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# MYCORRHIZAS AND ORGANIC FERTILIZER ROLE IN MANAGING SOIL PROPERTIES AND MAIZE CROP UNDER SALINE IRRIGATION CONDITIONS

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## SUMMARY

A factorial experiment succeeded in its conduct on maize (*Zea mays* L.) using a completely randomized block design with split-plot arrangement in sandy loam. The different organic fertilizers (control treatment, poultry manure at 10 µg ha$^{-1}$, and Agri M40 fertilizer at 80 L ha$^{-1}$) received the symbols M0, M1, and M2, respectively. The results showed a significant decrease in sodium and chloride concentrations once adding mycorrhizas for treatments F1 and F2. It has reached 16.56 mmol L$^{-1}$ and 15.71 mmol L$^{-1}$, respectively. For chloride concentration, it was 11.68 mmol L$^{-1}$ and 10.80 mmol L$^{-1}$, respectively, compared with the control treatment (F0), which achieved 17.12 for sodium and 12.40 mmol L$^{-1}$. The maize grain yield and nitrogen concentration also increased for the F2 treatment (10.57 µg ha$^{-1}$, 1.68%, 0.48%, and 32.22%). The M2 treatment reached 10.92 µg ha$^{-1}$ grain yield, 1.81% N, 0.57% sodium, and 44.07% chloride, compared with the control treatment (10.25 µg ha$^{-1}$, 1.58%, 0.41%, and 27.78%, respectively). The M2 treatment was superior to treatment M1 in all previous characteristics. The percentage of root infection with mycorrhizae in treatment M1 was 10.57 µg h$^{-1}$, 1.68%, 0.48%, and 32.22%, respectively, and in treatment M2, it was 10.92 µg h$^{-1}$, 1.81%, 0.57%, and 44.07%, respectively, versus the control treatment (10.25 µg h$^{-1}$, 1.58%, 0.41%, and 27.78%, respectively).

**Keywords:** Maize (*Zea mays* L.), mycorrhizas, organic fertilizer, saline irrigation water

**Key findings:** The maize (*Z. mays* L.) grain yield, the concentration of nitrogen in the grains, and the percentage of mycorrhizal infection of the roots had increased for the F2 treatment. It was 10.81 mg ha$^{-1}$, 0.54%, and 55.56%, respectively, compared with the F0 treatment. The F2 treatment was also significantly higher than the F1 treatment in all stated characteristics.

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## INTRODUCTION

For developing the agriculture field by preventing the decline in soil production capacity due to high soil salinity and limited freshwater sources for agriculture, it is necessary to find some techniques that reduce salt-stress impacts and increase nutrient availability. Likewise, these techniques can ensure the optimal use of lands affected by salinity and agricultural farms with a high salt concentration in growing strategic crops.

A technique that reduces the effect of salt stress on available nutrients and plant growth and production is inoculation with mycorrhizal fungi, which increases concentrations of nutrients and the percentage of chlorophyll in plant leaves (Xu *et al.*, 2018). Mycorrhizal fungi also absorb phosphorus from the soil through their hyphae and increase the availability and readiness of other nutrients through their secretion of growth regulators and coexistence with some growth-stimulating bacteria, including nitrogen-fixing bacteria (Nazari *et al.,* 2023).

Mycorrhizae programs achieve both a positive effect in providing plants with nutrients and increased water absorption and plant resistance to environmental stresses, such as heat, drought, and salts. They also reduce the effect of heavy metals and biological stresses through symbiosis with the host plant (Salam *et al*., 2017). Mycorrhizal fungi contribute to enhancing soil health by improving its structure due to binding soil particles together by the fungal hyphae and accelerating the decomposition of organic compounds (Thirkell *et al*., 2017). Mycorrhizae also secrete sticky glycoprotein compounds called glomalin-related, releasing them into the soil as an adhesive that contributes to aggregating soil particles and increasing stability and soil aggregates. Thus, it improves the structure and aeration of the soil and raises its ability to retain water and resist water and wind erosion (Driver *et al*., 2005).

Organic fertilizers are techniques that improve soil physical properties by reducing their bulk density, increasing their porosity, and retaining moisture and temperature. Moreover, they bond with ions to form compounds that are easy to leach away from the root zone. Thus, they reduce the effect of soil salinity and irrigation water and contribute to decreasing osmotic pressure on the roots while improving vital conditions for the growth and effectiveness of microorganisms (Oo *et al.,* 2015). Organic fertilizers also elevate plant productivity and nutrient concentrations in the soil and lessen the degree of their interaction (Naeem *et al.,* 2018). This study aimed to probe salt water in growing maize (*Zea mays* L.) and tried to reduce the effect of salt on soil characteristics, as well as the growth and yield of the plant, through inoculation with mycorrhizas and adding organic fertilizers.

## MATERIALS AND METHODS

The field experiment on maize (*Z. mays* L.) commenced in the fields of the College of Agriculture, Wasit University, Kut District, at longitude 45.842733 North and latitude 32.497105 East. The experiment started on August 5, 2022, by preparing the field before planting by plowing, smoothing, and amending operations (Table 1). The field, as divided into three blocks, had a distance of only 2 m between one block and another. Each block entailed further division into three plots, with the plots divided into nine experimental units, leaving a distance of only 2 m between one plot and another and 0.50 m between one experimental unit and another in one plot. The seeds of *Z. mays* (Ossek 515 F1 cultivar), having been planted, received nitrogen fertilizer at the rate of 150 kg N $ha^{-1}$, phosphorus (75 kg P $ha^{-1}$), and potassium (60 kg K $ha^{-1}$).

The experiment layout was according to a split-split plot, with a completely randomized block design and three replications. The field experiment had three factors. The first factor was water salinity irrigation—irrigation water with three salt concentrations (1.2, 3, and 6 $dSm^{-1}$) and the given symbols S1, S2, and S3, respectively. The second factor was mycorrhizal fungi use at three levels (0, 12, and 24 g), and their

**Table 1.** Some chemical and physical characteristics of the soil before planting.

| Characteristics | Value | Unit/s | |
|---|---|---|---|
| EC (1:1) | 2.82 | $dSm^{-1}$ | |
| pH (1:1) | 7.84 | - | |
| Soluble ions (mmol $L^{-1}$) | | | |
| $Ca^{++}$ | $Mg^{++}$ | $Na^{+}$ | $K^{+}$ |
| 6.70 | 2.60 | 4.35 | 0.84 |
| $SO_4^{-}$ | $Cl^{-}$ | $HCO_3^{-}$ | $CO_3^{=}$ |
| 8.65 | 10 | 0.80 | Nil |
| Macroelements (mg $kg^{-1}$) | | | |
| Nitrogen | Phosphorus | Potassium | |
| 30.50 | 15.49 | 184 | |
| Soil particles (g $kg^{-1}$) | | | |
| Sand | Silt | Clay | |
| 535 | 398 | 59 | |
| Texture | Sandy loam | | |
| Bulk density | 1.2 | 1.2 mg $m^{-3}$ | |

symbols were F0, F1, and F2, respectively, noting that each gram of this fertilizer contained 50 spores. The third factor was the organic fertilization. Poultry manure fertilizer employed had two levels (0 and 10 µg $ha^{-1}$), with symbols M0 and M1. The use of Agri M40 fertilizer also had two levels (0 and 80 L $ha^{-1}$), with symbols M0 and M2. The concentration of sodium and chloride underwent estimation. The grain yield and the concentration of nitrogen in the grains entailed calculation at the end of the experiment.

## RESULTS AND DISCUSSION

### Mycorrhizal inoculation and organics, sodium and chloride, in the soil

#### *Sodium (mmol $L^{-1}$)*

The results showed a significant increase in the concentration of soluble sodium in the soil with increasing saline irrigation water. It had reached 21.94 mmol $L^{-1}$ in S3 compared with S1, which recorded 11.06 mmol $L^{-1}$. However, the concentration decreased to 15.71 mmol $L^{-1}$ when inoculated with the mycorrhizal F2 compared with F0, which was at 17.12 mmol $L^{-1}$ (Table 2). Adding organic fertilizer was effective in reducing the concentration of soluble sodium in the soil from 18.59 mmol $L^{-1}$ in M0 to 14.24 mmol $L^{-1}$ in M2.

The findings revealed notable differences between the values of the two-way interaction between saline irrigation water and mycorrhizal inoculation. The S1F2 recorded the lowest concentration of soluble sodium in the soil solution, 10.70 mmol $L^{-1}$, while the highest concentration was 22.87 mmol $L^{-1}$ in the S3F0 interaction treatment, which reached 22.87 mmol. $L^{-1}$ (Table 2). It is clear that the level of soluble sodium decreased in the treatments when adding organic fertilizer, whether M1 or M2 treatments, with increasing salinity of irrigation water. The combined intervention S1M2 achieved the lowest concentration of sodium ions (9.76 mmol $L^{-1}$) compared with the combined intervention S3M0, which achieved the highest concentration of 25.19 mmol $L^{-1}$.

For the combined interaction between organic fertilizer and mycorrhizal inoculation, the results recorded a decrease in the concentration of soluble sodium in the soil solution with the addition of one or both factors. The lowest value recorded was 13.67 mmol $L^{-1}$ in the M2F2 interaction, while the highest value was 19.21 mmol $L^{-1}$ in M0F0 (Table 2). It is evident from the triple interaction between the study factors that the highest value of 26.70 mmol $L^{-1}$ appeared in the S3M0F0, while the lowest value of 9.56 mmol $L^{-1}$ emerged in the intervention S1M2F2.

#### *Chloride (mmol $L^{-1}$)*

Evidently, an increase in chloride concentration occurred with increasing saline irrigation water. It increased by 89.70% and 189.70% for S2

**Table 2**. Effect of mycorrhizal inoculation and organic fertilizer on sodium concentration (mmol $L^{-1}$) using saline irrigation water.

| Saline irrigation water | Organic fertilizer | Mycorrhizas | | | S*M |
|---|---|---|---|---|---|
| | | F0 | F1 | F2 | |
| S1 | M0 | 12.57 | 12.48 | 12.14 | 12.40 |
| | M1 | 11.78 | 10.88 | 10.41 | 11.02 |
| | M2 | 9.99 | 9.72 | 9.56 | 9.76 |
| S2 | M0 | 18.36 | 18.25 | 17.93 | 18.18 |
| | M1 | 17.72 | 17.41 | 15.67 | 16.93 |
| | M2 | 15.07 | 14.08 | 13.02 | 14.05 |
| S3 | M0 | 26.70 | 25.91 | 22.97 | 25.19 |
| | M1 | 22.16 | 21.75 | 21.25 | 21.72 |
| | M2 | 19.74 | 18.58 | 18.44 | 18.92 |
| LSD $_{S*M*F}$ | | 0.477 | | LSD $_{S*M}$ | 0.297 |
| S*F | | | | | |
| Saline irrigation water | | F0 | F1 | F2 | Average |
| S1 | | 11.45 | 11.03 | 10.70 | 11.06 |
| S2 | | 17.05 | 16.58 | 15.54 | 16.39 |
| S3 | | 22.87 | 22.08 | 20.89 | 21.94 |
| LSD $_{S*F}$ | | 0.291 | | LSD $_{S}$ | 0.238 |
| M*F | | | | | |
| Organic fertilizer | | F0 | F1 | F2 | Average |
| M0 | | 19.21 | 18.88 | 17.68 | 18.59 |
| M1 | | 17.22 | 16.68 | 15.77 | 16.56 |
| M2 | | 14.93 | 14.13 | 13.67 | 14.24 |
| LSD $_{M*F}$ | | 0.273 | | LSD $_{M}$ | 0.169 |
| F | | | | | |
| Mycorrhizas | | F0 | F1 | F2 | |
| Average | | 17.12 | 16.56 | 15.71 | |
| LSD $_{F}$ | | 0.159 | | | |

and S3 treatments, respectively, compared with treatment S1, wherein the chloride concentration reached 6.02 mmol $L^{-1}$ (Table 3). The inoculation with mycorrhizae led to a decrease in the chloride concentration in the soil at harvest. The chloride concentration decreased by 5.80% and 12.90% for the F1 and F2 treatments, respectively, versus the control treatment F0, which achieved the highest chloride concentration of 12.40 mmol $L^{-1}$.

The results further showed a significant decrease in chloride concentration when adding organic fertilizer. It decreased to 18.27% and 32.76% for M1 and M2 treatments, respectively, compared with the control treatment M0, which attained a chloride concentration of 14.01 mmol $L^{-1}$. All combined interactions between the three study factors showed significant differences in the values of those interactions in the concentration of soluble chloride in the soil solution. On the other hand, the results of the triple interaction between irrigation water salinity, mycorrhizas, and organic fertilizer have detailed the clarity of the single effect of each of the three factors on chloride concentration. The study noted the S3M0F0 interaction treatment gave the highest concentration, which reached 23.60 mmol $L^{-1}$, but the lowest concentration recorded was in the S1M2F2 interaction treatment with 4.37 mmol $L^{-1}$ (Table 3).

Notably, from the results, the effect of increasing salinity of irrigation water was significant as the concentration of soluble sodium and chloride in the soil solution increased (Tables 2 and 3). This increase may be due to continuous accumulation during the growing season and high temperatures, which raise evaporation rates and salt accumulation during the depth of irrigation water. For inoculation with mycorrhizas, it led to a

**Table 3.** Effect of mycorrhizal inoculation and organic fertilizer on chloride concentration (mmol $L^{-1}$) using saline irrigation water.

| Saline irrigation water | Organic fertilizer | Mycorrhizas | | | S*M |
|---|---|---|---|---|---|
| | | F0 | F1 | F2 | |
| S1 | M0 | 8.04 | 7.25 | 6.72 | 7.34 |
| | M1 | 6.53 | 6.38 | 5.33 | 6.08 |
| | M2 | 4.99 | 4.56 | 4.37 | 4.64 |
| S2 | M0 | 13.21 | 13.01 | 12.53 | 12.91 |
| | M1 | 12.48 | 11.95 | 11.62 | 12.02 |
| | M2 | 10.42 | 8.98 | 8.59 | 9.33 |
| S3 | M0 | 23.60 | 22.66 | 19.06 | 21.77 |
| | M1 | 17.33 | 16.03 | 15.41 | 16.26 |
| | M2 | 14.98 | 14.30 | 13.58 | 14.29 |
| LSD $_{S*M*F}$ | | 0.497 | | LSD $_{S*M}$ | 0.256 |
| S*F | | | | | |
| Saline irrigation water | | F0 | F1 | F2 | Average |
| S1 | | 6.52 | 6.06 | 5.47 | 6.02 |
| S2 | | 12.03 | 11.31 | 10.91 | 11.42 |
| S3 | | 18.64 | 17.67 | 16.02 | 17.44 |
| LSD $_{S*F}$ | | 0.293 | | LSD $_{S}$ | 0.200 |
| M*F | | | | | |
| Organic fertilizer | | F0 | F1 | F2 | Average |
| M0 | | 14.95 | 14.31 | 12.77 | 14.01 |
| M1 | | 12.11 | 11.46 | 10.78 | 11.45 |
| M2 | | 10.13 | 9.28 | 8.85 | 9.42 |
| LSD $_{M*F}$ | | 0.286 | | LSD $_{M}$ | 0.149 |
| F | | | | | |
| Mycorrhizas | | F0 | F1 | F2 | |
| Average | | 12.40 | 11.68 | 10.80 | |
| LSD $_{F}$ | | 0.179 | | | |

decrease in both sodium and chloride concentrations. The reason for this decrease may refer to the role of mycorrhizas in secreting organic acids, such as citric and oxalic acid, due to which the concentration of ions responsible for increasing the salinity concentration in the soil solution declined. Mycorrhizas also have a role in increasing the size of the root system, and, thus, secretions increase, improving soil conditions (Islam *et al*., 2023). Additionally, adding organic fertilizer to the soil led to a substantial decrease in the concentration of sodium and chloride.

The reason for the decrease may be because of the added organic fertilizer, which contains organic acids. Meanwhile, the decline in other qualities of the characteristics may be a result of the organic fertilizer improving the chemical and physical properties of the soil. Likewise, its chelation of these ions makes them more soluble and widespread. Therefore, reducing their concentration in the root zone occurs, as well as reducing their negative impact on the plant (Hafez *et al*., 2022). The added organic fertilizer also chelated the soluble ions in the soil solution and let them more easily leach away with irrigation water, reducing their concentration in the root zone. Additionally, organic and inorganic acids present in the organic fertilizer with the ions added to the irrigation water form soluble salts of sulfate and sodium. The organic matter, especially in the Agri M40 fertilizer, also improved the physical properties and increased the stability of soil aggregates. Thereby, it increased the porosity of the soil, which facilitated the movement of salts away from the root zone with irrigation water (Elgharably and Nafady, 2021).

**Table 4.** Effect of mycorrhizal inoculation and organic fertilization on grain yield (µg ha$^{-1}$) using saline irrigation water.

| Saline irrigation water | Organic fertilizer | Mycorrhizas | | | S*M |
|---|---|---|---|---|---|
| | | F0 | F1 | F2 | |
| S1 | M0 | 10.35 | 10.73 | 10.92 | 10.67 |
| | M1 | 10.41 | 11.30 | 11.30 | 11.00 |
| | M2 | 11.23 | 11.41 | 11.82 | 11.49 |
| S2 | M0 | 10.25 | 10.60 | 10.61 | 10.49 |
| | M1 | 10.40 | 10.99 | 11.00 | 10.80 |
| | M2 | 10.66 | 11.09 | 11.13 | 10.96 |
| S3 | M0 | 9.17 | 9.68 | 9.90 | 9.59 |
| | M1 | 9.60 | 9.97 | 10.14 | 9.90 |
| | M2 | 9.95 | 10.48 | 10.49 | 10.31 |
| LSD $_{S*M*F}$ | | 0.013 | | LSD $_{S*M}$ | 0.008 |
| S*F | | | | | |
| Saline irrigation water | | F0 | F1 | F2 | Average |
| S1 | | 10.67 | 11.15 | 11.35 | 11.05 |
| S2 | | 10.44 | 10.90 | 10.92 | 10.75 |
| S3 | | 9.57 | 10.05 | 10.18 | 9.93 |
| LSD $_{S*F}$ | | 0.009 | | LSD $_S$ | 0.008 |
| M*F | | | | | |
| Organic fertilizer | | F0 | F1 | F2 | Average |
| M0 | | 9.93 | 10.34 | 10.48 | 10.25 |
| M1 | | 10.14 | 10.75 | 10.82 | 10.57 |
| M2 | | 10.62 | 11.00 | 11.15 | 10.92 |
| LSD $_{M*F}$ | | 0.007 | | LSD $_M$ | 0.004 |
| F | | | | | |
| Mycorrhizas | | F0 | F1 | F2 | |
| Average | | 10.23 | 10.70 | 10.81 | |
| LSD $_F$ | | 0.004 | | | |

The results of the triple interaction between the study factors showed a significant superiority of sodium and chloride with increasing irrigation water salinity. It decreased with the addition of mycorrhizas and organic fertilizer because they reduced the harmful effect of saline irrigation water, as mycorrhizas secrete growth regulators and enzymes and increase the size of the root system. This improves soil conditions, while organic fertilizer reduces the effect of saline irrigation water by chelating ions and forming easy-to-leach compounds. The combined effect between mycorrhizae and organic fertilizer may have strengthened such reason (Islam *et al*., 2023).

**Mycorrhizae and organic fertilizer effect on grain yield using saline irrigation water**

The results showed the higher saline irrigation water affected the grain yield. The yield of treatments S2 and S3 decreased by 2.71% and 10.13%, respectively, compared with treatment S1, which gave 11.05 mg ha$^{-1}$ (Table 4). This may be due to increased osmotic pressure in the root zone and nutritional imbalance, which negatively influences water and nutrient absorption, which, in turn, alters grain yield (Nehela *et al*., 2021). The outcomes revealed that inoculation with mycorrhizae increased grain yield compared with the control treatment. It rose by 4.59% and 5.66% for the F1 and F2 treatments, respectively, compared with the F0 control treatment, which recorded a yield of 10.23 mg $ha^{-1}$. This may be ascribable to the role of mycorrhizae in secreting growth regulators that encourage roots to extend over larger areas of soil and absorb nutrients. This further manifested in an increase in grain yield (Yooyongwech *et al*., 2022).

The considerable increase in organic fertilizer treatments also added to grain yield, as evident by the 3.12% and 6.53% rise for treatments M1 and M2, respectively, compared with the control treatment. This may be due to organic fertilizer improving soil conditions and supplying it with nutrients. Thus, an increase in the absorption of nutrients is apparent in grain yield (Irfan *et al*., 2021). The combined interaction between saline irrigation water and mycorrhizae showed the significant increase of treatments to which adding mycorrhizae gave the lowest concentration of saline irrigation water. The S1M2 combined interaction recorded the highest grain yield weight of 11.35 µg $ha^{-1}$ and the lowest grain yield weight of 9.57 µg $ha^{-1}$ occurred with the S3M0 interaction. This is because the mycorrhizae hyphae secrete some organic acids that bind with the ions responsible for increasing salinity, in addition to the absorption of nutrients by their hyphae (Yang *et al*., 2022).

An increase in grain yield when interfering may be because both mycorrhizae and organic fertilizer raise the availability of nutrients and improve soil conditions and plant growth, which is reflected in grain yield (Hamed, 2021). The results of the interaction between the three study factors indicated the significant differences of the S1M2F2 intervention, which gave a grain yield of 11.82 µg $ha^{-1}$, with an increase rate of 28.89% over the S3M0F0 intervention. It achieved the lowest average grain yield of 9.17 µg $ha^{-1}$. The increase in yield could mean that both mycorrhizae and organic fertilizer reduce the effect of salinity and increase the availability of nutrients.

**Mycorrhizae and organic fertilizer effect on grains' nitrogen using saline irrigation water**

***Nitrogen in grains (%)***

The results showed a significant decrease in the concentration of nitrogen in grains with increasing salinity of irrigation water. The nitrogen concentration decreased from 1.87% in treatment S1 to 1.48% in treatment S3. The concentration of nitrogen in grains rose upon inoculation with mycorrhizae (Table 5). The nitrogen concentration increased from 1.56% in the control F0 to 1.73% and 1.78% in the F1 and F2, respectively. It is clear from the results that adding organic fertilizer heightened the nitrogen concentration in grains from 1.58% in the M0 to 1.81% in the M2. The combination of saline irrigation water and mycorrhizae shows the remarkable increase in treatments inoculated with mycorrhizae, as treatment S3F0 gave the lowest nitrogen concentration of 1.38%, while the highest concentration reached 2.01% in S1F2.

The outcomes of the combined saline irrigation water and the addition of organic fertilizer indicate a significant increase in treatments where organic fertilizer was added in the concentration of nitrogen in grains. It decreased with increasing saline irrigation water. The lowest concentration was in the S3M0 interaction, reaching 1.39%, and the highest concentration was in the S1M2 interaction, reaching 2.06%. Evidently, from the triple interaction between saline irrigation water, organic fertilizer, and mycorrhizae, a double effect of organic fertilizer and mycorrhizae reduces the negative effect of saline irrigation water and increases nitrogen concentration in grains. The concentration increased from 1.33% in the S3M0F0 intervention to 1.67% in the S3M2F2 intervention. One can note that at the same salinity level of the irrigation water, this rise occurred due to the addition of organic fertilizer and mycorrhizae. The highest nitrogen concentration resulted in the S1M2F2 triple intervention reaching 2.20%.

**Table 5.** Effect of mycorrhizal inoculation and organic fertilization on total nitrogen concentration in grains (%) using saline irrigation water.

| Saline irrigation water | Organic fertilizer | Mycorrhizas | | | S*M |
|---|---|---|---|---|---|
| | | F0 | F1 | F2 | |
| S1 | M0 | 1.57 | 1.75 | 1.78 | 1.70 |
| | M1 | 1.64 | 1.88 | 2.05 | 1.86 |
| | M2 | 1.85 | 2.14 | 2.20 | 2.06 |
| S2 | M0 | 1.54 | 1.69 | 1.71 | 1.65 |
| | M1 | 1.61 | 1.79 | 1.79 | 1.73 |
| | M2 | 1.73 | 1.82 | 1.82 | 1.79 |
| S3 | M0 | 1.33 | 1.41 | 1.43 | 1.39 |
| | M1 | 1.37 | 1.49 | 1.53 | 1.46 |
| | M2 | 1.44 | 1.65 | 1.67 | 1.58 |
| LSD $_{S*M*F}$ | | 0.038 | | LSD $_{S*M}$ | 0.025 |
| S*F | | | | | |
| Saline irrigation water | | F0 | F1 | F2 | Average |
| S1 | | 1.68 | 1.93 | 2.01 | 1.87 |
| S2 | | 1.63 | 1.76 | 1.78 | 1.72 |
| S3 | | 1.38 | 1.51 | 1.54 | 1.48 |
| LSD $_{S*F}$ | | 0.024 | | LSD $_S$ | 0.020 |
| M*F | | | | | |
| Organic fertilizer | | F0 | F1 | F2 | Average |
| M0 | | 1.48 | 1.62 | 1.64 | 1.58 |
| M1 | | 1.54 | 1.72 | 1.79 | 1.68 |
| M2 | | 1.67 | 1.87 | 1.90 | 1.81 |
| LSD $_{M*F}$ | | 0.022 | | LSD $_M$ | 0.014 |
| F | | | | | |
| Mycorrhizas | | F0 | F1 | F2 | |
| Average | | 1.56 | 1.73 | 1.78 | |
| LSD $_F$ | | 0.012 | | | |

Distinctly, from the results, the concentration of nitrogen in grains decreases when the salinity of irrigation water increases (Tables 5). The reason for the decrease could refer to a decrease in the concentration of nitrogen in the soil as a result of the negative effect of ions that raise osmotic pressure. Moreover, the volatilization of nitrogen from the soil and the lack of effectiveness of nitrogen-fixing bacteria are other reasons. Thus, the plant's absorption of nitrogen decreases, as reflected in its concentration in the grains (Rodrigues *et al*., 2021; Nehela *et al*., 2021; Ma *et al*., 2022).

Organic fertilization showed a remarkable rise in the concentration of nitrogen in grains at harvest. This increase in nitrogen concentration may be due to the addition of organic fertilizer because it adds a percentage of nitrogen to the soil and improves soil conditions. Poultry waste also has a role in increasing the readiness and absorption of nutrients and raising the ability of plant tissues to move nitrogen between plant parts. This enhances the process of photosynthesis and food manufacturing in the leaves, as thus reflected in its concentration in the grains.

The interaction between saline irrigation water and organic fertilization revealed the significant superiority of the treatments to which organic fertilizer was added in the concentration of nitrogen. The organic fertilizer Agri M40 was higher than the poultry manure in nitrogen and phosphorus concentrations in grains. The reason may refer to the fertilizer being completely decomposed and having a lower salinity than the poultry manure. Its addition occurred at multiple intervals during the growing season as a spray on the soil. As for the role of organic fertilizers in the nitrogen concentration, one can note an increase in nitrogen concentration. The rise may be because organic fertilizers, along with soluble ions, form compounds that are easy to spread and leach in the root zone. The humic acids reduce the degree of soil interaction and, thus, the available readiness of nutrients, increasing the concentration of nitrogen in the grains.

Liu *et al*. (2019) had been using humic acid and vermicompost when growing corn in saline soils. They noticed a decrease in soil salinity and an increase in the availability of nitrogen in the soil, leaves, and grains, as well as an elevation in microbial activity and in the stability of soil aggregates, reflecting an improvement. The combined treatment of mycorrhizae and organic fertilizer showed a significant superiority in the concentration of nitrogen in grains, as the concentration of nitrogen increased with this interaction. The reason could be because organic fertilizer improves soil conditions and increases the activity of microorganisms. Mycorrhizae activity sought to infect plant roots at the largest possible rate, increasing their cells that extend into the soil and secrete hormones and enzymes. It raises the available nutrients by increasing the activity of microorganisms that fix atmospheric nitrogen and boost acids. The organic matter resulting from the addition of organic fertilizers enriches the availability of nitrogen and enhances the ability of the roots to absorb water and nutrients (Gao *et al*., 2020).

The triple interaction between the study factors provided the significant superiority of the treatments with the adding of mycorrhizae and organic fertilization in the concentration of nitrogen in the grains. The increase is ascribable to the role of the combined organic fertilizer and mycorrhizae in improving the growth environment and increasing nutrient availability; hence, the concentration in the grains increases (Gao *et al*., 2020). It can also refer to the decrease in concentration with the negative role of saline irrigation water on the chemical, physical, and biological properties of the soil. Consequently, the absorption of nutrients decreases, and the nitrogen concentration in corn grains also decreases at harvest (Nehela *et al*., 2021). The concentration rose when adding mycorrhizae and organic fertilizer due to the positive and combined effect of both organic fertilizer and mycorrhizae in improving soil conditions. This boosted the availability of nutrients, supplying the soil with nutrients by the organic fertilizer (Gao *et al*., 2020).

The results of the interaction between saline irrigation water and organic fertilizer indicate that treatments with added organic fertilizer significantly increased the incidence of mycorrhizal infection of roots, regardless of the salinity level of the irrigation water. However, the incidence gradually decreased as the salinity of irrigation water increased due to the negative effect of salinity on the symbiotic relationship between mycorrhizae and plant roots, especially at high salinity levels, as confirmed by Yang *et al*. (2020).

The role of organic fertilizer in increasing the incidence of mycorrhizal infection is raising the incidence rate by boosting the stability of soil aggregates and improving their structure, thereby increasing the ability of roots to grow and penetrate the soil. Regarding the two-way interaction between organic fertilizer and mycorrhizae, the treatments with added biofertilizer showed significant superiority.

The M2F2 interaction recorded the highest average mycorrhizal infection rate, reaching 71.11%. The reason for the increased infection rate may be due to organic fertilizer improving the chemical, physical, and biological properties of the soil, thus encouraging the growth of mycorrhizal hyphae. Compared with the M0F0, M1F0, and M2F0 interactions, they did not record any root infection (Table 6). This may refer to the absence of fungi in the soil. These results are consistent with the findings of Al-Maliki and Al-Masoudi (2018). The triple interaction between the study factors did not show any significant differences in the percentage of mycorrhizal infection of the maize roots. The treatments with no mycorrhiza added to them did not record any infection. Meanwhile, the treatments inoculated with mycorrhiza all

**Table 6**. Effect of mycorrhizal inoculation and organic fertilization on the percentage of mycorrhizal root infection (%) using saline irrigation water.

| Saline irrigation water | Organic fertilizer | Mycorrhizas | | | S*M |
|---|---|---|---|---|---|
| | | F0 | F1 | F2 | |
| S1 | M0 | 0.00 | 56.67 | 63.33 | 40.00 |
| | M1 | 0.00 | 63.33 | 66.67 | 43.33 |
| | M2 | 0.00 | 83.33 | 86.67 | 56.67 |
| S2 | M0 | 0.00 | 36.67 | 43.33 | 26.67 |
| | M1 | 0.00 | 53.33 | 63.33 | 38.89 |
| | M2 | 0.00 | 66.67 | 83.33 | 50.00 |
| S3 | M0 | 0.00 | 23.33 | 26.67 | 16.67 |
| | M1 | 0.00 | 20.00 | 23.33 | 14.44 |
| | M2 | 0.00 | 33.33 | 43.33 | 25.56 |
| LSD $_{S*M*F}$ | | ns | | LSD | 3.563 |
| S*F | | | | | |
| Saline irrigation water | | F0 | F1 | F2 | Average |
| S1 | | 0.00 | 67.78 | 72.22 | 46.67 |
| S2 | | 0.00 | 52.22 | 63.33 | 38.52 |
| S3 | | 0.00 | 25.56 | 31.11 | 18.89 |
| LSD $_{S*F}$ | | 4.562 | | LSD $_S$ | 3.027 |
| M*F | | | | | |
| Organic fertilizer | | F0 | F1 | F2 | Average |
| M0 | | 0.00 | 38.89 | 44.44 | 27.78 |
| M1 | | 0.00 | 45.56 | 51.11 | 32.22 |
| M2 | | 0.00 | 61.11 | 71.11 | 44.07 |
| LSD $_{M*F}$ | | 4.325 | | LSD | 1.921 |
| F | | | | | |
| Mycorrhizas | | F0 | F1 | F2 | |
| Average | | 0.00 | 48.52 | 55.56 | |
| LSD $_F$ | | 2.811 | | | |

recorded infections, ranging from the lowest infection rate of 20.00% in the interaction S3M1F1 to the highest infection rate of 86.67% in the interaction S1M2F2.

## CONCLUSIONS

The study concludes that the triple interaction between the study factors showed significant superiority of the treatments, to which mycorrhizae and organic fertilization addition succeeded in the concentration of nitrogen in the maize (*Z. mays* L.,**)** grains. The results revealed a considerable decrease in the concentration of nitrogen in grains with increasing salinity of irrigation water.

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