Abstract. An experiment was performed at Orman Botanical Garden, Giza, Egypt to determine the role of magnetite ore at either 2 or 4 g/pot in reducing the harmful effects of soil salinity on growth and quality of Moringa oleifera Lam. grown in soil mixture salinized with a mixture of NaCl and CaCl₂ salts at concentrations of 0, 2000, 4000, 6000 and 8000 ppm. The effect of the interaction between salinity and magnetite was also studied. The results indicated that a gradual decrease in survival percentage was observed with the gradual increments in salinity, but it was progressively increased with higher magnetite rates irrespective of salinity concentration. Connecting between magnetite at any dose and salinity up to 4000 ppm gave the highest percentage of survival rate in the two seasons. While, the lowest survival rate was recorded at 8000 ppm, especially in the absence of magnetite. A response similar to that of survival percentage occurred for vegetative and root growth traits, and leaf chemical composition, with few exceptions in both seasons. Thus, it is advised to drench soil mixture with magnetite at 4 g/pot to enhance growth and quality of Moringa oleifera transplants under salt stress.

Keywords: salinity, Moringa oleifera, magnetite, carotenoids, proline

Introduction

Among many species included in Fam. Moringaceae is considered the miracle species having tremendous uses, such as aorestation, alley cropping, medicines, water purification biopesticides, biogas, green manure and gum production, domestic cleaning agent and as a vegetable for their edible roots, young leaves, fruits and seeds, from which oil is often extracted (Aiyelaagbe, 2011). It grows rapidly up to 9-10 m height in poor soil with little care for long periods of drought (McConnachie, 1999). It is originated in India and Pakistan, but is now distributed to most tropical areas as ornamental, fodder, fibrous, malnutrition solving and economic plant (Fahey, 2005; Thurber and Fahey, 2009). It is easily propagated by seeds and stem cuttings, tolerates a wide range of soil conditions, but prefers a neutral to slightly acidic (pH 6.5-7), well drained sandy or loamy soils. It is considered as drought resistant, but water logging sensitive (Suein, 2008).

Regarding salinity tolerance of Moringa oleifera, Dos Santos et al. (2011) noticed that the gradual increase in NaCl concentration (0, 25, 50, 100, 200 and 250 mol/m³) caused a gradual decrement in germination % germination speed index and seedling length. Moreover, Nouman et al. (2012a) reported that moringa seedlings survived up to 3500 ppm NaCl salinity with a slight reduction in its biomass, chlorophyll a, crude protein and mineral concentrations. Activity of superoxide dismutase (SOD) and peroxidase (POD) and Ca, K and Mg concentrations were progressively decreased, but
catalase (CAT), total phenols, chlorophyll b, β-carotene, Na and P concentrations were significantly increased with raising salinity up to 5500 ppm relative to control. Similarly, were those results of Nouman et al. (2012b), Rivas et al. (2013) and Elhag and Abdalla (2014) on *Moringa oleifera*.

The deleterious effects of salinity on ornamentals, such as reduction of plant growth and leaf yellowing, browning of the leaf tips and margins, defoliation, root shortening and may ultimately plant die were previously suggested by Al-Qubaie et al. (2003) on *Bongainvillea aglabra*, *Conocarpus erectus*, *Ficus benghalensis*, *Jasminum azoricum*, *Tamarix articulata* and *Ziziphus spina-christi*, Shahin et al. (2008) on *Ficus macrocarpavvar*, *Hawaii and Euonymus Japonica* cv. Mediopicta, Shahin et al. (2013) on *Ficus benjamina cv. Samantha and Schefflera arboricola* cv. Gold Capella, El-Fouly et al. (2015) on *Iris tingitana* cv. Wedgewood, Jose et al. (2016) on *Eucalyptus urophylla* and Shahin et al. (2017) on *Casuarina equisetifolia* and *Eucalyptus rostrata*. However, these harms were minimized by some practical methods, such as those revealed by Moustafa et al. (2017) on *Moringa oleifera* using magnetic iron. The role of magnetite in reducing hazards of salinity was also documented by Abdel-Fattah (2014) on *Jacaranda australis*, Ahmed et al. (2016) on *Acalypha wilkesiana*, Shahin et al. (2018) on *Terminalia arjuna* and El-Sayed et al. (2019) on *Enterolobium contortisiliquum*.

Such trial, however aims to evaluate the role of magnetic iron in reducing the harmful effects of soil salinity on growth and quality of *Moringa oleifera* transplants during rearing period in the nursery.

**Materials and methods**

The current study was conducted in the full sun the average temperature between (27-38°C) and the average percentage of humidity 56% at the nursery of Orman Botanical garden, Giza, Egypt throughout the two successive seasons of 2018 and 2019 as an attempt to verify the benefit of magnetite in minimizing the hazards of soil salinity on growth and quality of moringa transplants, and to detect its role in helping these nusrings to grow well under such stress.

Thus, 4-months-old, uniform transplants of the plant at a length of about 30 cm with 3-4 leaves were transplanted on April, 1st for every season to 15-cm-diameter polyethylene black bags (one seedling/bag) filled with about 3.5 kg of sand and clay mixture at equal volume parts (1:1, v/v). The physical and chemical properties of the soil mixture used in the two seasons were determined and illustrated in Table 1.

**Table 1.** The physical and chemical analysis of the soil mixture used in 2018 and 2019 seasons

| Soil mixture                  | Particle size distribution (%) | S.P. | E.C. (dS/m) | pH  | Ca<sup>++</sup> | Mg<sup>++</sup> | Na<sup>+</sup> | K<sup>+</sup> |
|------------------------------|--------------------------------|------|-------------|-----|--------------|---------------|--------------|-------------|
| Sandy + Clay (1:1, v/v)      | Coarse sand 38.6 | Fine sand 31.3 | Silt 20.6 | Clay 9.5 | 25 | 6.5 | 7.86 | 17.8 | 14.2 | 33.1 | 0.9 |

**Soil texture**

|                     | HCO<sub>3</sub> | Cl<sup>-</sup> | SO<sub>4</sub><sup>2-</sup> | CO<sub>3</sub> | N | P | K | Fe | Zn | Mn | Cu |
|---------------------|-----------------|----------------|-----------------|----------------|---|---|---|----|----|----|----|
| Sandy clay          | 2.10            | 58.40          | 5.50            | 0.00           | 173.10 | 15.78 | 361.76 | 15.80 | 4.36 | 8.03 | 8.81 |
Immediately before transplanting, the above soil mixture was salinized with an equal mixture of NaCl and CaCl$_2$ pure salts (1:1, by weight) at the concentrations of 0, 2000, 4000, 6000 and 8000 ppm. After planting, however the soil mixture was thoroughly drenched with magnetic iron (Fe$_3$O$_4$, 22.5%) secured from Alahram Mining Co., Maadi, Cairo at the rates of 0, 2 and 4 g/plant, as one batch at the beginning of the season. Each level of salinity was combined with each one of magnetic iron to formalize 15 interaction treatments.

The transplants under various experimental treatments were fertilized 3 times during the course of this study with 2 g/transplants of NPK + micro elements chemical fertilizer (Kristalon, 19:19:19) and watered every other day. Furthermore, all the other agricultural practices needed for such plantation were done as usually grower did. A factorial in complete randomized design with 3 replicates, as each one contained 5 seedlings was used in every season (Mead et al., 1993).

Data recorded, at the end of each season (on October, 1st), were: survival (%), plant height (cm), stem diameter (cm), number of leaves/plant, leaf length (cm), the longest root length (cm), root collar diameter (cm), aerial parts and roots fresh and dry weights (g) and salt resistance index as a percentage (SRI %) was calculated from the equation of Wu and Huff (1983) as follows:

$$
\text{SRI} (\%) = \frac{\text{Mean root length of the longest root in salt treated plant}}{\text{mean root length of the longest root in control one}} \times 100 \quad \text{(Eq.1)}
$$

In addition, the benefit coefficient of magnetite (Fe$_3$O$_4$) under various salinity levels as a percentage (B. Coe %) was estimated from the following equation:

$$
\text{B. Coe} (\%) = \frac{\text{Increase rate in dry matter of treated plant}}{\text{dry matter of control one}} \times 100. \quad \text{(Eq.2)}
$$

In fresh samples concentrations of photosynthetic pigments (chlorophyll a, b and carotenoids, mg/g f.w.) were determined according to the method of Sumanta et al. (2014), while in dry ones the percentages of nitrogen (Blake, 1965), phosphorus (Luatanab and Olsen, 1965), as well as potassium, sodium and chloride (Jackson, 1973) were measured. Concentration of the free proline (mg/100 g d.w.) was also assessed in dry leaf samples by the method of Batels et al. (1973). The abovementioned constituents were evaluated in the second season only.

Data were then subjected to analysis of variance using the computer program of SAS Institute (2009), followed by Duncan's New Multiple Range t-Test (Steel and Torrie, 1980) for means comparison.

Results

**Effect of soil salinity, magnetite and their interaction on vegetative and root growth parameters**

Data presented in Table 2 show that survival % means were descendingly decreased with increasing salinity level to reach the minimum at 8000 ppm level in both seasons, but progressively increased with rising magnetite rate to be maximum at 4 g/plant rate
regardless of salinity level. Combining between any dose of magnetic iron and salinity up to 4000 ppm gave the highest survival percentage in the two seasons. A significant reduction in means of this character was observed when salinity level was elevated to 6000 ppm, but it was still higher than 50% in most cases of both seasons especially in the presence of magnetite. The least records however were attained by 8000 ppm salinity level, even in the presence of Fe$_3$O$_4$, but its absence greatly reduced means of such trait to 27.4% in the first season and to 0.00% in the second one due to death of the plants.

Table 2. Effect of salinity levels, magnetite rates and their interactions on survival and height of Moringa oleifera Lam. transplants during 2018 and 2019 seasons

| Fe$_3$O$_4$ rate (g/plant) | Survival (%) | Plant height (cm) |
|---------------------------|--------------|-------------------|
| Salinity level (ppm)      | First season; 2018 | Second season; 2019 |
| 0.00                     | 100.00a 100.00a 100.00a 100.00A 94.67d 103.0b 108.9a 102.2A | 73.96C 81.20B 83.45A | 73.71C 81.36B 89.25A |
| 2000                     | 100.00a 100.00a 100.00a 100.00A 92.00e 98.99c 102.6b 97.86B | 84.83ef 100.1c 102.2bc 95.71B |
| 4000                     | 89.22b 100.00a 100.00a 96.41B 70.78i 78.93h 88.51f 79.41C | 73.33c 87.20b 100.00a 86.94B 76.67g 83.67f 94.43d 84.92C |
| 6000                     | 53.17e 70.82d 76.91c 66.97C 62.12j 70.17i 83.11g 71.80D | 41.53f 58.30e 65.80d 55.21C 64.50i 73.90h 87.27e 75.22D |
| 8000                     | 27.40g 35.17f 40.34f 34.30D 49.00l 55.73k 63.10j 55.95E | 0.00h 34.50g 38.30g 24.27D 0.00l 33.07k 36.10j 23.06E |
| Mean                     | 73.96C 81.20B 83.45A | 73.71C 81.36B 89.25A |

Mean followed by the same letter in a column or row don’t differ significantly according to Duncan’s New Multiple Range test.

A similar trend to that of survival percentage was just obtained regarding plant height (cm), stem diameter (cm), No. leaves/plant, leaf length (cm), root length (cm), root collar diameter (cm), as well as aerial parts and roots fresh and dry weights (g) attributes (Tables 2, 3, 4, 5 and 6), as the means of these traits were gradually decreased with increasing salinity levels, but progressively increased with raising magnetic iron rate. The highest averages were also recorded by the concentrations between salinity concentration up to 4000 ppm and any dose of magnetite. Increasing salinity level to 6000 ppm caused a significant reduction in the means of foregoing criteria, with the exception for plants which received Fe$_3$O$_4$ at any rate. The minimal values were however acquired by 8000 ppm salinity treatments especially for plants abandoned of magnetic iron.

Salt resistance index (SRI %) and benefit coefficient of magnetite (B. Coe. %).

It is clear from data presented in Table 7 that percent of salt resistance index was linearly decreased as salinity concentration was increased. Thus, the least SRI value was achieved by 8000 ppm concentration to be 53.54% in the first season and 39.46% in the...
second one. Decrement mean of this index to less than 50% really indicates the low tolerance of moringa to salinity higher than 6000 ppm. Magnetite at the rate of 2 g/plant scored the highest percentages of SRI in the two seasons, followed by 4 g/plant rate. Under control treatment, a pronounced decline in the values of this index was acquired with increasing salinity level to be less than 50% in both seasons by 8000 ppm treatment. This confirms that moringa is not able to tolerate salinity higher than 6000 ppm as mentioned before. On the other side, application of Fe$_3$O$_4$ improved the means of such index to be higher than 50% even under 8000 ppm treatment, showing the important role of this natural ore in enhancing moringa tolerance to high salinity.

Table 3. Effect of salinity levels, magnetite rates and their interactions on stem diameter and No. leaves/plant of Moringa oleifera Lam. transplants during 2018 and 2019 seasons

| Fe$_3$O$_4$ rate (g/plant) | Salinity level (ppm) | Stem diameter (cm) | Mean | No. leaves /plant | Mean |
|---------------------------|----------------------|--------------------|------|-------------------|------|
|                           | First season; 2018   |                    |      |                   |      |
|                           | 0.00                 | 0.797c 0.870b 0.947a 0.871A | 7.07c 8.33b 9.67a 8.36A |
|                           | 2000                 | 0.740d 0.830c 0.890b 0.820B | 6.50d 8.50b 9.50a 8.17B |
|                           | 4000                 | 0.683ef 0.737d 0.803c 0.741C | 5.67e 7.17c 8.33b 7.06C |
|                           | 6000                 | 0.577g 0.647f 0.693e 0.639D | 3.83g 5.67e 6.50d 5.33D |
|                           | 8000                 | 0.477i 0.497j 0.527h 0.500E | 3.00h 4.00g 4.83f 3.94E |
| Mean                      |                      | 0.655C 0.716B 0.772A | 5.21C 6.33B 7.77A |
|                           | Second season; 2019  |                    |      |                   |      |
|                           | 0.00                 | 0.750de 0.877b 0.930a 0.852A | 7.33e 8.67c 9.67a 8.56A |
|                           | 2000                 | 0.740de 0.837bc 0.863b 0.813A | 5.33g 9.00c 9.33ab 7.89B |
|                           | 4000                 | 0.660f 0.713e 0.793cd 0.722B | 5.67g 7.00ef 8.00d 6.89C |
|                           | 6000                 | 0.547g 0.627f 0.730e 0.634C | 4.67h 5.67g 6.67f 5.67D |
|                           | 8000                 | 0.00i 0.353h 0.387h 0.247D | 0.00j 3.33i 4.67h 2.67E |
| Mean                      |                      | 0.539C 0.681B 0.741A | 4.60C 6.73B 7.67A |

Mean followed by the same letter in a column or row don’t differ significantly according to Duncan’s New Multiple Range test.

As for the benefit coefficient of magnetite percentage (B. Coe. %), as a real indicator for the advantage of magnetic iron in reducing hazards of salinity, with promoting plant growth, is presented in Table 7 which exhibits that Fe$_3$O$_4$ significantly increased dry matter production of treated plants under the different salinity levels over control in the two seasons. However, the upper hand in the increased means of such coefficient in the first season was for magnetite under 2000 and 6000 ppm salinity treatments, as 31.88 and 31.27% against 15.97% for control, followed by magnetite under 4000 ppm level, while in the second season, that was true for magnetite under 8000 ppm level, which raised the percent of this coefficient to 259.0% versus 27.85% for control. Likewise, a progressive increment was occurred in the means of this coefficient with raising Fe$_3$O$_4$ rate. So, the greatest benefit of this ore was recorded in both seasons by 4 g/plant dose. Interaction treatments also encouraged dry matter production as applying Fe$_3$O$_4$ at 2 or 4 g/plant caused a significant increase in the production of dry matter over control regardless of salinity level in the two seasons.
**Table 4.** Effect of salinity levels, magnetite rates and their interactions on leaf and root length and root callar diameter of *Moringa oleifera* Lam. transplants during 2018 and 2019 seasons

| Fe$_3$O$_4$ rate (g/plant) | Salinity level (ppm) | Leaf length (cm) | Root length (cm) | Root callar diameter (cm) |
|---------------------------|----------------------|------------------|------------------|---------------------------|
|                           |                      | 0.00             | 2 g              | 4 g                       | Mean                        | 0.00             | 2 g              | 4 g                       | Mean                        | 0.00             | 2 g              | 4 g                       | Mean                        |
|                           | 0.00                 | 15.81g           | 14.94h           | 16.11f           | 15.62C                     | 13.44cd                     | 13.97bc               | 16.19a                     | 14.53A                     | 1.87de                     | 2.20c               | 2.37b                     | 2.14B                     |
|                           | 2000                 | 16.67ef          | 18.78d           | 20.50b           | 18.65A                     | 12.49e                      | 13.07d                 | 14.37b                     | 13.31B                     | 1.80ef                     | 2.40b               | 2.47b                     | 2.22AB                    |
|                           | 4000                 | 11.90i           | 19.45c           | 21.72a           | 17.69B                     | 10.92f                      | 11.44f                 | 13.35d                     | 11.91C                     | 1.67fg                     | 2.27b               | 2.67a                     | 2.27A                     |
|                           | 6000                 | 10.78j           | 16.06g           | 17.23e           | 14.69D                     | 8.86h                       | 9.93g                  | 10.93f                     | 9.91D                      | 1.50g                      | 1.92de              | 1.99d                     | 1.80C                     |
|                           | 8000                 | 9.03l            | 9.65k            | 10.80j           | 9.93E                      | 3.10j                       | 4.20i                  | 4.95h                      | 7.83E                      | 1.76m                      | 1.67e               | 1.58f                     | 1.60m                     |
|                           | Mean                 | 12.84C           | 15.78B           | 17.27A           | 10.36C                     | 11.32B                      | 12.78A                 | 1.62C                      | 2.11B                     | 2.22A                     |

First season; 2018

|                           |                      |                  |                  |                            | Mean                        | 0.00             | 2 g              | 4 g                       | Mean                        | 0.00             | 2 g              | 4 g                       | Mean                        |
|                           | 0.00                 | 15.55b           | 16.96a           | 17.25a           | 16.59A                     | 12.50c                      | 13.22b                 | 15.36a                     | 13.70A                     | 2.20bc                     | 2.24b               | 2.57a                     | 2.34A                     |
|                           | 2000                 | 14.19c           | 15.15b           | 17.28a           | 15.54B                     | 11.44d                      | 11.52d                 | 13.45b                     | 12.14B                     | 2.02d                      | 2.04cd              | 2.37b                     | 2.14B                     |
|                           | 4000                 | 13.06d           | 14.17c           | 15.25b           | 14.16C                     | 10.16f                      | 10.78e                 | 13.00c                     | 11.31C                     | 1.79e                      | 1.90de              | 2.31b                     | 2.00C                     |
|                           | 6000                 | 11.94e           | 11.42ef          | 14.00c           | 12.45D                     | 8.31h                       | 8.94g                  | 10.03f                     | 9.09D                      | 1.45g                      | 1.58fg              | 1.74ef                    | 1.59D                     |
|                           | 8000                 | 0.00h            | 8.06g            | 11.33f           | 6.47E                      | 0.00i                       | 8.11h                  | 8.61g                      | 5.57E                      | 0.00h                      | 1.43g               | 1.48g                     | 0.97E                     |
|                           | Mean                 | 10.95C           | 13.15B           | 15.02A           | 8.48C                      | 10.51B                      | 12.09A                 | 1.49C                      | 1.84B                     | 2.09A                     |

Mean followed by the same letter in a column or row don’t differ significantly according to Duncan’s New Multiple Range test.
Table 5. Effect of salinity levels, magnetite rates and their interactions on aerial parts fresh and dry weights of Moringa oleifera Lam. transplants during 2018 and 2019 seasons

| Fe\textsubscript{3}O\textsubscript{4} rate (g/plant) | Salinity level (ppm) | Aerial parts fresh weights (g) | Mean | Aerial parts dry weights (g) | Mean |
|----------------|---------------------|------------------------------|------|----------------------------|------|
|                 | 0.00                | 2 g                          | 4 g  | Mean                      | 0.00 | 2 g                          | 4 g  | Mean                      |
|                 |                     |                              |      |                           |      |                              |      |                           |
| First season; 2018 | 0.00                | 13.64de                      | 14.17d| 19.44a                   | 15.75A| 6.37c-e                      | 6.94c| 8.48a                     | 7.27A|
|                 | 2000                | 10.95f                       | 15.19c| 17.60b                   | 14.58B| 5.15f                        | 6.98c| 7.63b                     | 6.59B|
|                 | 4000                | 9.80g                        | 13.12e| 15.44c                   | 12.78C| 4.59f                        | 6.06de| 6.74cd                   | 5.80C|
|                 | 6000                | 8.00h                        | 11.10f| 13.35e                   | 10.82D| 3.74hi                       | 4.94fg| 5.81e                     | 4.83D|
|                 | 8000                | 6.62i                        | 8.72h | 9.98g                    | 8.44E | 3.10i                        | 3.89b | 4.34gh                    | 3.78E|
| Mean            |                     | 9.80C                        | 12.46B| 15.16A                   | 11.77| 4.59C                        | 5.76B | 6.60A                     | 5.17E|

Mean followed by the same letter in a column or row don’t differ significantly according to Duncan’s New Multiple Range test

Table 6. Effect of salinity levels, magnetite rates and their interactions on roots fresh and dry weights of Moringa oleifera Lam. transplants during 2018 and 2019 seasons

| Fe\textsubscript{3}O\textsubscript{4} rate (g/plant) | Salinity level (ppm) | Roots fresh weights (g) | Mean | Roots dry weights (g) | Mean |
|----------------|---------------------|-------------------------|------|-----------------------|------|
|                 | 0.00                | 2 g                     | 4 g  | Mean                  | 0.00 | 2 g                     | 4 g  | Mean                  |
|                 |                     |                         |      |                       |      |                         |      |                       |
| First season; 2018 | 0.00                | 13.38e                   | 22.38b| 25.78a                 | 20.51A| 4.13f                    | 7.99b | 10.31a                 | 7.48A|
|                 | 2000                | 13.81d                   | 22.42b| 25.73a                 | 20.65A| 4.28f                    | 8.02b | 10.25a                 | 7.52A|
|                 | 4000                | 11.23f                   | 18.97b| 20.39c                 | 16.86B| 3.46g                    | 6.73c | 8.13b                 | 6.10B|
|                 | 6000                | 9.23gh                   | 13.28e| 15.33d                 | 12.61C| 2.85h                    | 4.68e | 6.12d                 | 4.55C|
|                 | 8000                | 7.16j                    | 8.38hi| 10.62g                 | 8.72D | 2.20i                    | 2.98h | 4.19f                 | 3.13D|
| Mean            |                     | 10.96C                   | 17.09B| 19.57A                 | 16.17| 3.38C                    | 6.08B | 7.80A                 | 6.55B|

Mean followed by the same letter in a column or row don’t differ significantly according to Duncan’s New Multiple Range test
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Table 7. Effect of salinity levels, magnetite rates and their interactions on resistance index and benefit coefficient of Moringa oleifera Lam. transplants during 2018 and 2019 seasons

| Fe₃O₄ rate (g/plant) | Salt resistance index (%) | Benefit coefficient of Fe₃O₄ (%) |
|----------------------|---------------------------|----------------------------------|
|                      | 0.00  2 g  4 g Mean       | 0.00  2 g  4 g Mean              |
| Salinity level (ppm) |                           |                                  |
| 0.00                 | 100.00a 100.00a 100.00a 100.00A | 0.00h  9.57g 38.34de 15.97D     |
| 2000                 | 93.62b 94.15b 89.23c 92.33B | 0.00h  40.97cd 54.67b 31.88A    |
| 4000                 | 82.03d 81.97d 82.90d 82.30C | 0.00h  35.20h 51.77b 28.99B     |
| 6000                 | 65.86f 71.37e 68.11f 68.45D | 0.00h  34.74f 59.05a 31.27A     |
| 8000                 | 45.39h 58.91g 56.33h 53.54E | 0.00h  27.70f 42.57c 23.42C     |
| Mean                 | 77.38C 81.28A 79.61B       | 0.00C  29.64A 49.28A            |

First season; 2018

Second season; 2019

Mean followed by the same letter in a column or row don’t differ significantly according to Duncan’s New Multiple Range test

Chemical composition of the leaves

It is evident from data presented in Table 8 that the gradual increase of salinity level resulted a gradual decrease in concentrations of chlorophyll a, b and carotenoids (mg/g f.w.) and the percentages of N and P except for 2000 ppm salinity level that raised P concentration to 0.752% versus 0.657% for control. The opposite was the right in relation to K, Na and Cl percentages as well free proline (mg/100 g d.w.). Which was progressively increased with increasing salinity level.

Magnetite, on the other side, linearly elevated concentrations of the previous constituents as the rate of its application was increased except for N and Na percentages which were adversely affected. Also, Fe₃O₄ at 4 g/plant rate diminished Cl %, whereas 2 g/plant rate increased it.

The highest concentrations of chlorophyll a, b, carotenoids and nitrogen were attained by interacting between either zero or 2000 ppm salinity and magnetic iron, especially at 4 g/plant dose, but the highest percent of phosphorus was obtained from 2000 ppm salinity level + magnetite at either 2 or 4 g/plant. The opposite was the right concerning K, Na, Cl and proline, as their maximal concentrations were obtained by combining between 8000 ppm salinity and magnetite at 2 g/plant in most cases of both seasons.
Table 8. Effect of salinity levels, magnetite rates and their interactions on some constituent's concentrations in *Moringa oleifera* Lam. leaves during 2019 seasons

| FeO\(_4\) rate (g/plant) | Chlorophyll a (mg/g f.w.) | Chlorophyll b (mg/g f.w.) | Carotenoids (mg/g f.w.) |
|--------------------------|---------------------------|---------------------------|------------------------|
|                          | 0.00 | 2 g | 4 g | Mean | 0.00 | 2 g | 4 g | Mean | 0.00 | 2 g | 4 g | Mean |
| 0.00                     | 2.103g | 3.384a | 3.219c | 2.902A | 1.640f | 1.837d | 2.226a | 1.901A | 0.733a-c | 0.810a | 0.796ab | 0.780A |
| 2000                     | 2.04g | 3.319b | 3.110d | 2.823B | 1.631f | 1.755e | 2.083b | 1.823B | 0.734a-c | 0.817a | 0.781ab | 0.777A |
| 4000                     | 1.503h | 2.233f | 2.467e | 2.068C | 1.36g | 1.640f | 1.937c | 1.651C | 0.697c | 0.810a | 0.790ab | 0.766A |
| 6000                     | 1.299i | 2.061g | 2.201f | 1.854D | 1.045i | 1.321h | 1.375g | 1.247D | 0.675c | 0.724bc | 0.733-c | 0.711B |
| 8000                     | 0.00j | 1.293i | 1.358i | 1.326E | 0.00j | 1.039i | 1.050i | 1.045E | 0.000e | 0.501d | 0.540d | 0.521C |
| Mean                     | 1.736B | 2.458A | 2.471A | 1.423C | 1.518B | 1.734A | 0.71B | 0.733A | 0.728A | 0.71B | 0.733A | 0.728A |

| Salinity level (ppm)    | N (%) | P (%) | K (%) |
|-------------------------|-------|-------|-------|
| 0.00                    | 4.250bc | 4.250bc | 4.310a | 4.270A | 0.651cd | 0.658c | 0.663c | 0.657B | 1.073l | 1.170g | 1.177h | 1.138E |
| 2000                    | 4.230c | 4.240c | 4.300ab | 4.260A | 0.649cd | 0.726b | 0.880a | 0.752A | 1.328j | 1.396i | 1.465h | 1.396D |
| 4000                    | 3.760f | 3.950e | 4.070d | 3.930B | 0.476g | 0.617e | 0.635d | 0.576C | 1.670g | 1.795f | 1.881e | 1.781C |
| 6000                    | 3.350h | 3.610g | 3.780f | 3.580C | 0.418hi | 0.479g | 0.521f | 0.473D | 1.911d | 2.013c | 2.094b | 2.066B |
| 8000                    | 0.00k | 2.360j | 2.450i | 2.410D | 0.00j | 0.411i | 0.429h | 0.420E | 0.00m | 2.133a | 2.148a | 2.141A |
| Mean                    | 3.900C | 3.680B | 3.782A | 0.549C | 0.578B | 0.626A | 1.496C | 1.700B | 1.753A | 1.496C | 1.700B | 1.753A |

| Mean followed by the same letter in a column or row don’t differ significantly according to Duncan’s New Multiple Range test. |
Discussion

Effect of soil salinity, magnetite and their interaction on vegetative and root growth parameters

The adverse effects of saline soil on growth may be attributed to either low water uptake due to low potential of soil water (Munns, 2002) or certain ion toxicity (Na⁺ and Cl⁻) or both (Carter et al., 2005). This fact was emphasized by Elhag and Abdalla (2014) who stated that salinity depresses plant growth via affecting water absorption and biochemical processes such as N, CO₂ assimilation and protein biosynthesis or accumulated high concentration of potentially toxic ions (Na⁺ and Cl⁻). Jose et al. (2016) ascribed the reduction in growth by salinity to the effect of osmotic stress and the inhibition of cell division rather than cell expansion coupled with the great reduction in photosynthesis. High salinity also leads to leaf abscission due to ion accumulation in the leaves, particularly the oldest ones. Reduction of growth by salinity may be attributed to a decrease in all volume at a constant cell number. Mechanism of salt may result in inhibition of cell division, consequently reduces the rate of plant development (Khan et al., 2009). Jou et al. (2006), however suggested that ATPase participates in the endoplasmic Reticulum-Golgi mediated, protein sorting machinery for both housekeeping function and compartmentalization of excess Na⁺ under high salinity. Such truth was aforementioned by Munns (2002) who proposed that salt tolerant plants may have a low rate of Na⁺ and Cl⁻ transport to leaves beside their ability to compartmentalize these ions in vacuoles to prevent their buildup in the cytoplasm or cell walls and thus avoid salt toxicity. The previous results are in accordance with those postulated by Elhag and Abdalla (2014) who found that stem length and No. leaves of 2-months-old moringa transplants were significantly reduced (30 and 40% successively) by the highest NaCl concentration (0.8%). Hence, the 2-months-old moringa transplants can tolerate NaCl concentration up to 0.4%. This tolerance may be attributed to its ability to restrict the transport of toxic Na⁺ and Cl⁻ ions to the shoot at such lower concentration and their accumulation in the older leaves at higher ones to get rid of them by shedding of those older leaves. So, the mechanism of salinity tolerance of moringa may be the avoidance of toxic ions. Likewise, Cassaniti et al. (2013) claimed that brackish water can be commercially used for production of Chrysanthemum morifolium, Dianthus caryophyllus, Gerbera jamesonii, Hippeastrum vittatum and Anthurium andreanum, up to 2500 ppm. Similarly, were those results of Shahin et al. (2008) on Ficus macrocarpa var. Hawaii and Euonymus Japonica cv. Mediopicta, Shahin et al. (2013) on Ficus benjamina cv. Samanathaand Schefflera arboricola cv. Gold Capella, El-Fouly et al. (2015) on Iris tingitana cv. Wedgewood, Jose et al. (2016) on Eucalyptus urophylla and the hybrid of E. urophylla x E. grandis Shahin et al. (2017) affirmed that a gradual decrement in vegetative and root growth of both Casuarina equisetifolia and Eucalyptus rostrata seedlings was observed due to the gradual increment in salinity concentration from 5000 to 15000 ppm.

On the other hand, the positive effect of magnetic iron on growth of plants suffered from salt stress may be due to its role in promoting the uptake of N, P, K and Fe which stimulates plant growth against the toxicity of Na⁺ and Cl⁻ ions that inhibit it. It induces cell metabolism and mitosis of meristematic cells (Barage et al., 2009). It is believed that new protein bands are formed in plants that are treated with Fe₃O₄ and these proteins are responsible for the increased growth (Hozyan and Abdul-Qodos, 2010). Furthermore, it declines the hydration of salt ions and colloids, increasing salt solubility,
and finally leading to leaching such salts from the soil. In the iron atom, there is a number of valence electrons that generates a magnetic field influence on the biochemical processes in plants and renders the roots to exhibit symptoms of magnetism that kills nematodes and injurious bacteria (Yuliando et al., 2016). The aforementioned gains are in harmony with those obtained by Dos Santos et al. (2011) and Nouman et al. (2012b) on *Moringa oleifera* and Moustafa et al. (2017) who pointed out that seedlings length, No. leaves, root length, No. roots and aerial parts and roots fresh and dry weights of *Moringa oleifera* seedling subjected to salinity up to 8000 ppm were improved in response to applying Fe$_3$O$_4$ at 2 g/pot. Supporting results for this study were also obtained by Abdel-Fattah (2014) on *Jacaranda acutifolia*, Ahmed et al. (2016) on *Acalypha wilkesiana*, Shahin et al. (2018) on *Terminalia arjuna* and El-Sayed et al. (2019) on elephant’s ear tree.

**Salt resistance index (SRI %) and benefit coefficient of magnetite (B. Coe. %).**

These results are reasonable because magnetite usually solubilizes and leaches salts from the soil, and this gives roots a chance to penetrate and distribute well through the growing medium, consequently uptake enough water and nutrients necessary for good and healthy growth. On the same line were those results attained by Al-Qubaie et al. (2003) on *Ficus benghalensis*, Bougainvillea glabra, Jasminum azoricum, Conocarpus erectus, Tamarix articulata and Ziziphus spina-christi, Shahin et al. (2008) on *Ficus macrocarpa* Var. Hawaii and Euonymus Japonica cv. Mediopicta, Abdel-Fattah et al. (2012a) on *Ficus retusa*, Abdel-Fattah et al. (2012b) on *Ficus benjamina* and El-Sayed et al. (2019) on *Enterolobium contortisiliquum*.

**Chemical composition of the leaves**

The previous data showed the effect of the gradual increase of salinity level may be reasonable because salts usually reduces the water potential of soil solution, consequently decreases minerals and water uptake by roots, accompanied by a depression of photosynthesis and enzymes activity (Munns, 2002). It was also remarkable that accumulation of some amino acids and amides in the leaves and roots of salinity-stressed plants may be attributed to *de novo* synthesis by protein sorting machinery and not the result of protein degradation (Jou et al., 2006).

On the other hand, improving constituent’s concentrations by magnetic iron may indicate its role in repairing salinity harms by reducing Na$^+$ and Cl$^-$ toxic ions in the medium, coupled with increasing the free proline formation which improves as a colloid water balance in plant cells (Mostafazadeh et al., 2012). Further, Fe$_3$O$_4$ may create a high energy magnetic field in the root medium which may increase the solubility of N, P, K and Fe nutrients and this in turn promotes the absorption of such minerals, improving ultimately plant growth (Yuliando et al., 2016).

These results, showed a similar trend to those of Elhag and Abdalla (2014) and Moustafa et al. (2017) on *Moringa oleifera*, Ahmed et al. (2016) on *Acalypha wilkesiana*, Shahin et al. (2018) on *Terminalia arjuna* and El-Sayed et al. (2019) who observed that chlorophyll a, b, carotenoids and total carbohydrates concentrations were increased in the leaves of *Enterolobium contortisiliquum* under salt stress by application of Fe$_3$O$_4$ at either 2 or 4 g/plant.
Conclusion

From the previous findings, it can be proposed to apply magnetic iron at the rate 4 g/plant for enhancing growth and quality of Moringa oleifera seedlings under salt stress up to 6000 ppm.

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