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# The effect of the interaction of magnetic treatment and different irrigation water salinity on the quantitative effects on the growth parameters of Balkız Bean (*Phaseolus vulgaris*)

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*Magnetic water treatment, Bean, Salinity stress, Yield response factor*

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**ABSTRACT**

Salinity is one of the important factors that limit plant growth and development. Therefore, new tools must be developed to use saline water in agriculture and reduce its harm. One of these tools is the use of magnetically treated water to irrigate crops, which has an effective effect on the development and growth of plants and reduces the accumulation of salts in the soil. Therefore, this study was conducted to find out the effect of the interaction between magnetic treatment (MT), non-magnetic (NMT) and the salinity of irrigation water (T1 = 0.38 $dSm^{-1}$ (tap water), T2 = 1.50 $dSm^{-1}$, T3 = 4.50 $dSm^{-1}$ and T4 = 7.0 $dSm^{-1}$) on the amount of accumulated salt (ASA) and relative water content of leaves (RLWC) and quantitative effects on the growth parameters of the Bean. The study results showed that salinity stress led to a significant decrease in total plant fresh weight (TPFW), leaf relative water content (RLWC), and total plant dry weight (TPDW), While it increased (ASA) significantly. Magnetically treated irrigation water (MT) increased the (TPFW) and weight (TPDW) by 25.24% and 21.47%, respectively, while the (ASA) decreased by 22.70% compared with NMT treatment. The highest (RLWC) values were obtained at MT with T1 salinity (tap water) (0.38 $dSm^{-1}$) and were 79.27%. The yield response factor (Ky) value was found 1.68 and 1.69 for MT and NMT treatments, respectively. The results showed that magnetic water has a positive effect on the quantitative effects of bean plant growth indicators and that salinity reduces plant growth.

# تأثير تفاعل المعالجة المغناطيسية وملوحة مياه الري المختلفة على التأثيرات الكمية على عوامل النمو (*Phaseolus Vulgaris*)

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**الخلاصة**

الملوحة هي أحد العوامل المهمة التي تحد من نمو النبات وتطوره. لذلك ، يجب تطوير أدوات جديدة لاستخدام المياه المالحة في الزراعة والحد من ضررها. ومن هذه الأدوات استخدام المياه المعالجة مغناطيسيا لري المحاصيل ، مما له تأثير فعال على نمو النباتات ونموها ويقلل من تراكم الأملاح في التربة. لذلك ، أجريت هذه الدراسة لمعرفة تأثير التفاعل بين المعالجة المغناطيسية (MT) ، غير المغناطيسية (NMT) وملوحة مياه الري ( T1 = 0.38 dSm-1 (tap water), T2 = 1.50 dSm-1, T3 = 4.50 dSm-1 and T4 = 7.0 dSm-1) على كمية الملح المتراكم (ASA) والمحتوى المائي النسبي للأوراق (RLWC) والآثار الكمية على المعلمات نمو الفول. أظهرت نتائج الدراسة أن إجهاد الملوحة أدى إلى انخفاض كبير في إجمالي وزن النبات ، ومحتوى الماء النسبي للأوراق ، وإجمالي وزن النبات الجاف ، بينما زاد بشكل ملحوظ. وزادت مياه الري المعالجة مغناطيسيا (TPFW) والوزن (TPDW) بنسبة 25.24 ٪ و 21.47 ٪ على التوالي ، في حين انخفض (ASA) بنسبة 22.70 ٪ مقارنة مع العلاج نمت. تم الحصول على أعلى قيم (RLWC) عند طن متري مع ملوحة تي 1 (tap water) (0.38 دسم-1) وكانت 79.27٪. تم العثور على قيمة عامل استجابة العائد (Ky) 1.68 و 1.69 ل مت و نمت العلاجات ، على التوالي. أظهرت النتائج أن الماء المغناطيسي له تأثير إيجابي على التأثيرات الكمية لمؤشرات نمو نبات الفول وأن الملوحة تقلل من نمو النبات.

**الكلمات المفتاحية:** معالجة المياه المغناطيسية ، إجهاد الملوحة ، عامل استجابة الغلة.

## INTRODUCTION

The bean is the most widely cultivated legume crop in the world, and is widely produced worldwide in Asia, Latin America, and African countries (Broughton *et al.*,, 2003; Türker and Çoruh, 2003). According to FAO 2020 data, world the area of green bean cultivation is 1,579,489 dunums and production is 23,276,716 tons, while the area of dry bean cultivation is 34,801,567 dunums and production is 27,545,942 tons (FAO, 2022). According to FAO 2020 data, In Turkey, ranks 4th in the world in green bean production, Turkey the area of green bean cultivation is 39,255 dunums and production is 547,349 tons, while the area of dry bean cultivation is 102,963 dunums and production is 279,518 tons (FAO, 2022).

Water is considered one of the important factors in agriculture, and due to the shortage of water in the world and the increase in the world population, the water demand has increased day after day. Therefore, farmers resorted to using saline water to fill the water shortage. Salinity stress is one of the main problems for irrigation water and soil and poses a serious threat to crops (Alsuvaid, 2021; Alsuvaid *et al.*,, 2022). However, the salinity of irrigation water is considered an important factor that affects the growth and development of plants and the decline in crop productivity in many countries of the world (Beyaz and Kazankaya, 2024). Salinity reduces the development and growth of plants due to osmotic pressure, which reduces the absorption of water by the roots, which in turn leads to an increase in the accumulation of salts in the roots of the plant (Alsuvaid, 2021; Alsuvaid and Demir., 2022). Salinity is one of the important environmental factors that negatively affect agriculture. Therefore, appropriate measures must be taken to reduce the effects of salinity on plant development and growth. One of the approaches to the measures to be taken may be to produce new salt-tolerant plants and the selection of an appropriate irrigation method (Alsuvaid *et al.*,, 2022).

At present, new strategies are used that are magnetic water technology (Rezende *et al.*,, 2019). Magnetic water, compared to non-magnetic water, aims to break the hydrogen bonds between water molecules, which leads to a decrease in the molecular size and a decrease in the viscosity of the water (Hozayn and Ahmed, 2019, Alsuvaid *et al.*,, 2022; Alsuvaid and Demir., 2022). The magnetic treatment greatly changes surface tension, hydrogen bonding angle, and decreases viscosity, which ultimately affects the solubility of metals in the water Alsuvaid *et al.,* (2022). Several researchers found that magnetic treatment positively affected seed germination (Hozayn *et al.,* 2015). The magnetic treatment of irrigation water positively affects the growth and development of plants. (Hozayn *et al.,* 2014; ul Haq *et al.,* 2016). The magnetic treatment of irrigation water can help improve plant growth and crop quality (Massah *et al.*,, 2019). Besides, irrigation with magnetically treated water helps improve soil properties and reduces the accumulation of salts around the plant (Hamza *et al.*,, 2021).

The relative water content of the leaves (RLWC) is a good indication of the state of water in the leaves of the plant and an important tool to endure water in the leaves of the plant and crops. (Virginia *et al.*,, 2012). Leaf relative water content (LRWC) affects the physiological processes of plants, stomata conduction, photosynthesis, and plant growth (Meguekam *et al.*,, 2021). Leaf relative water content (RLWC) is an important factor for yield stability, the higher the RLWC the higher the crop yield (Jafari and Garmdareh, 2019; Meguekam *et al.*,, 2021). With an increase in RLWC values, grain yield values increase. (Zhang *et al.*,, 2021). They found that as salinity levels increased, the relative water content (RLWC) decreased (El-Bassiouny and Bekheta, 2005; Jafari and Garmdareh, 2019). Plant quantitative growth parameters help to establish a relationship between yield-determining factors in plants and yield (Poorter and Garnier, 1996). Plant quantitative growth parameters allow the determination of plant life cycles, stages of development, and nutrients accumulated in plants (Uzun, 1996). Quantitative plant growth parameters have been widely used in different fields such as plant ecology and plant breeding (Poorter and Garnier, 1996).

However, there are still few studies on understanding how different water salinity conditions and magnetic applications affect the growth parameters of green bean cultivation. The current study aims to better understand how to evaluate and model the quantitative effects on bean growth parameters, yield response factor (Ky), leaf relative water content (RLWC), dry matter ratio of leaf-stem-root (DM), and amount of salt accumulated under different salinity conditions of magnetically and non-magnetic treated water.

## MATERIAL AND METHODS

### Experiment specifications and plant source

The experiment was conducted by the Faculty of Agriculture of Ondokuz Mayis University in Turkey Fig. **1**, in a rain shelter (20 m long, 6 m wide, and 120 $m^2$), covered with a plastic cover from the top open from four sides. From May 8 to August 28, 2018, the green bean plant "Balkız" was used in the study. A daily relative humidity and temperature data logger was placed in the middle of the rain shelter at a height of 2 m, a

Datalogger (KISTOCK Brand KIMO datalogger) was used to record the data. Table 1 shows the minimum and maximum values of temperature and relative humidity monthly.


Figure 1. Map of the experimental field of research work

Table 1. The minimum and maximum values of temperature and relative humidity monthly.

| | Months | May | June | July | August |
|---|---|---|---|---|---|
| Temperature (° C) | Maximum | 26.4 | 28.2 | 33.5 | 37.4 |
| | Minimum | 17.3 | 18.7 | 22.8 | 26.5 |
| Relative humidity (%) | Maximum | 88.4 | 93.3 | 90.3 | 86.8 |
| | Minimum | 52.1 | 49.5 | 45.8 | 37.8 |

The magnetic device (VR-WS-D-001), which is made in China by Vigorrain Technology Co., Ltd., was used. Specifications (diameter 51mm, connector port 1/2-inch, and total length 120mm). Magnetized irrigation water is obtained by passing it through a magnetic field (Fig. 2).

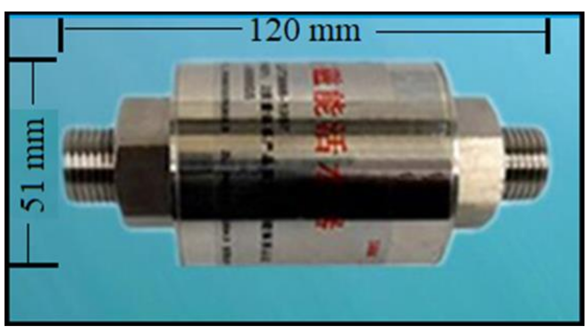


Figure 2. Magnetic treatment device

Table 2. Chemical and physical analysis of soil

| Physical properties | Values | Unit |
|---|---|---|
| **Clay** | 301 | g $kg^{-1}$ |
| **Sand** | 473 | g $kg^{-1}$ |
| **Silt** | 224 | g $kg^{-1}$ |
| **Soil texture** | Sandy clay loam | - |
| **Field capacity** | 32.2 | g $kg^{-1}$ |
| **Wilting point** | 15.4 | g $kg^{-1}$ |
| **Soil depth** | 25 | cm |
| **Total N** | 0.0268 | g $kg^{-1}$ |
| **Total P** | 156**0.0** | g $kg^{-1}$ |
| **Total K** | 245**0.0** | g $kg^{-1}$ |
| **Total Ca** | 0.0081 | g $kg^{-1}$ |
| **Organic matter** | 1.22 | g $kg^{-1}$ |
| **Saturated pH** | 7.95 | - |
| **Saturated $EC_e$** | 0.31 | $dSm^{-1}$ |

Note: The N, Ca, P, and K imply Nitrogen, Calcium, Phosphor, and Potassium, respectively

Polyethylene pots of 25 liters were used [height 33 cm, top diameter 34 cm, 29.5 cm, base diameter]. To provide good drainage for the plant, 3.5 kg sand-gravel was filled at the bottom of the pots, then 25 kg air-dried soil was added after sifting through a 4 mm mesh sieve. Before sowing the bean plant seeds, urea fertilizers at the rate of 3.36 g $pot^{-1}$, and diammonium phosphate fertilizer at the rate of 1.20 g $pot^{-1}$, were added to the soil. The fertilizers were added based on the results of the soil analysis used. Table 2 shows the chemical and physical analysis of soil.

**Experimental design and irrigation practices**

The experiment design was conducted in a completely randomized design with two factors (magnetic irrigation water treatments and irrigation water salinity) with three replications. Magnetic treatment was applied at two levels, non-magnetic treated water (NMT) and magnetic treated water (MT). In addition, four levels of the irrigation water salinity were applied (T2 = 1.50 $dSm^{-1}$, T3 = 4.50 $dSm^{-1}$ and T4 = 7.0 $dSm^{-1}$) and tap (normal) water (T1 = 0.38 $dSm^{-1}$). Saline waters were obtained by adding salts (MgSO4, CaCl2, and NaCl) to tap (normal) water (T1 = 0.38 $dSm^{-1}$) for each treatment. The chemical analysis of water before and after magnetization is shown in Table 3. Total number unit of the experiment 24 pots

Table 3. Chemical properties of irrigation water

| saline water $dSm^{-1}$ | | Parameters | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | EC ($dSm^{-1}$) | pH | $Na^{+}$ ($cmolcL^{-1}$) | $K^{+}$ ($cmolcL^{-1}$) | $Ca^{++}$ ($cmolcL^{-1}$) | $CI^{-1}$ ($cmolcL^{-1}$) | $SO4^{-2}$ ($cmolcL^{-1}$) | $Mg^{+2}$ ($cmolcL^{-1}$) | SAR |
| NMT | $T_1$ (0.38) | 0.038 | 7.65 | 0.09 | 0.004 | 0.063 | 0.152 | 0.258 | 0.564 | 0.51 |
| | $T_2$ (1.5) | 1.5 | 7.78 | 0.43 | 0.008 | 0.286 | 1.005 | 0.774 | 1.086 | 1.64 |
| | $T_3$ (4.5) | 4.5 | 7.86 | 1.83 | 0.032 | 1.257 | 4.215 | 5.245 | 5.615 | 3.12 |
| | $T_4$ (7.0) | 7 | 8.08 | 3.683 | 0.0697 | 2.472 | 6.913 | 9.351 | 9.327 | 4.8 |
| MT | $T_1$ (0.38) | 0.39 | 7.67 | 0.087 | 0.004 | 0.061 | 0.143 | 0.2.47 | 0.552 | 0.5 |
| | $T_2$ (1.5) | 1.47 | 7.8 | 0.421 | 0.008 | 0.281 | 0.994 | .763**0** | 1.073 | 1.62 |
| | $T_3$ (4.5) | 4.45 | 7.87 | 1.799 | 0.029 | 1.249 | 4.201 | 5.237 | 5.596 | 3.08 |
| | $T_4$ (7.0) | 6.9 | 8.1 | 3.614 | 0.066 | 2.462 | 6.896 | 9.34 | 9.311 | 4.71 |

**Note**: MT: magnetized irrigation treatment; NMT: non-magnetized irrigation treatment.
Irrigation water (IW) was added according to equation (1) (Ünlükara *et al.*,, 2010; Alsuvaid *et al.*, 2022).

$$IW=\frac{\frac{W_{FC}-W_a}{\rho_w}}{1-LF} \qquad (1)$$

LF: leaching fraction and its value LF = 15% Ayers & Westcot (1985); IW: amount of the irrigation water (liter); $\rho_w$: the bulk density for water and its value (1 kg $L^{-1}$); $W_{FC}$ and $W_a$: pot weight at field capacity and immediately before irrigation respectively (kg).
Irrigation was practiced when 70% of the soil's field capacity was reached. The field capacity was maintained by knowing the change in the weight of the pot every day. The process of adding the required irrigation water is done manually to the plant.

**Yield and plant growth parameters**

Bean plants were harvested, and yield (fresh weight of green beans) and plant growth characteristics (leaf-stem-root fresh weights, and leaf area per plant) were determined. The leaf-stem-root was placed in an oven at 75 °Cto constant dry weights were reached, to obtain leaf-stem-root dry weights (g $plant^{-1}$). The equations used to calculate the quantitative growth parameters are given in Table 4. Plant leaf area was calculated by scanning the plant leaf (1:1) using a digital scanner and then calculating the leaf area using the software Adobe Photoshop CS6.

Table 4. Equations used in calculating quantitative growth parameters

| **Traits** | **Measurement methods** |
|---|---|
| Specific Leaf Area (SLA) | Total leaf area ($cm^2$)/ Total leaf dry weight(g) |
| Leaf Area Ratio (LAR) | Total leaf area ($cm^2$)/ Total plant dry weight(g) |
| Leaf Weight Ratio (LWR) | Total leaf dry weight (g) / Total plant dry weight (g) |
| Stem Weight Ratio (SWR) | Total stem dry weight (g) / Total plant dry weight (g) |
| Root Weight Ratio (RWR) | Total root dry weight (g) / Total plant dry weight (g) |

**Evapotranspiration (ET), Ky, RLWC, DM, and Amount of Salt Accumulated**

Evapotranspiration was calculated according to the following equation (2) (Alsuvaid and Demir., 2022).

$$ET=\frac{IW\ -\ DP\ \pm\ \Delta S}{\rho_w} \quad (2)$$

Where IW: amount of the irrigation water (liter), ΔS: changes in the soil storage of water in the pots between two successive irrigations (kg), DP is the deep percolation (liter) (the volume of leachate water collected from the drain pan placed under the pots).

Yield response factor (Ky) to water stress, to estimate bean yield under magnetized and unmagnetized irrigation water salinity conditions, was determined according to the equation (Doorenbos and Kassam (1986)).

$$\left[1-\frac{Y_a}{Y_m}\right]=K_y\left[1-\frac{ET_a}{ET_m}\right] \quad (3)$$

Where, Ya is the bean yield under salinity conditions (g pot$^{-1}$), Ym is the bean yield under control treatment (g pot$^{-1}$), ETa and ETm are, respectively, actual evapotranspiration (mm) for salinity treatments and maximum evapotranspiration (mm) for control treatments. Relative leaf water content (RLWC) (%) Leaf samples were taken from the plant before harvesting in the early morning hours and transferred directly to the laboratory. Circular pieces of leaves were taken using a cutting cylinder with a diameter of 3 cm, and the fresh weight of leaves (FW) was determined by weighing them. The weighed leaves were placed in distilled water for 24 hours in a closed petri dish. After drying the surface of the leaves with a paper towel, the weight of the samples was taken to determine the total mass (TW). It was placed in an oven at 75°C for48 hours to determine the dry weight. was determined according to the equation explained by (Yamasaki and Dillenburg, 1999) (Larbi and Mekliche, 2004) (Jafari and Garmdareh, 2019)

$$RLWC=\left[\frac{FW-DW}{TW-DW)}\right]\times 100 \quad (4)$$

TW, FW, DW: turgid, fresh, dry weight (g), respectively.

The dry matter (DM) ratio was determined according to equation 3, samples taken from the leaf, stem, and root of plants were dehydrated at70 °C to reach a constant dry weight (Kacar **&** İnal 2008).

$$DM=\left[\frac{FW\ (g\ pot^{-1})}{DW\ (g\ pot^{-1})}\right]\times 100 \quad (5)$$

Amount of Salt Accumulated (ASA) (g pot$^{-1}$) After harvesting the bean plants, soil samples were taken from the middle of each pot, air-dried and sieved through a 2-mm-diameter sieve. The soil salinity (ECe) was measured according to the saturated soil extract method (Rhoades *et al.*, 1989), and the (ECe) was measured by an Eutech pc 510EC / pH meter.

$$ASA=\left[\frac{640\times ECe\times WS}{1000}\right] \quad (6)$$

Where WS is the weight of the soil that was placed in the pot at the start of the experiment (kg).

**Statistical analysis**

JMP version 13.2 and Design-Expert version 13.0 were used to analyze the data to evaluate the quantitative effects on the growth parameters of Balkız Bean (Phaseolus Vulgaris) under different irrigation water salinity levels and magnetic applications. Data analysis was performed statistically by two-way analysis of variance (ANOVA) at the level of significance (LS D, P <0.05) (Steel and Torrie 1980).

## RESULTS AND DISCUSSION

The effects of irrigation water salinity and magnetic treatments on the amount of accumulated salt (ASA) and relative leaf water content (RLWC) were statistically significant ($p \leq 0.0001$) (Table 6). The amount of salt accumulated in the soil increased with the increase in the salinity levels of the irrigation water. The lowest ASA value of 10.53 (g pot$^{-1}$) was found in treatment T1 (0.38 dSm$^{-1}$), while the highest value was found at 66.56 (g pot$^{-1}$) in treatment T4 (7.00 dSm$^{-1}$) (Table 6). This result is similar to Mohamed and Ebead (2013) and Feng *et al.,* (2017) that irrigation with saline water increased the accumulation of salts in the soil. However, ASA values were significantly decreased in magnetic irrigation (MT) water by 22.70% compared with NMT (Table 6). The interaction effects between irrigation water salinity and magnetic treatments on ASA were statistically significant ($p \leq 0.0001$) (Table 5). The highest ASA value of 75.36 (g pot$^{-1}$) was obtained in NMT treatment with T4 irrigation water salinity, while the lowest ASA value of 9.56 (g pot$^{-1}$) was obtained in MT with T1 salinity (Table 6). ASA was positively associated with LDMA (r = 0.93), SDMA (r = 0.95), RDMA (r = 0.90) and LWR (r = 0.84) and was negatively associated with TPFW (r = -0.95) and TPDW (r = -0.95) which was significant at levels $p \leq 0.0001$ (Fig. 4).

Table 5. Summary of analysis of variance (ANOVA) for the effects of magnetic treatments (MT) and irrigation water salinity (IWS) on the amount of salt accumulated (ASA), relative leaf water content (RLWC), total plant fresh weight (TPFW), total plant dry weight (TPDW), leaf area ratio (LAR) and specific leaf area (SLA) of balkız bean crops.

| Source of variation | dF | ASA (g pot$^{-1}$) | | RLWC (%) | | TPFW (g plant-1) | |
|---|---|---|---|---|---|---|---|
| | | Mean Square | $LSD_{0.05}$ | Mean Square | $LSD_{0.05}$ | Mean Square | $LSD_{0.05}$ |
| C. Total | 23 | | | | | | |
| MT | 1 | 516.31*** | 0.81 | 3.17*** | 0.27 | 581.71*** | 0.97 |
| IWS | 3 | 3996.86*** | 1.15 | 129.54*** | 0.39 | 3164.38*** | 1.37 |
| MT* IWS | 3 | 69.98*** | 1.63 | 0.25*** | 0.55 | 16.52** | 1.94 |
| Error | 16 | 0.86 | - | 0.10 | - | 1.23 | - |
| CV (%) | - | - | 2.56 | - | 0.43 | - | 2.53 |
| **Source of variation** | **dF** | **TPDW (g plant$^{-1}$)** | | **LAR (cm$^2$ g$^{-1}$)** | | **SLA (cm$^2$ g$^{-1}$)** | |
| | | Mean Square | $LSD_{0.05}$ | Mean Square | $LSD_{0.05}$ | Mean Square | $LSD_{0.05}$ |
| C. Total | 23 | | | | | | |
| MT | 1 | 25.12*** | 0.27 | 229.04*** | 1.39 | 201.60* | 4.47 |
| IWS | 3 | 148.08*** | 0.39 | 13344.76*** | 1.97 | 150970.60*** | 6.33 |
| MT* IWS | 3 | 0.84** | 0.55 | 52.05*** | 2.79 | 780.90*** | 8.95 |
| Error | 16 | 0.10 | - | 2.53 | - | 26.10 | - |
| CV (%) | - | - | 2.97 | - | 1.00 | - | 1.32 |

NS: Not significant,* Significant at $p \leq 0.05$,** Significant at $p \leq 0.001$,*** Significant at $p \leq 0.0001$.CV¼: coefficient of variation,dF: degrees of freedom

The maximum leaf relative water content was 79.02 (RLWC) occurred for the T1 treatment, while the minimum for the T4 treatment was 68.03 recorded. The RLWC for T2, T3, and T4 treatments decreased by 7.20%, 10.11%, and 13.90%, respectively, compared to the T1 treatment (Table 6). Increasing levels of irrigation water salinity lead to a decrease in the leaf relative water content (RLWC) (Meguekam *et al.*, 2021). Similarly, our results showed that with increasing levels of irrigation water salinity increased soil salt accumulation resulting in lower RLWC. A similar result was reported in wheat (El-Bassiouny and Bekheta 2005), pepper (Wang *et al.*, 2012), Iris lacteal (Taffouo *et al.*, 2017) peanut, and (Meguekam *et al.,* 2021). An increase in salinity leads to the plants not being able to take up their water needs and this leads to a rapid decrease in the growth rate of plants (Munns 2002). The highest RLWC value (79.27) was obtained in the MT treatment, and the lowest value (67.38) was observed in the NMT treatment. The interaction effects between irrigation water salinity and magnetic treatments on RLWC were statistically significant ($p \leq 0.0001$) (Table 5). The highest RLWC value of 79.27 % was determined in the MTT1 treatment, while the lowest RLWC value of 67.38 % was obtained in the NMTT4 treatment (Table 6). The RLWC was significantly positively associated with LAR ($r = 0.94$), SLA ($r = 0.98$), TPFW ($r = 0.92$), TPDW ($r = 0.94$) and SWR ($r = 0.74$) and was negatively associated with LWR ($r = -0.74$), LDMA ($r = -0.84$), SDMA ($r = -0.85$), RDMA ($r = -0.81$) and ASA ($r = -0.91$) which were significant at $p \leq 0.0001$ levels (Fig. 4).

Table 6. Effects of magnetic treatments and different irrigation water salinity on the amount of salt accumulated (ASA), relative leaf water content (RLWC), total plant fresh weight (TPFW), total plant dry weight (TPDW), specific leaf area (SLA) and leaf area ratio (LAR) of balkız bean crops.

| Magnetic effect | Treatments | ASA (g pot$^{-1}$) | RLWC (%) | TPFW (g plant$^{-1}$) | TPDW (g plant$^{-1}$) | LAR (cm$^2$ g$^{-1}$) | SLA (cm$^2$ g$^{-1}$) |
|---|---|---|---|---|---|---|---|
| NMT | | 40.86a | 72.49b | 39.00b | 9.53b | 162.81a | 389.91a |
| MT | | 31.59b | 73.22a | 48.85a | 11.58a | 156.63b | 384.12b |
| Irrigation water salinity effect | | | | | | | |
| $T_1$ (0.38 dSm$^{-1}$) | | 10.53d | 79.02a | 68.39a | 16.11a | 225.59a | 592.75a |
| $T_2$ (1.50 dSm$^{-1}$) | | 19.63c | 73.33b | 52.81b | 12.18b | 162.09b | 419.17b |
| $T_3$ (4.00 dSm$^{-1}$) | | 48.16b | 71.03c | 40.47c | 9.67c | 125.68c | 311.81c |
| $T_4$ (7.00 dSm$^{-1}$) | | 66.56a | 68.03d | 14.04d | 4.25d | 125.53c | 224.33d |
| Magnetic Treatments x irrigation water salinity interaction | | | | | | | |
| NMT | $T_1$ | 11.50g | 78.76a | 61.90b | 14.88b | 231.23a | 607.63a |
| | $T_2$ | 22.59e | 72.96c | 48.86d | 11.52d | 164.62c | 419.34c |
| | $T_3$ | 54.00c | 70.85d | 34.31e | 8.23e | 130.70e | 320.00d |
| | $T_4$ | 75.36a | 67.38f | 10.95g | 3.49g | 124.69f | 212.68g |
| MT | $T_1$ | 9.56h | 79.27a | 74.87a | 17.35a | 219.95b | 577.88b |
| | $T_2$ | 16.68f | 73.70b | 56.76c | 12.84c | 159.56d | 418.99c |
| | $T_3$ | 42.33d | 71.21d | 46.63d | 11.11d | 120.65g | 303.63e |
| | $T_4$ | 57.77b | 68.68e | 17.143f | 5.01f | 126.37f | 235.97f |

**Note:** MT:magnetized irrigation treatment; NMT:non-magnetized irrigation treatment.Mean values in the same columns followed by the same letters are not significantly different according to the LSD test ($P < 0.05$).

The effects of irrigation water salinity and magnetic treatments and the interaction effects between irrigation water salinity and magnetic treatments on the total plant fresh weight (TPFW) and total plant dry weight (TPDW) were statistically significant ($p \leq 0.0001$) (Table 5). The total plant fresh weight (TPFW) decreased from 68.39 to 14.04 g plant$^{-1}$ when the salinity of the irrigation water increased from 0.38 dSm$^{-1}$ to 7.00 dSm$^{-1}$ (Table 6). Increasing the salinity level of the irrigation water from 0.38 dSm$^{-1}$ to 7.00 dSm$^{-1}$ resulted in a decrease of 79.46% in TPFW. Moreover, the use of magnetic irrigation water (MT) increased TPFW values by 16.20% compared to NMT (Table 6). The lowest TPFW values of 10.95 g plant$^{-1}$ were obtained at 7.00 dSm$^{-1}$ IWS under NMT conditions. In addition, TPFW values of 74.78 g plant$^{-1}$ were reasonably higher for MT with 0.38 dSm$^{-1}$ treatment (Table 6). There was a significant positive association between TPFW and LAR (r = 0.80), SLA (r = 0.91) and SWR (r = 0.89) and it was negatively associated with LWR (r = -0.89), LDMA (r = -0.96), SDMA (r = -0.95), RDMA (r = -0.94) which were significant at p≤0.0001 levels (Fig. 3). An increase in the salinity level of the irrigation water (IWS) resulted in a significant decrease in the total plant dry weight (TPDW). TPDW decreased by 24.44%, 40.00% and 73.61% for 1.50, 4.50 and 7.00 $dSm^{-1}$, respectively, compared to 0.38 $dSm^{-1}$ (Table 6). Besides, TPDW increased by 17.67% when using magnetic irrigation water (MT) compared with NMT (Table 6). TPDW values decreased significantly with increasing IWS from 0.38 $dSm^{-1}$ to 7.00 $dSm^{-1}$ IWS. The highest value of TPDW was 17.35 observed in MT at 0.38 $dSm^{-1}$ IWS, while the lowest value was 3.49 in NMT at 7.00 $dSm^{-1}$. In addition, TPDW values decreased by 22.63%, 44.72%, 76.53% for NMTT2, NMTT3, NMTT4 processors, and 25.99%, 35.95%, 71.10% for MTT2, MTT3, MTT4, respectively, compared to NMTT1 and MTT1 processors (Table 6). There was a significant positive association between TPDW and LAR (r = 0.82), SLA (r = 0.93) and SWR (r = 0.87) and it was negatively associated with LWR (r = -0.88), LDMA (r = -0.95), SDMA (r = -0.94), RDMA (r = -0.93) which were significant at p≤0.0001 levels (Fig. 4).

The effect of magnetic treatments and the interaction effects between irrigation water salinity and magnetic treatments on leaf area ratio (LAR) and specific leaf area (SLA) was statistically significant (P<0.0001), and the effect of irrigation water salinity on LAR and SLA were statistically significant (P<0.0001) and (P<0.05) respectively (Table 5). The LAR and SLA values decreased with the increase in the salinity of the irrigation water. LAR and SLA decreased from 225.59 $cm^2g^{-1}$ and 592.75 $cm^2\ g^{-1}$ for T1 treatment to 125.53 $cm^2\ g^{-1}$ and 224.33 $cm^2\ g^{-1}$ for T4 treatment, a decrease of 44.35% and 62.16%, respectively (Table 6). The mean LAR and SLA values for NMT treatment were higher than the mean values for MT treatment. The LAR values decreased by 28.81%, 43.48%, 46.08% for the NMTT2, NMTT3, and NMTT4 treatments, and 27.46%, 45.14%, 42.54% for MTT2, MTT3, and MTT4, respectively, compared to the NMTT1 and MTT1 treatments. In addition, SLA values decreased by 30.99%, 47.34%, 65.00% for the NMTT2, NMTT3, and NMTT4 treatments, and 27.49%, 47.46%, 59.17% for MTT2, MTT3, and MTT4, respectively, compared to the NMTT1 and MTT1 treatments (Table 6). There was a significant positive association between LAR and SLA (r = 0.97) and it was negatively associated with LDMA (r = -0.68), SDMA (r = -0.72), RDMA (r = -0.64) which were significant at p≤0.0001 levels (Fig. 4).

Table 7. Summary of analysis of variance (ANOVA) for the effects of magnetic treatments (MT) and irrigation water salinity (IWS) on the leaf dry matter amount (LDMA), stem dry matter amount (SDMA), root dry matter amount (RDMA), root weight ratio (RWR), leaf weight ratio (LWR) and stem weight ratio (SWR) of balkız bean crops.

| Source of variation | dF | LDMA (%) | | SDMA (%) | | RDMA (%) | |
|---|---|---|---|---|---|---|---|
| | | Mean Square | $LSD_{0.05}$ | Mean Square | $LSD_{0.05}$ | Mean Square | $LSD_{0.05}$ |
| C. Total | 23 | | | | | | |
| MT | 1 | 25.44*** | 0.37 | 6.42*** | 0.42 | 13.97** | 0.67 |
| IWS | 3 | 369.41*** | 0.52 | 394.08*** | 0.60 | 409.09*** | 0.95 |
| MT* IWS | 3 | 0.33 $^{NS}$ | 0.73 | 0.60 $^{NS}$ | 0.85 | 0.10 $^{NS}$ | 1.35 |
| Error | 14 | 0.18 | - | 0.24 | - | 0.59 | - |
| CV (%) | - | - | 1.32 | - | 1.94 | - | 2.14 |
| Source of variation | dF | LWR (g $g^{-1}$) | | RWR (g $g^{-1}$) | | SWR (g $g^{-1}$) | |
| | | Mean Square | $LSD_{0.05}$ | Mean Square | $LSD_{0.05}$ | Mean Square | $LSD_{0.05}$ |
| C. Total | 23 | | | | | | |
| MT | 1 | 0.00182*** | 0.0036 | 0.0000019 $^{NS}$ | 0.0026 | 0.00153*** | 0.0043 |
| IWS | 3 | 0.04395*** | 0.0051 | 0.0001795*** | 0.0037 | 0.03783*** | 0.0061 |
| MT* IWS | 3 | 0.00047*** | 0.0072 | 0.0000473** | 0.0053 | 0.00048*** | 0.0087 |
| Error | 14 | 0.00002 | - | 0.0000090 | - | 0.00003 | - |
| CV (%) | - | - | 0.95 | - | 2.07 | - | 1.18 |

$^{NS}$: Not significant, * Significant at p≤0.05, ** Significant at p≤0.001, *** Significant at p≤0.0001. CV¼: coefficient of variation, dF: degrees of freedom

The effect of irrigation water salinity on leaf dry matter amount (LDMA), stem dry matter amount (SDMA), and root dry matter amount (RDMA) was statistically significant (P<0.0001), The effect of magnetic treatments on LDMA, SDMA and RDMA were statistically significant (P<0.0001), (P<0.0001) and (P<0.001) respectively (Table 7). The interaction effects between irrigation water salinity and magnetic treatments on LDMA, SDMA and RDMA were not significant. The values of LDMA, SDMA, and RDMA increased with the increase in salinity of the irrigation water. LDMA, SDMA, and RDMA values increased from 25.54 %, 18.61% and 30.00% for T1 treatment to 42.86%, 36.17%, and 48.05% for T4 treatment, respectively. However, the values of LDMA, SDMA and RDMA in magnetic irrigation (MT) water decreased by 6.73%, 4.23% and 4.33%, respectively compared with NMT (Table 8). The lowest LDMA, SDMA, and RDMA values of 24.63%, 18.44% and 29.39%, respectively, were obtained at 0.38 $dSm^{-1}$ under MT conditions. In addition, LDMA, SDMA, and RDMA values of 44.17%, 36.97%, and 48.85%, respectively, were reasonably higher for NMT with 7.00 $dSm^{-1}$ treatment (Table 6). There was a significant positive association between LDMA and SDMA (r = 0.99) and RDMA (r = 0.99) and it was negatively associated with SLA (r = -0.84) and SWR (r = -0.97) which were significant at p≤0.0001 levels (Fig. 4).

Table 8. Effects of magnetic treatments and different irrigation water salinity on the leaf dry matter amount (LDMA), stem dry matter amount (SDMA), root dry matter amount (RDMA), root weight ratio (RWR), leaf weight ratio (LWR) and stem weight ratio (SWR) of balkız bean crops.

| Magnetic effect | Treatments | LDMA (%) | SDMA (%) | RDMA (%) | LWR ($g\ g^{-1}$) | RWR ($g\ g^{-1}$) | SWR ($g\ g^{-1}$) |
|---|---|---|---|---|---|---|---|
| NMT | | 32.65a | 25.46a | 36.79a | 0.44a | 0.145a | 0.412b |
| MT | | 30.60a | 24.43b | 35.26b | 0.42b | 0.144a | 0.428a |
| Irrigation water salinity effect | | | | | | | |
| $T_1$ (0.38 $dSm^{-1}$) | | 25.54d | 18.61d | 30.00d | 0.38d | 0.142c | 0.468a |
| $T_2$ (1.50 $dSm^{-1}$) | | 27.03c | 19.42c | 31.35c | 0.39c | 0.148b | 0.459b |
| $T_3$ (4.00 $dSm^{-1}$) | | 31.06b | 25.59b | 34.70b | 0.40b | 0.151a | 0.450c |
| $T_4$ (7.00 $dSm^{-1}$) | | 42.86a | 36.17a | 48.05a | 0.56a | 0.139c | 0.301d |
| Magnetic Treatments x irrigation water salinity interaction | | | | | | | |
| NMT | $T_1$ | 26.45f | 18.78f | 30.61f | 0.39f | 0.142b | 0.464ab |
| | $T_2$ | 27.81e | 19.75e | 32.08e | 0.39de | 0.144b | 0.460b |
| | $T_3$ | 32.19c | 26.36c | 35.60c | 0.41c | 0.153a | 0.443c |
| | $T_4$ | 44.17a | 36.97a | 48.85a | 0.58a | 0.142b | 0.281e |
| MT | $T_1$ | 24.63g | 18.44f | 29.39f | 0.38g | 0.142b | 0.472a |
| | $T_2$ | 26.26f | 19.09ef | 30.61f | 0.39ef | 0.151a | 0.459b |
| | $T_3$ | 29.94d | 24.81d | 33.79d | 0.40d | 0.150a | 0.458b |
| | $T_4$ | 41.56b | 35.37b | 47.25b | 0.54b | 0.137c | 0.321d |

**Note:** MT:magnetized irrigation treatment; NMT:non-magnetized irrigation treatment.Mean values in the same columns followed by the same letters are not significantly different according to the LSD test ($P < 0.05$).

The effect of irrigation water salinity and the interaction effects between irrigation water salinity and magnetic treatments on root weight ratio (RWR), leaf weight ratio (LWR) and stem weight ratio (SWR) were statistically significant ($P<0.0001$) (Table 7). The LWR values increased with the increase in the salinity of the irrigation water. The lowest LWR value was for T1 treatment, and the highest value was for T4 treatment. The mean LWR increased from 0.38 $g\ g^{-1}$ for T1 treatment to 0.56 $g\ g^{-1}$ for T4 treatment with an increase of 32.04%. The highest LWR value (0.58 $g\ g^{-1}$) was obtained in the NMTT4 treatment, while the lowest (0.38 $g\ g^{-1}$) value was obtained in the MTT1 treatment. As shown in Table 8, the mean LWR values for MT were slightly lower than the mean values for NMT treatment. The RWR values ranged from 0.137 $g\ g^{-1}$ to 0.151 $g\ g^{-1}$ in the magnetically treated water salinities and from 0.142 $g\ g^{-1}$ to 0.153 $g\ g^{-1}$ in the non-magnetic treated water salinity (Table 8). The RWR values decreased from 0.151 $g\ g^{-1}$ for T3 treatment to 0.139 $g\ g^{-1}$ for T4 treatment. The highest RWR value of 0.153 $g\ g^{-1}$ was obtained in the NMTT3 treatment, while the lowest 0.137 $g\ g^{-1}$ value was obtained in the MTT4 treatment. The SWR values decreased with the increase in the salinity of the irrigation water. SWR decreased from 0.468 $g\ g^{-1}$ for T1 treatment to 0.301 $g\ g^{-1}$ for T4 treatment. The SWR for T2, T3, and T4 treatments decreased by 1.79%, 3.70% and 35.65% respectively, compared with the T1 treatment. The mean SWR values for MT 0.428 $g\ g^{-1}$ were higher than the mean values for NMT 0.412 $g\ g^{-1}$. The highest SWR value of 0.472 $g\ g^{-1}$ was obtained in the MTT1 treatment, while the lowest 0.281 $g\ g^{-1}$ value was obtained in the NMTT4 treatment (Table 8). There was a significant positive association between LWR and LDMA ($r = 0.97$), SDMA ($r = 0.95$), and RDMA ($r = 0.96$) and it was negatively associated with SLA (r = -0.74) and RLWC (r = -.0.74) which were significant at p≤0.0001 levels (Fig. 4).

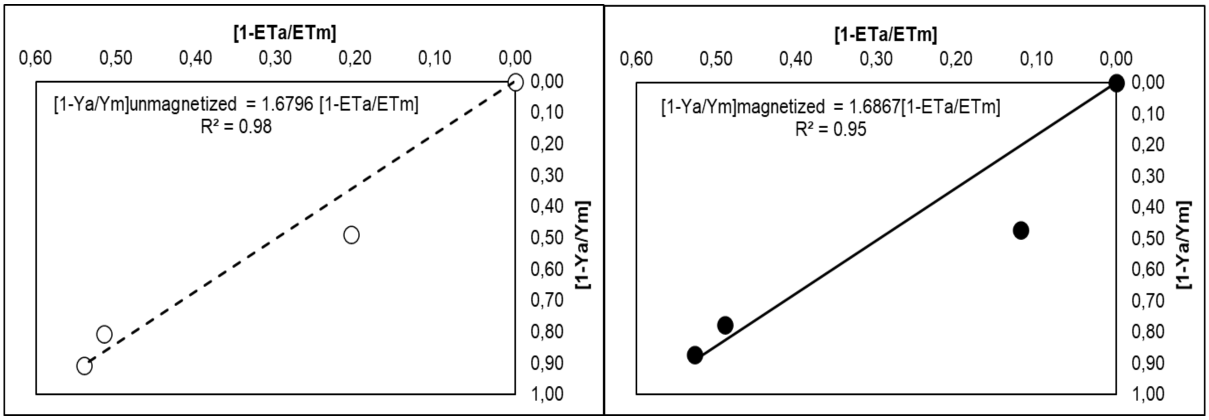


Fig.3.The yield response factors of balkız bean under magnetic and non-magnetic irrigation water salinity conditions

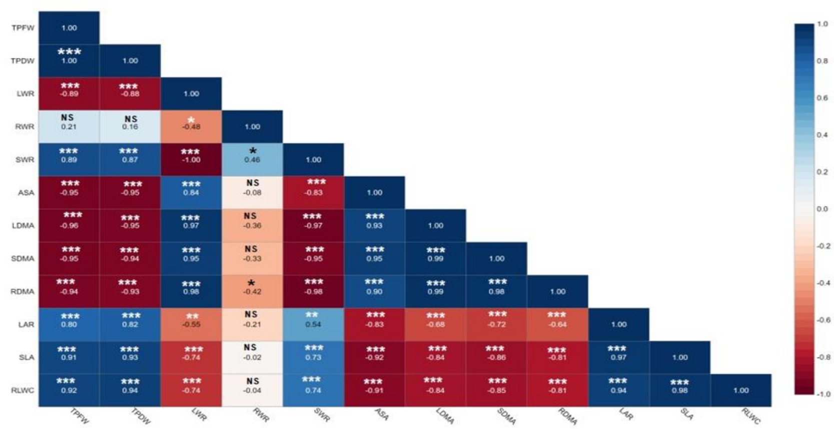


Fig. 4. Correlation coefficients between the parameters of the bean plant resulting from of magnetic and non-magnetic irrigation water salinity using the mean values of the studied traits. NS:Not significant,* Significant at (p≤0.05),** Significant at (p≤0.001),*** Significant at (p≤0.0001).

The amount of salt accumulated in the soil increased with the increase in the salinity levels of the irrigation water. However, ASA values were significantly decreased in magnetic irrigation (MT) water compared with NMT. The amount of salt accumulated (ASA) was decreased by 20.29% in MTT1 compared to the NMTT1 treatment. Mohamed and Ebead (2013) and Hamza *et al.*, (2021) mentioned a decrease in the accumulation of salts in soil irrigated with magnetized water compared to non-magnetized water. Soil salinity differed significantly, when magnetically and non-magnetically treated saline irrigation water was used and a decrease was found in soil salinity irrigated with magnetically treated water Ogunlela and Yusuf (2016) and Alsuvaid *et al.*, (2022). Found by Alsuvaid and Demir., (2022) that the use of magnetically treated water affects not only the chemical properties of water but also the plant root structure, soil properties, and cell membrane permeability. In our study, we noticed that when the chemical properties of irrigation water were analyzed (Table 3), the salinity of the irrigation water was reduced and the chemical properties of the water were changed when using magnetized water compared to non-magnetized water. Besides, the magnetic treatment greatly affects the chemical properties of water, a change in surface tension, hydrogen bonding angle, and a decrease in viscosity, which ultimately affects the solubility of metals in the water leading to a change in osmotic pressure Alsuvaid *et al.*, (2022). These results are consistent with (Hilal and Hilal 2000a; Hilal and Hilal 2000b; Grewal and Maheshwari, 2011; Abd-Elrahman and Shalaby 2017; Zlotopolski, 2017; Hamza *et al.,* 2021) which showed that the salt concentration in the soil decreased significantly when magnetically treated irrigation water was used, this may be due to the slight increase in the desalination ability of the magnetically treated water in the soil. These results are in agreement with those of Amer *et al.,* (2014) and Alsuvaid *et al.,* (2022), who found that the use of magnetically treated water led to a change in the hydrogen bonds between water molecules, which led to a change in the size of large salt crystals and transformed them into small crystals, and this change increased the removal of salts in the soil.

Increasing levels of irrigation water salinity led to a decrease in RLWC. The RLWC values for beans were higher in the MT treatments than in the NMT treatments. This is because irrigation with MT water reduced the accumulation of salt in the soil and decreased osmotic pressure, thus increasing the ability of plants to meet their water needs. These results can be explained by the results of the study by Reina and Pascual (2001) which stated that magnetically treated water caused changes in the ability of cellular tissues to absorb water and osmotic pressure, which led to an improvement in plant growth and development. The increase in RLWC values in our study can also be explained by the fact that when irrigating plants with magnetically treated water led to an increase in the plants' absorption of more water due to the small water molecules compared to non-magnetically treated water and thus increasing the absorption of nutrients led to an increase in the productivity of plants Maheshwari and Grewal (2009). The results of this study agree with the results of Sadeghipour (2016), when the cowpea crop was irrigated with magnetically treated water, the growth ability of the crops increased and the relative water content of cowpea crops increased.

The values of TPFW and TPDW decreased with the increase of the salinity level of irrigation water from 0.38 $dSm^{-1}$ to 7.00 $dSm^{-1}$. A similar result was reported by Martins *et al.,* (2019). The decrease in the fresh and dry weight of the plant may be due to the negative effect of salinity on the plant and the decrease in water absorption due to the increase in osmotic pressure resulting from the increase in the amount of salt accumulated in the soil. Moreover, the values of TPFW and TPDW increased with the use of magnetic irrigation water (MT) compared to NMT. A similar result was reported in tomato (De Souza *et al.,* (2006)), chickpea, and snow pea (Grewal and Maheshwari, 2011), common bean (Moussa (2011)) and wheat (Hozayn and Abdul Qados, 2010). The reason for the increase in the fresh and dry weight of the plant may be due to the positive effect of the magnetic treatment of the irrigation water, which led to a decrease in the amount of salt accumulated in the soil, which enhances the increase in water and nutrients absorption due to the decrease in osmotic pressure. Maheshwari and Grewal (2009), mentioned that when magnetic water is used, changes occur in the chemical and physical properties of water, which leads to improved cell activity and crop growth, consequently increasing the wet and dry weight of the plant.

The changes in Ky values of the balkız bean crops under unmagnetized and magnetized irrigation water salinity conditions are illustrated in Fig 3a and Fig 3b. respectively. The Ky values for unmagnetized and magnetized conditions were calculated as 1.68 and 1.69. consecutively. indicating balkız bean to be very sensitive to water stress caused by salt stress under magnetically and non-magnetically treated irrigation water conditions. Doorenbos and Kassam (1979), Sezen *et al.*, (2005), Buyukcangaz *et al.*, (2008) reported Ky values of 1.15, 1.23 and 1.33, 1.07 respectively, for the whole growing season of the bean. In another study, Khataar *et al.,* (2018) found a value of 1.30 Ky for bean crops under 0.7 $dSm^{-1}$ irrigation water salinity conditions. Based on the result of our study, the higher ky value in our study as compared to previous studies is mainly because of the green bean losses raised with an increase in soil salinity. In other words, this result may be due to the salt tolerance of the bean crops, because Ayers and Westcot (1985) classified the bean crop as a salt-sensitive crop with a salinity threshold of 1.0 $dSm^{-1}$. Additionally, the results indicated that when green bean crops are irrigated with magnetically or non-magnetically saline water, the reduction in bean yield is proportionally higher than the relative evapotranspiration, this could be mainly related to an increase in soil osmotic potential caused by soil salinity. Overall, differences in ky values could be attributed to variation in cultivar, climatic conditions, growing season length, and soil-water management practices**.**

## CONCLUSION

The results of the experiment showed the positive effect of magnetically treated water on the quantitative effects of bean plant growth parameters under the influence of water salinity. Salinity stress decreased the values of the relative leaf water content (RLWC), total plant dry weight (TPDW) and total plant fresh weight (TPFW), leaf dry matter amount (LDMA), stem dry matter amount (SDMA), root dry matter amount (RDMA), specific leaf area (SLA) and leaf area ratio (LAR) while the of the amount of accumulated salt (ASA) increased. Magnetic treatment of irrigation water increased the values of (RLWC), (TPFW), (TPDW), and (LAR). While the values of (ASA), (LDMA), (SDMA), (RDMA), leaf weight ratio (LWR), and root weight ratio (RWR) decreased compared to the NMT treatment. Magnetic treatment of irrigation water resulted in a significant reduction in the amount of accumulated salt (ASA) compared to untreated magnetic irrigation water. This result shows the positive effect of magnetic water on plant growth and reducing salt accumulation in the soil. We recommend its application in agricultural lands and in areas that suffer from high salinity of irrigation water. More studies should be conducted on the use of magnetic water to better understand it, especially in areas that suffer from water scarcity.

## CONFLICT OF INTEREST

The authors declare no conflicts of interest associated with this manuscript.

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