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Magnetically treated water influences soil properties, water absorption and nutrients in *Beta vulgaris* L.

A água tratada magneticamente influencia as propriedades do solo, absorção de água e nutrientes em *Beta vulgaris* L.

Agua tratada magnéticamente influye en las propiedades del suelo, absorción de agua y nutrientes en *Beta vulgaris* L.

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Abstract

The effect of magnetically treated water on the physico-chemical properties of water and soil as well as nutrient absorption during the growth of *Beta vulgaris* L. was evaluated in this study. The plants were either irrigated with magnetically treated water (MW), i.e., treatment group, or irrigated with common water (C), i.e., control group. The MW was obtained using a magnetic device in the range of 0.8 - 0.9 T of magnetic induction. Magnetic treatment caused a higher dissolution of salts and an increase in electrical conductivity in the water of the irrigated soil compared to common water. At the same time, the soil irrigated with MW showed a decrease in the concentrations of Ca^{2+} (16.6 %), K^+ (9.7 %), and Na^+ (13.4 %) with significant differences compared to the soil irrigated with control. However, in plants irrigated with MW, an increase in the concentration of Na^+ (4.91 %) in the leaves and Fe^{2+} (126.3 %) in the roots was observed with significant differences compared to the control plants. In addition, several biometric parameters were significantly increased in plants irrigated with MW compared to control plants, more specifically for their fresh and dry weights of leaves (25.5 - 25.1 %) and roots (6.4 - 39.8 %), respectively. In conclusion, the magnetic treatment caused an increase in electrical conductivity in the soil and water. Consequently, an increase in the mineral absorption and the behaviour of the physiological activity in *Beta vulgaris* L. culture were obtained.

Keywords: Minerals; Beet; Magnetized water.

Resumo

O efeito da água tratada magneticamente nas propriedades físico-químicas da água e do solo, bem como na absorção de nutrientes durante o crescimento de *Beta vulgaris* L. foi avaliado neste estudo. As plantas foram irrigadas com água tratada magneticamente (ATM), ou seja, grupo de tratamento, ou irrigadas com água comum (Controle), grupo controle. A ATM foi obtida usando um dispositivo magnético na faixa de 0,8 - 0,9 T de indução magnética. O tratamento magnético causou maior dissolução de sais e aumento da condutividade elétrica na água do solo irrigado em relação à água comum com seu solo irrigado. Ao mesmo tempo, o solo irrigado com água tratada magneticamente apresentou diminuição nas concentrações de Ca^{2+} (16,6 %), K^+ (9,7 %) e Na^+ (13,4 %) com diferenças significativas em relação ao solo irrigado com água comum. No entanto, nas plantas irrigadas com MW observou-se um aumento na concentração de Na^+ (4,91 %) nas folhas e Fe^{2+} (126,3 %) nas raízes, com diferenças significativas em relação às plantas controle. Além disso, vários parâmetros biométricos foram significativamente aumentados em plantas irrigadas com ATM em comparação com plantas controle, mais especificamente para seus pesos frescos e secos de folhas (25,5 - 25,1 %) e raízes (6,4 - 39,8 %), respectivamente. No entanto, o número de estômatos, a razão estomática e a área de abertura foram menores nas plantas irrigadas com ATM do que nas plantas controle. Em conclusão, o tratamento magnético causou um aumento na condutividade elétrica no solo e na água. Consequentemente, obteve-se um aumento na absorção do mineral e no comportamento da atividade fisiológica na cultura de *Beta vulgaris* L.

Palavras-chave: Minerais; Beterraba; Água magnetizada.

Resumen

En este estudio se evaluó el efecto del agua tratada magnéticamente sobre las propiedades fisicoquímicas del agua y del suelo, así como sobre la absorción de nutrientes durante el crecimiento de *Beta vulgaris* L. Las plantas se regaron con agua tratada magnéticamente (ATM), es decir, grupo tratamiento, o se regaron con agua común (Control), grupo control. El ATM se obtuvo utilizando un dispositivo magnético en el rango de 0,8 - 0,9 T de inducción magnética. El tratamiento magnético provocó mayor disolución de sales y mayor conductividad eléctrica en el agua del suelo regado en relación al agua común con su suelo regado. A su vez, el suelo regado con agua tratada magnéticamente mostró una disminución en las concentraciones de Ca^{2+} (16,6%), K^+ (9,7%) y Na^+ (13,4%) con diferencias significativas en relación al suelo regado con agua común. Sin embargo, en las plantas regadas con ATM se observó un aumento en la concentración de Na^+ (4,91%) en las hojas y Fe^{2+} (126,3%) en las raíces, con diferencias significativas en relación a las plantas testigo. Además, varios parámetros biométricos aumentaron significativamente en las plantas regadas con ATM en comparación con las plantas de control, más específicamente para sus pesos frescos y secos de hojas (25,5 - 25,1 %) y raíces (6,4 - 39,8 %), respectivamente. Sin embargo, el número de estomas, la proporción estomática y el área de apertura fueron menores en las plantas regadas con ATM que en las plantas control. En conclusión, el tratamiento magnético provocó un aumento de la conductividad eléctrica en el suelo y el agua. En consecuencia, hubo un incremento en la absorción de minerales y en el comportamiento de la actividad fisiológica en el cultivo de *Beta vulgaris* L.

Palabras clave: Minerales; Remolacha; Agua magnetizada.

1. Introduction

Mineral fertilization is one of the agricultural practices leading to significant yield increases. However, inappropriate use adversely affects the environment, creating unfavorable nutrient conditions in the soil, such as soil salinization and pollution of groundwater tables due to nutrient leaching. This may result in nutritional imbalances in plants but might also disrupt the soil biota. Moreover, it contributes to global warming through the release of nitrogen gases derived from elevated soil nitrogen levels into the atmosphere (Grzebisz et al., 2013).

Soil or water salinity, caused by the excessive use of fertilizers, is one of the most severe environmental factors limiting the productivity of agricultural crops. As an important crop, *Beta vulgaris* L. (beet) is grown almost all over the world to be consumed fresh in salads. It is furthermore highly valued for its high sugar, mineral and carotene contents and substances of utmost importance for human health. In the presence of salinity, plant growth and development tend to decline, with the consequent reduction of its economic value (Am et al., 2014; Alattar et al., 2021a, 2021b; El-Mugrbi et al., 2022).

In addition to nutrients, a sufficient water supply and hence irrigation with water is essential for crop production. In this regard, previous research has indicated that external application of a magnetic field to irrigation water causes changes in the electronic, atomic and molecular structure of the water, leading to differences in viscosity, boiling and solidifying point, and other physico-chemical properties (Pang, 2014). Therefore, irrigation with magnetically treated water (MW) could affect soil nutrient availability and hence improve the morphological and physiological characteristics associated with plant growth and nutrient uptake (Hozayn et al., 2019; Llauradó Maury et al., 2020; Pang, 2014; Shabrangy et al., 2021). Vegetables have been benefited using magnetically treated water, promoting better performance of lettuce (Silva et al., 2022a, 2022c), radish (Silva et al., 2022b), tomato (Aguilera & Martin, 2016; Ferrer-Dubois et al., 2018; Yusuf et al., 2019) and peppers (Aguilera et al., 2021). In addition, MW increases soil moisture compared to the control, playing an important role in decreasing the amount of water used for irrigation and crop diseases (Maffei, 2014).

In previous research, some evidence about the positive effect of irrigation with different levels of saline MW was described. These studies indicated that there was no association with the nutritional levels in pear seedlings (El Sayed, 2014). To gain better insight into the altered characteristics in MW in relation to plant growth and nutritional uptake, the objective of this study was to determine the effect of magnetic treatment on the water and MW irrigation of the soil on the physico-chemical properties of water and soil, respectively, and relate this to nutrient uptake and biomass production of *B. vulgaris* L.

2. Material and Methods

The experiments were developed on a brown sialic soil without carbonate, according to the Cuban Soil Genetic Classification New Version (Hernández et al., 1999). A slightly wavy terrain toward the 1 % slope was predominant with the presence of some gullies.

The land was suitable for arable farming with a fairly made layer, an effective depth of 30-40 cm, good surface and internal drainage and an infiltration rate of 33 %. The soil characteristics are described as follows: organic matter content (2.3 %); field capacity (45.7 %); bulk density (1.59 gcm^{-3}); and density (2.09 gcm^{-3}). During the experiment, several climatological average values were collected, such as temperature (27.5 °C), rainfall (123.5 mm), relative humidity (70.3 %) and wind speed (11.8 km h^{-1}).

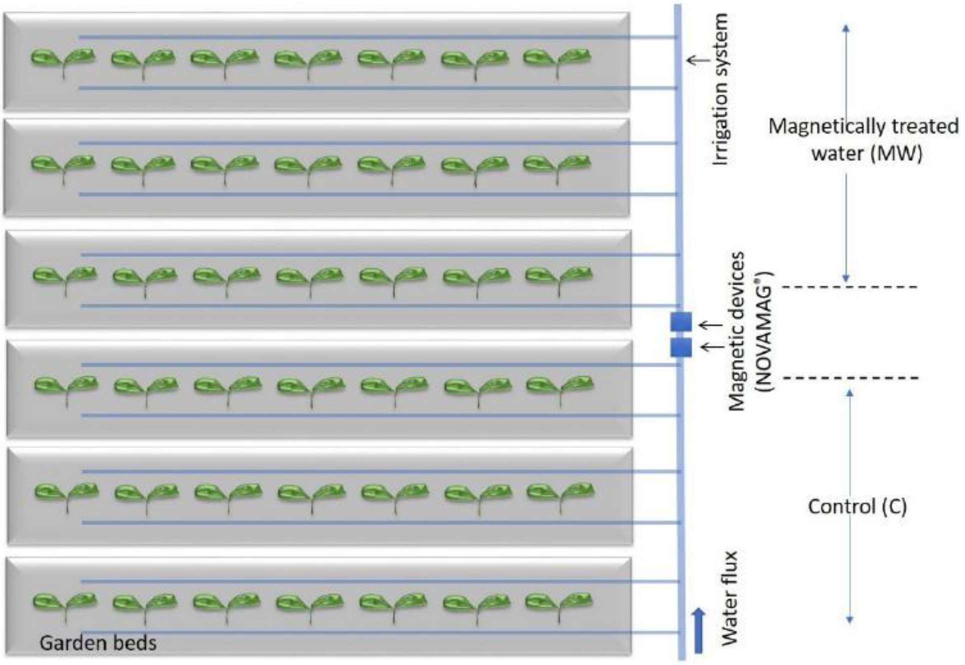
2.1 Growing conditions

The protected crop facilities used in this experiment were typology 2 greenhouses, which have the following characteristics for plant growth: 10 one-row garden beds, 190 plants each with 0.20 m between plants, for a total of 1900 plants per greenhouse, using a drip irrigation system with 1900 drippers.

The irrigation frequency was set at four irrigation times per day (4:00, 10:00, 16:00 and 22:00 hours) of thirty minutes each. Drip irrigation was carried out at 21 l min^{-1} using a Mix Rite pump. On the third planting day, *Beta vulgaris* L. cv Delcol seeds began to sprout.

The experimental area was divided into two segments, each for five garden beds. This gave rise to irrigation with water without magnetic treatment in the first segment leading to the common water or control (C) crop production and, in the second segment, the magnetically treated water (MW) crop production (Figure 1). Two magnetic devices were attached to the outside surface of the pipe for water treatment.

Figure 1. Scheme of the experimental area. (Area: 800 m2, 10 one-row garden beds).



Source: Authors.

The magnetic devices are constituent elements of the technological package for irrigation with MW in agricultural systems GREMAG® (Dubois et al., 2019). The magnetic devices (NOVAMAG®) have a magnetic induction range of 0.8 – 0.9 T.

2.2 Physical and chemical characteristics of irrigation water and soil during beet growing

The water analyses were conducted at two different time points. The first analysis was performed before the placement of the magnetic device, and the second analysis was carried out 24 days after the placement of the device.

The quality of the irrigation water was determined through analysis of calcium hardness (mg L^{-1}), magnesium hardness (mg L^{-1}), alkalinity (mg L^{-1}), chlorides (mg L^{-1}), dissolved oxygen (mg L^{-1}), turbidity (Nephelometric Turbidity Units (NTU), chlorophyll (mg L^{-1}) and phycocyanin (µg L^{-1}) contents, pH (25 °C) and electrical conductivity (25 °C) (µS cm^{-1}).

Total, calcium, magnesium hardness (mg L^{-1}), total alkalinity and chloride contents were determined using the volumetric method (Bezgin et al., 2019; Panchagnula, 2017). For the determination of dissolved oxygen, a BBE-AlgaeTroch (Germany) was used with the optical probe YSI ProDSS. Additionally, chlorophyll and phycocyanin were determined in situ using BBE-AlgaeTorch equipment.

Turbidity was spectrophotometrically (UV/Visible, Genesys Corp., Germany) determined at a wavelength of 750 nm (A750) (Deloya-Martínez, 2006). Distilled water was used as a blank solution. To calculate turbidity in NTU, the following formula was used:

$$NTU=0{,}191 + (926{,}1942 \times A_{750}) \quad \text{....Equation (1)}$$

in which:

NTU: Nephelometric Turbidity Units

A_{750}: Absorbance 750 nm

The pH determination of the irrigation water was performed with a pH meter (Brand MV 88 PRACITORNIC, Germany), and electrical conductivity (25 °C) (µS cm^{-1}) was analysed by means of a conductivity meter (DDSJ-308ª, China). Salinity analysis (%) was determined with a Portable analytical instrument Mettler Toledo (China).

2.3 Soil chemical analysis

The soil chemical analysis was conducted using 80 soil samples collected at random positions in zigzags from the garden beds either irrigated with MW (40 soil samples) or C (40 soil samples), taking the boundary effects at the garden beds into account. Samples were dried at 105 °C for three hours and placed in a desiccator at room temperature. The weighed samples were placed again in the oven (MWL-200, VEB, Germany) until a constant mass was obtained (Lizcano et al., 2017). For the elemental analyses, 20 mg of 103Rh was added to one litre of distilled water as an internal standard. Samples were analysed using inductively coupled plasma–mass spectrometry (ICP–MS; ELAN 6000, Perkin-Elmer SCIEX) (Paneque; Calderon, 2010). The percentages of mineral contents, such as Fe^{2+}, Mg^{2+}, Mn^{2+}, Ca^{2+}, K^{+}, and Na^{+}, were calculated.

Soil electrical conductivity and pH were determined based on the soil oversaturation method (Paneque; Calderon, 2010). Eighty grams of dried soil was collected and placed in a plastic container, in which distilled water was added and mixed with a spatula to saturation (60 ml). The mixture was allowed to rest for one hour, and the saturation degree was tested. The container was covered and allowed to rest for another 24 hours because it was a clayish soil. Afterwards, water was recovered using filter paper and a funnel, which was connected to a vacuum filtration system until an extract of approximately 50 ml was obtained. The pH was determined using a pH meter (MV SS PRACITORNIC, Germany), and electrical conductivity was determined using a conductivity meter (Model DDSJ-308a, China).

2.4 Morphological and physiological plant variables

To investigate plant leaf morphological characteristics, the second pair of leaves was used to determine leaf area. Fifty plants per treatment for a total of 100 plants were measured. To perform the stomatal prints, nail polish was applied on the underside (abaxial side) of the leaf and allowed to dry for a few minutes (Sánchez-Urdaneta; Suárez-Calleja, 2011). Later, this was pasted to adhesive tape, and the impression obtained was placed on a slide to investigate the stomatal index, stomatal area, and stomatal aperture using light microscopy (10x and 40x magnification). Stomatal measurements were analysed using ImageTool 3.00 software.

For biomass analyses, a selection of five leaves and three roots per plant irrigated with either MW or C was used. The mass of these organs was measured immediately after harvest to obtain the fresh weight. For dry mass, samples were dried at 105 °C for three hours. The samples were placed in a desiccator, allowed to cool to room temperature, weighed, placed again in an oven (MWL-200, VEB, Germany) for one hour, and reweighed until a constant mass was obtained (Lizcano et al., 2017).

The percentage of humidity for leaves and roots was estimated according to the formula:

$$\%H=M2-M1/M2-M \times 100 \ldots\text{. Equation (2)}$$

in which:

% H = loss of weight by desiccation (%)

M2 = capsule mass with sample (g)

M1 = capsule mass with desiccate sample (g)

M = empty capsule mass

To determine the concentrations of micro- and macronutrients in leaves and fruits, ICP–MS (ELAN 6000, Perkin-Elmer SCIEX) was used. Six grams of leaf and fruit tissues were weighed and dried for 48 hours at 70 °C. Then, one gram of dried tissue was placed in the muffle furnace at 250 °C, and the temperature was gradually increased (0,013°C s^{-1}) until 450 °C to obtain ashes. Thereafter, 1 ml of nitric acid (70 %) and 2 mL of distilled water were added to extract the elements (Isaac-Aleman et al., 2016).

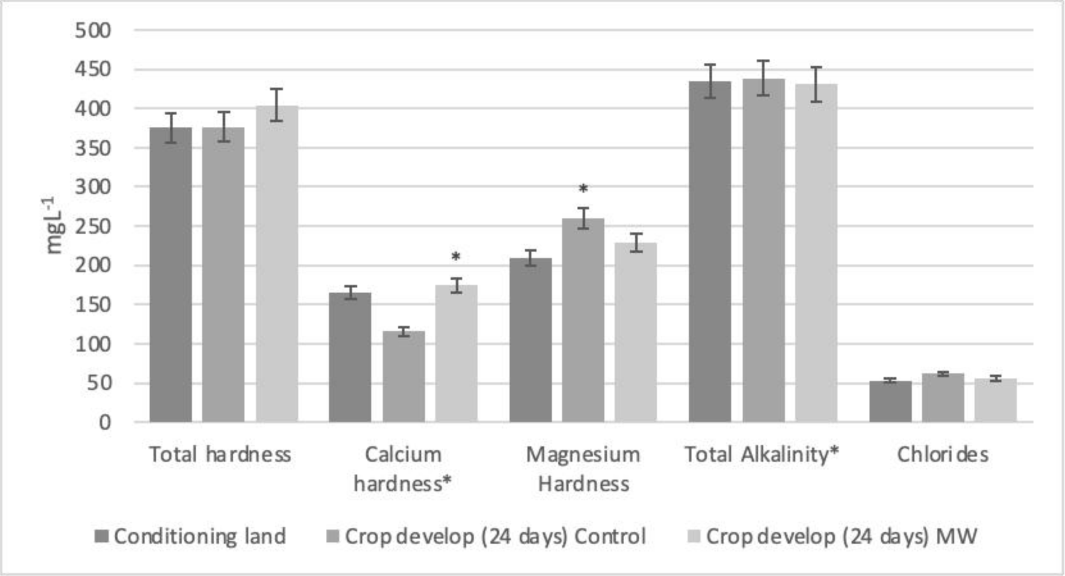
2.5 Statistical Analysis

A complete randomized design was applied. The data are the means from 3 biological replicates. The data were submitted to the Kolmogorov–Smirnov normality test. An analysis of variance using the general linear model and one-way ANOVA was performed. The significant differences between means (least significant difference a posteriori test) at $p < 0.05$ were calculated. Data for control and treated samples were statistically compared by Student´s t test. The Statgraphics® version 15.0 statistical package was used.

3. Results and Discussion

To investigate whether the magnetic treatment affected the properties of the irrigation water, the water was analysed before the start of the experiment and 24 days after the beginning of crop planting (Figure 2).

Figure 2. Physico-chemical water analysis before and 24 days after the beginning of crop planting.



*Expressed as CaCO3, Control (common water), MW (magnetically treated water). All data are expressed as the mean of three replicates ± standard deviation. LSD test - * significant at $P < 0.05$. Source: Authors.

No differences between the conditions on water physico-chemical characteristics could be observed for total hardness, except for calcium and magnesium hardness. The results indicate that the prolonged use of water for irrigation in *B. vulgaris* crops is possible, although the tendency to incrust at the PVC pipes of the irrigation system should be observed.

At the same time, pH, dissolved oxygen, total chlorophyll, phycocyanin, and turbidity showed the maximum admissible limits for the chemical components of irrigation water (Table 1). Both C and MW are useful for the agricultural system.

Table 1. Results of physico-chemical water analysis during *Beta vulgaris* L. plants growing with magnetically treated water.

Parameters	Conditioning of the land	Crop development (24 days)	
		Control	MW
Dissolved Oxygen (mg L^{-1})	6.97 ± 0.05	8.63 ± 0.05 *	8.21 ± 0.05
Turbidity (NTU)	408.20 ± 3.85 *****	118.80 ± 5.04	222.20 ± 1.24
Total Chlorophyll (mg L^{-1})	1.90 ± 0.02	15.30 ± 0.11 *****	9.40 ± 0.15
Phycocyanin (µg L^{-1})	0.00	5.70 ± 0.20 *****	0.00
pH (25 °C)	7.80 ± 0.01	7.83 ± 0.01	7.84 ± 0.02
Electrical conductivity (25 °C) (µS cm^{-1})	876.00 ± 0.05	863.00 ± 0.05	885.00 ± 0.05 *

*Expressed as $CaCO_3$, Control (common water), MW (magnetically treated water). All data are expressed as the mean of three replicates ± standard deviation. LSD test - * significant at $P < 0.05$. Source: Authors.

In common water samples, a decrease in turbidity was obtained 24 days after the start of the culture, which consequently resulted in an increase in dissolved oxygen and concentrations of chlorophyll pigments and phycocyanin. Total chlorophylls could be associated with an algal blooming that was not cyanobacteria, e.g., *Chlorella vulgaris* and *Cosmarium margaritiferum* present in the irrigation water. Changes in these parameters over time suggest changes in water quality from the supply source of the production system.

The results of the samples of MW in comparison with C showed an increase in turbidity, which suggests a limited activity of the microalgae present in the water, expressed in a decrease in dissolved oxygen and the concentration of chlorophyll pigments.

pH did not present differences between the samples, but electrical conductivity increased in MW. This corresponds to the results expressed in Table 2 and the salt dissolutions as a consequence of magnetic treatment. The water pH was slightly alkaline and suitable for agricultural irrigation, since it was within a normal range of 6.5 - 8.4, according to the established regulations.

Visual analysis of the soil was carried out. Salt deposits on the soil surface were observed in both control and treated plants (Figure 3).

Figure 3. Visual analysis of the salt deposited on soil surface during *Beta vulgaris* L culture for WT plants and control plants.

Source: Authors.

On the other hand, an increase in the soil conductivity was observed when irrigated with magnetically treated water in comparison to control water (Table 2).

Table 2. pH and conductivity analysis of soil during *Beta vulgaris* L. growth using control and magnetically treated water for irrigation

Parameters	Conditioning of the land	Crop development (24 days)	
		Control	MW
pH	7.79 ± 0.20	7.90 ± 0.10	8.03 ± 0.15
Electric conductivity (25 °C) (mS cm^{-1})	1.56 ± 0.22	1.48 ± 0.27	2.91 ± 0.31*

Control (irrigation with common water), MW (irrigation with magnetically treated water). Conditioning of land: time point zero (before planting). All data are expressed as the mean of five replicates ± standard deviation. LSD test - * significant at $P < 0.05$. Source: Authors.

According to the percentages obtained for Ca^{2+}, Mg^{2+}, K^+ and Na^+, and following the pH values, the soil category was slightly - moderately alkaline. Despite the fact that the optimal interval pH ranges for *B. vulgaris* growth are between 6.1 and 7.4, the results obtained could be considered acceptable for beet growth. The increase in soil conductivity confirmed the effects of the magnetic treatment on salt dissolution.

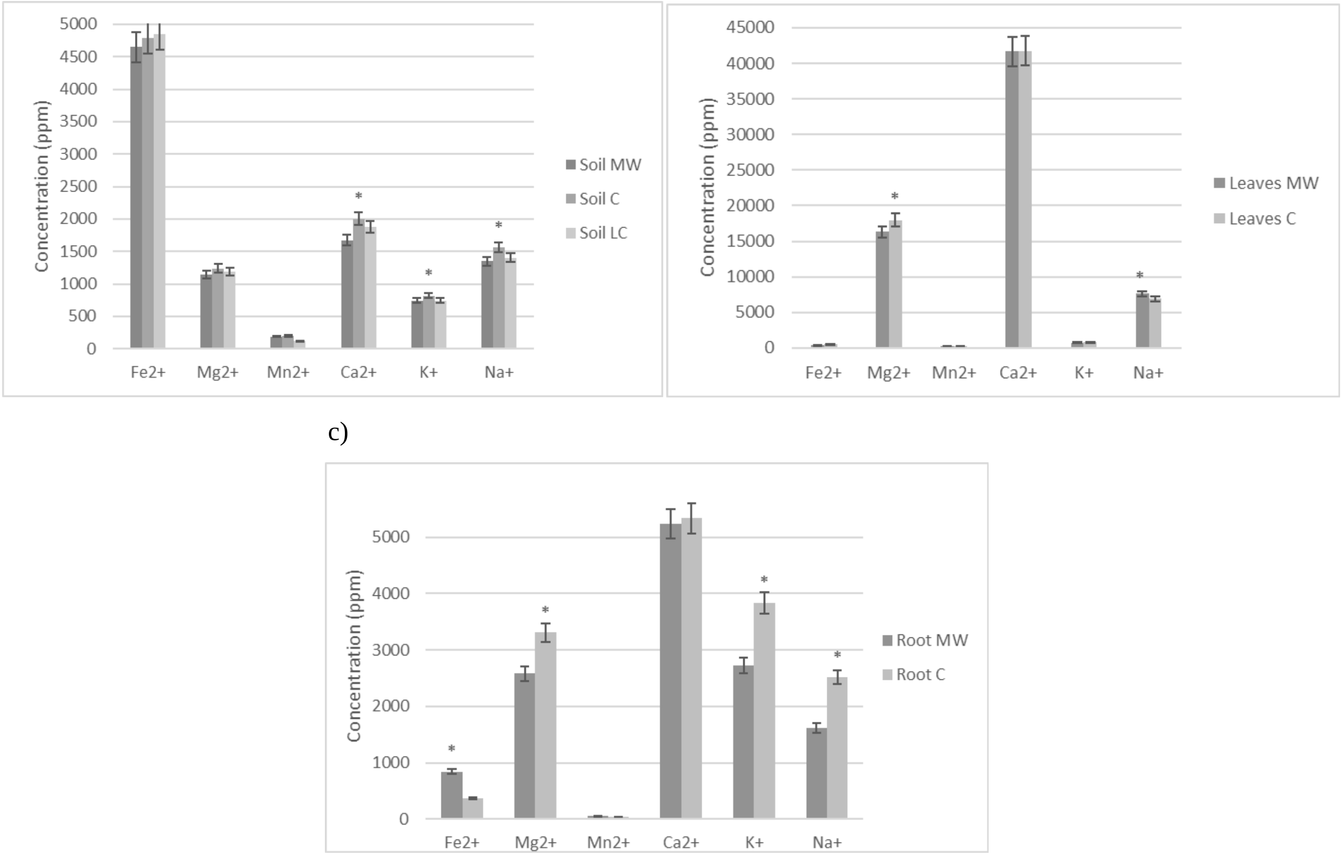
A comprehensive analysis of the minerals present in the soil as well as the leaves and roots of the *Beta vulgaris* L. plants is shown in Figure 4. The concentrations of mineral compounds in the soil before the initiation of the culture did not show significant differences compared to the concentrations of these compounds 24 days after crop growth. The values were considered adequate according to the regulations established for cultivable soils (Rody et al., 2013). The soil irrigated with MW showed a decrease in the concentrations of Ca^{2+} (16.6 %), K^+ (9.7 %) and Na^+ (13. 4 %) with significant differences compared to the control. However, in plants irrigated with MW, an increase in the concentrations of Na^+ (4.91 %) in the leaves and Fe^{2+} (126.3 %) in the roots was observed, with significant differences compared to the control plants. The other mineral compounds did not show significant differences. These results agree with the increase in the soil conductivity with the magnetic treatment obtained and, consequently, an improvement in the absorption of mineral compounds by plants.

It is well known that when water flows in the presence of a magnetic field, different parameters change, such as pH, surface tension, solubility, optical density and electrical conductivity (Pang, 2014). This was also evidenced by the results obtained in our study. Water analysis showed an increase in the level of chlorides (mg L^{-1}) after placing the magnetic device. This indicates a greater availability for these minerals during irrigation. Although the soil under study was moderately alkaline, it must be considered acceptable for beet growing.

At the same time, the increase in electrical conductivity of the soil with MW is favourable for the plants because the absorption of the minerals inside plants increased. These results could be related to the effect of magnetic treatment on changes in hydrogen bonds present in water, not by breaking them but with the increase in length ion-dipole interaction, and concomitantly with this, an increase in mineral solubility (Pang, 2014).

Some authors found that magnetic treatment induces changes in the solubility of some soil mineral compounds as well as its pH, leading to an increase in the uptake of nutrients by plants (Sarraf et al., 2020; Faridvand et al., 2021).

Figure 4. Effect of magnetically treated water on mineral compounds present in the soil (a), leaves (b) and roots (c) of *Beta vulgaris* L. crops.



a)

b)

c)

MW (magnetically treated water), C (common water), LC (land conditions). All data are expressed as the mean of three replicates ± standard deviations. Student´s test - * significant at $P < 0.05$. Source: Authors.

On the other hand, soil Na^+ concentrations decrease, probably because it is easily transported to the leaves, which is the same for potassium. Both elements participate in the active transport of other nutrients and therefore play an important role in plant physiology, which could be related to plant growth. Some authors describe an increase in micronutrient absorption of the roots to the leaves of plants and in the dissolution and deeper penetration of fertilizers in soil irrigated with MW compared with untreated water (Hashemabadi et al., 2015; Moussa, 2011). Similar results were obtained by Hozayn et al. (2013) in *Beta vulgaris* L. var. Baraca.

A significant increase in the number of leaves, leaf area, stomatal area and root fresh mass was observed in plants irrigated with magnetically treated water compared to the control group (Table 3).

Even though the other variables did not present significant differences, the fresh mass of plants irrigated with MW increased by 25.52 % and 6.40 % for leaves and roots, respectively, compared to the control and by 25.7 % and 39.8 % for the dry biomass. On the other hand, the stomatal index and stomatal aperture area were lower in plants irrigated with magnetically treated water than in control plants (Table 3).

Table 3. Morphological and physiological variables of the *Beta vulgaris* L. plants grown using control and magnetically treated water for irrigation.

Parameters	MW	CONTROL
Number of leaves	7.80 ± 1.25 *	6.60 ± 0.88
Leaf area (cm^2)	818.26 ± 241.61 *	723.55 ± 195.82
Stomatal index	2371.43 ± 611.60	2801.53 ± 768.66*
Stomatal area (µm)	927.00 ± 294.36 *	844.858± 245.33
Area of stomatal aperture (µm)	207.54 ± 62.03	258.59 ± 60.27*
FreshMass (g)		
Leaf	56.56 ± 21.37	45.06 ± 12.95
Root (agricultural fruit)	153.57 ± 32.03	144.33 ± 25.32
Dried Mass (g)		
Leaf	5.85 ± 1.67	4.65 ± 1.32
Root (agricultural fruit)	27.57 ± 11.42 *	19.71 ± 8.25
Humidity (%*H*)		
Leaf	98.37 ± 26.72	97.11 ± 23.59
Root (agricultural fruit)	82.90 ± 26.54	87.30 ± 26.67 *

Control (irrigation with common water), MW (irrigation with magnetically treated water). All data are expressed as the mean of five replicates ± standard deviation* (statistically significant differences) $P \leq 0.05$. Source: Authors.

The information on the fresh and dry weight of the roots are also consistent with those obtained in *Triticum* spp. (wheat), which indicates that the magnetically treated water increased the length and fresh weight, 100-grain fresh and dry mass, and water productivity (119.5, 119.1, 114.2, 116.6 and 122.3 %, respectively) compared with the control groups (Sarraf, et al., 2020).

The results reveal that an increase in water content in the leaves could be associated with an increase in the transpiration activity in plants and related to the increase in the leaf area and the stomatal index. The positive effects of MW on evapotranspiration from soil and transpiration of plants were observed in plants of *Apium graveolens* (celery), *Pisum sativum* (snow pea) and *Pisum sativum* (pea) (Maheshwari; Grewal, 2009).

In roots, the reduction in water content in treated plants with respect to the control is favourable because it suggests a greater formation of fibre tissue. Similar results were obtained in plants of *Medicago sativa* L. (alfalfa) and *Solanum lycopersicum* L. (tomato) (Ferrer-Dubois et al., 2018; Yusuf et al., 2019). These results can be associated with the increase in the mineral components stated above. It has been shown that the root system grows more when irrigation is applied with magnetically treated water.

4. Conclusion

Magnetic treatment caused an increase in conductivity in the soil and water. Consequently, an increase in the mineral absorption and the behavior of the physiological activity in *Beta vulgaris* L. culture were obtained. For this reason, the magnetic treatment of irrigation water is confirmed to be an efficient technology for crop production.

The expansion of applications of magnetically treated water is our main objective, to be able to show that these benefits shown in the present work can be applied in fruit and forestry, to expand the applications of this technology in agriculture in general.

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