 30 days than at 10 days but decreased with increasing soil salinity at all harvests, although the extent of this difference decreased with increasing salinity between 3.5 and 12 dSm$^{-1}$ (Asghari, 2008). Lower K concentrations in mycorrhizal plants are in accordance with the reduction in root surface and indicate a relatively low hyphal capacity for K delivery.

In the present study, increase in the micronutrient uptake (iron and copper significantly than zinc) was observed in the treatments at all the three levels of salt than the control. Hamel et al., (2000) also recorded increase in micronutrient contents due to inoculation of G. intraradices in Tomato. Giri et al., (2007) reported the effect of AM inoculation in soils, at 1.2, 4.0, and 6.5 dS m$^{-1}$ salinity levels where mycorrhizal plants maintained greater root and shoot biomass at all salinity with higher P, Zn, and Cu concentrations than uninoculated plants. Also, micronutrient uptake by plants was descending along with increase in salinity levels and was lowest at L3, (4.5 dSm$^{-1}$) in this study. These results are in accordance
with Giri et al., (2007) who showed the concentrations of P, Zn, and Cu were higher for mycorrhizal plants, but the magnitude decreased with increasing levels of salinity. A decrease in mycorrhizal colonization due to high soil phosphorus levels can lead to plant deficiencies in other micronutrients (Timmer and Leyden 1980). Though the available nutrients were influenced due to treatments the decrease in root colonization observed in this study may be the reason for such decrease in the uptake of nutrients. The reduced uptake of micronutrients with increase in the salt levels was also reported by Asghari (2008) who reported the difference was nonsignificant between the interactions.

With increasing salinity levels, Na uptake by plants was found to be increased in both mycorrhizal and nonmycorrhizal plants in the present study. AM inoculated plants showed significantly less uptake of sodium than the control at all the levels of salt while significant difference was not observed at high salt, L3 (3.0 dSm\(^{-1}\)) Also Asghari, (2008) showed that at higher salt levels, the root Na concentration in mycorrhizal plants was significantly lower than non-mycorrhizal plants. This increase in plant sodium concentration above a particular stress level shows the intolerance of the inoculated species to high stress leading to interruption and reduced uptake of other essential nutrients at high salt levels.

Similarly, Pfeiffer and Bloss (1988) stated that the major effect of the mycorrhiza on sodium uptake is through mediation of phosphorus accumulation. Other mechanisms that improve salt tolerance may include maintaining membrane integrity (Rinaldelli and Mancuso, 1996) that would facilitate compartmentalization within vacuoles, and selective ion intake. Induction of osmotica could lead to osmotic adjustment (Duke et al., 1986), and improved and balanced nutrition in plants could also increase salt tolerance (Marschner, 1995). Such mechanisms could all involve salt tolerance effects of AM fungi. Among the treatments TFS 1 showed higher sodium contents in plants which may be due to intolerance of this species to survive the stress. Salinity affects the formation and function of mycorrhizal symbiosis (Giri et al., 2003). Mycorrhizal Onion roots generally had greater P, Fe, and Cu Na concentrations (Cantrell and Lindermann, 2001).

In saline conditions, best results were obtained at moderate levels of salinity (3.5-5 dS/m) at 30 days after transplaning (Asghari, 2008). Improved mineral nutrition (Al-Karaki and Al-Raddad, 1997), improved water potential (Marulanda et al., 2003), improved physiological processes (increased carbon dioxide exchange rate, transpiration, stomatal conductance and water use efficiency) (Ruiz-Lozano and Azcón, 2000) are the most important salinity tolerance mechanisms in mycorrhizal plants that have been reported.

In the present study, the soil nutrient status decreased with respect to age of the crop as well as increasing levels of the salt. The availability of nutrients getting lowered at harvest showed the increased uptake by the inoculated plants. The effects of P on soil aggregation may be indirect, as P availability affects shoot and root growth, and increases plant production and ground cover. The availability of P also influences colonization of arbuscular mycorrhizal fungi (AM fungi) (Facelli and Facelli, 2002), which affect root morphology and aggregation. Application of P as fertilizer and phosphoric acid can lead to the formation of \(\text{Al}^{3+}\) or \(\text{Ca}^{2+}\) phosphates, which act as aggregate bonding agents (Haynes and Naidu, 1998).

Also the higher available N:P ratio suggests the promotion in crop growth. A high soil N:P
ratio may promote the establishment of the plants, in association with AM fungi (Eschen et al., 2009). The level of AM fungal colonization of plant roots and its effect on plant growth may vary not only depending on the composition and abundance of the AM fungal species but also the available nutrients (Reynolds et al., 2006). The significant correlations between N:P ratio, P and K concentrations in soil, and the fraction of colonized root length containing arbuscules across aboveground and belowground environment types reported by Blanke et al., (2005) and Eschen et al., (2009) confirmed the results that plants are more likely to encounter circumstances (biotic and abiotic stress conditions) that promote AM fungal colonization and show higher establishment rates.

In the present investigation inoculation due to G. intraradices showed significant increase in micronutrient contents and this is in line with Hamel et al., (1997) who showed inoculation with G. intraradices and G. versiforme responded positive to available nutrient content in soils of Leek plants.

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