International Journal of Agriculture Innovations and Research
Volume 12, Issue 6, ISSN (Online) 2319-1473
Manuscript Processing Details (dd/mm/yyyy):
Received: 16/05/2024 | Accepted on: 18/06/2024 | Published: 30/06/2024

Effects of Magnetically Treated Irrigation Water on Soil Properties and Citrus Leaves in the Cap Bon Region, Tunisia

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Abstract **– As part of a contribution to the search for solutions for saline water valorization in agriculture, the current study considers the technique of magnetization of irrigation water. This has been used on sandy soil cultivated with citrus fruits in the Cap Bon region. This work promotes sustainable development by preserving natural resources, particularly the soil. The objective of the work was to highlight the impact of these waters, more or less concentrated in soluble salts as chlorides, sulfates and bicarbonates, on the physico-chemical properties of the soil and on the physiological behavior of the crop studied. The experimental protocol includes a bi-monthly sampling of irrigation water, soil and citrus leaves before and after the magnetic treatment followed by a chemical analysis in the laboratory. The results indicated periodic changes in the ionic balances of water and aqueous extracts of soils, but the differences between treated and untreated sample are not very obvious. The comparison of the electrical conductivities of soils irrigated by magnetized water and those irrigated by non-magnetized water, showed a relative positive contribution of magnetization on the salt training to the depth. The analysis of concentrations in basic cations (K^+ and Na^+) and in N, P and K elements in leaves indicated a variable evolution of these elements according to the period of monitoring from April 2019 to June 2020.**

Keywords **– Magnetic Treatment, Irrigation Water, Soil, Salinity and Citrus.**

I. Introduction

Due to the rapid expansion of irrigated agriculture, efficient use of the limited water resources in arid and semi-arid regions is becoming more and more vital. However, water salinity is a major problem due to its negative influence on the yields of many crops. Citrus, one of the most important fruit crops in the world, is sensitive to many environmental stresses including salt stress. The negative effects of stresses often lead to poor tree growth and reductions in fruit yield and quality. Under natural conditions, citrus trees often experience multiple stresses at the same time so there are direct and indirect interactions between salinity and almost all physical abiotic stresses that include flooding, drought, nutrient deficiency, high irradiance, high temperature, and high atmospheric evaporative demand [1]. Salinity is a significant osmotic stressor for Citrus, leading to reduction in general health and well-being. Ongoing climate change and sea level rise maximize this danger. The sensitivity of Citrus plants to salt is mainly related to their sensitivity to chloride ions, which causes oxidative stress [2]. In addition, salinity stress also has direct effects on roots predisposing trees to biotic environmental stresses including attack by root rot, nematodes and bacterial disease [1]. In citrus, the use of reclaimed water with high salinity values reduces gas exchange parameters and fruit quality [3] forcing growers to implement specific water management practices. Secondary salinization from irrigation sources is a growing problem in commercial agriculture. Citrus is grown preferentially in semiarid areas where irrigation is required to produce maximum yield. In these areas, many soils and waters contain amounts of salts that can inhibit the growth and yields of citrus crops. Due to the use of saline water for irrigation, the increase of soil salinity is one of the major abiotic constraints for the citrus industry, especially where irrigation is required [4].

Citrus trees are classified as "salt sensitive". Therefore, salinity reduces growth and fruit productivity by inducing plant physiological disorders [1]. High mortality is registered when salt concentrations increase over 3 dS m^{-1} [5]. More recent data indicated that salinity induces solubilization and mobilization of a specific protein, citrin, in citrus seeds, and that this protein could be detrimental for seedling because it causes premature depletion of citrin-like storage compounds that are normally useful during seedling establishment under non-stressed conditions [6].

The technology of physical water treatment by a magnetic device allows recreating a natural water structure and optimized in its capacity to dissolve and transport minerals. This technique involves sending a magnetic field over water molecules that have clumped together into large particles to break them up into small clumps that can easily diffuse through root membranes and move more quickly through fine pores in the soil. The magnetization process changes the metal ions and, therefore, they do not act as salt ions, thus reducing the ability of the water molecules to bind to the ions. Ben Amor et al., (2017) reported that the application of a magnetic field influenced the water parameters, decreasing its surface tension by up to 24% and increasing its evaporated volume compared with the raw water [7]. Surendran et al., (2016) affirmed that magnetic treatment tends to reduce electrical conductivity, total dissolved solids and salinity levels; also, they showed that irrigation with magnetized irrigation water caused higher soil moisture compared with the control [8]. It has been found that magnetism leads to use of natural levels of salts in the water without causing any harmful effects on the plant and, thus, causing the sodium and chlorine to not accumulate in the plant's tissues and the soil as reported by [9] and [10]. Also, Abd-Elrahman et al., (2019) indicated that magnetized water had a positive effect on all studied water, soil and plant treatments and improved water and soil characteristics while increasing plant productivity [11]. Zhou et al., (2021) studied the effect of magnetic water irrigation on the improvement of salinized soil and found that the magnetized irrigation water can change the distribution of water and salt in all salinized soils, increase the water holding capacity and salt leaching of soil, and reduce the soil salt contents in the soil profile [12]. Based on periodic monitoring of the quality of irrigation water, soil salinity and the concentration of nutrients in citrus leaves (N, P and K in particular), results were compiled and then processed by evolutionary and comparative study followed by correlation tests between edaphic parameters and nutrients' accumulation.

II. Material and Methods

A. *Experimental Site*

Field work was carried out in the experimental station of the Citrus Technical Center in Beni Khalled in the governorate of Nabeul, on two citrus plots (Clementine variety MA3): the first was irrigated with water from a well catching the underlying water table (NT) and the second was irrigated by the same water, but treated by magnetization (T). The experimental protocol includes a bi-monthly sampling of irrigation water before and after the magnetic treatment followed by a chemical analysis in the laboratory. At the same time, soil samples were taken by auger at 5 depths from 0 to 100 cm, at the rate of 3 repetitions per sampling point. The leaves from the trees under which the soil sampling was carried out were also collected.

B. *Magnetic Device*

The experimental study was carried out using permanent magnets, model GMX 8000. The world-renowned physicist Dr. Klaus Kronenburg, an authority on Magneto Hydro Dynamics, designed GMX products after years of research and discovery. It is a physical water treatment technology to solve the problems of salinity and water hardness. The principle of GMX is based on the application of a magnetic field on water. This application makes it possible to give movement and energy to the water which stagnates in the pipes and/or in the reserve tanks [13].

B. *Water Analyses*

The parameters measured were the electrical conductivity (EC), the pH and the ionic balance: cations (Ca^{2+}, Mg^{2+}, Na^+, K^+), anions (Cl^-, SO_4^{2-}, HCO_3^-). The analytical methods used refer to those developed by [14]. The method of analysis is the same as that applied to aqueous extracts of soils. The ratio between dissolved sodium and the square root of the divalent cations ((Ca^{2+} + Mg^{2+})/2) defines the SAR (sodium absorption ratio) [15].

C. *Soil Analyses*

Soil samples were taken by auger at 5 depths from 0 to 100 cm, at the rate of 3 repetitions per sampling point. The analysis has concerned the electrical conductivity (EC) of the soil saturated paste extract, the percentage of total limestone, the total organic matter (MO) and the soil texture. The techniques used are those cited by [14]. The Electrical conductivity was measured with a conductivity meter (JENWAY) and expressed in dS/m and the particle size composition of the samples was determined by the Robinson pipette method [14].

D. *Citrus Leaves Analyses*

The citrus leaves were oven dried at 65 °C to determine the dry weight (DW). Samples, with 3 repetitions, of citrus leaves were chemically analyzed for K^+ and Na^+ contents using flame photometer (JENWAY). Total nitrogen (N) was determined by [16] method based on the conversion of organic nitrogen into ammonium by boiling with sulphuric acid and distilling with alkali to liberate ammonia by titration. The phosphorus content P_2O_5 was estimated by the chlorostannous molybdo-phosphoric blue color method [17].

E. *Correlations' Analyses*

The raw data entry was done on the Excel spreadsheet. Simple linear correlation tests were applied to available data to identify the impact of salinity parameters on nutrient accumulations in citrus leaves. The significance level of the correlations (coefficient r) was fixed at the 5% threshold.

III. Results and Discussion

A. *Chemical Properties of Water*

The values of pH, EC and chemical composition of irrigation water before and after magnetic treatment are presented in Table 1.

Table 1. Chemical properties of irrigation water (NT: non treated water; T: magnetic treated water).

	30/04/2019		16/07/2019		10/10/2019		12/12/2019		20/02/2020		29/06/2020	
Parameter	**NT**	**T**	**NT**	**T**	**NT**	**T**	**NT**	**T**	**NT**	**T**	**NT**	**T**
pH	7	7	7.18	7.13	7.64	7.67	7.29	7.20	7.42	7.40	7.11	7.06

	30/04/2019		16/07/2019		10/10/2019		12/12/2019		20/02/2020		29/06/2020	
Parameter	**NT**	**T**	**NT**	**T**	**NT**	**T**	**NT**	**T**	**NT**	**T**	**NT**	**T**
EC (dS m^{-1})	4	4.01	4.71	4.88	5.10	5.10	4.52	4.51	5.55	5.55	4.74	4.63
Ca^{2+} (meq/L)	20.05	20.00	33.13	34.38	24.00	23.40	42.08	38.08	34.38	35.31	38.44	38.44
Mg^{2+} (meq/L)	10.92	11.17	19.89	19.83	9.35	12.91	2.03	4.01	18.64	18.30	18.15	13.98
Na^{+} (meq/L)	13.35	12.91	16.80	17.30	17.59	17.68	14.30	14.61	18.26	17.76	16.49	17.38
K^{+} (meq/L)	0.17	0.17	0.18	0.20	0.15	0.14	0.20	0.20	0.14	0.14	0.17	0.15
SO_4^{2-} (meq/L)	12.92	12.92	34.14	37.50	25.00	19.90	24.58	24.79	37.38	36.37	35.65	34.12
Cl^{-} (meq/L)	24.57	24.57	23.84	20.68	21.12	23.26	15.70	19.26	22.12	21.83	22.98	22.83
HCO_3^{-} (meq/L)	5.77	4.59	6.00	7.20	6.70	6.60	1.16	2.50	6.70	6.50	8.50	8,00
SAR	3.39	3.27	3.26	3.32	4.31	4.15	3.05	3.18	3.55	3.43	3.10	3.40

Source: Authors own computation data, 2019/2020.

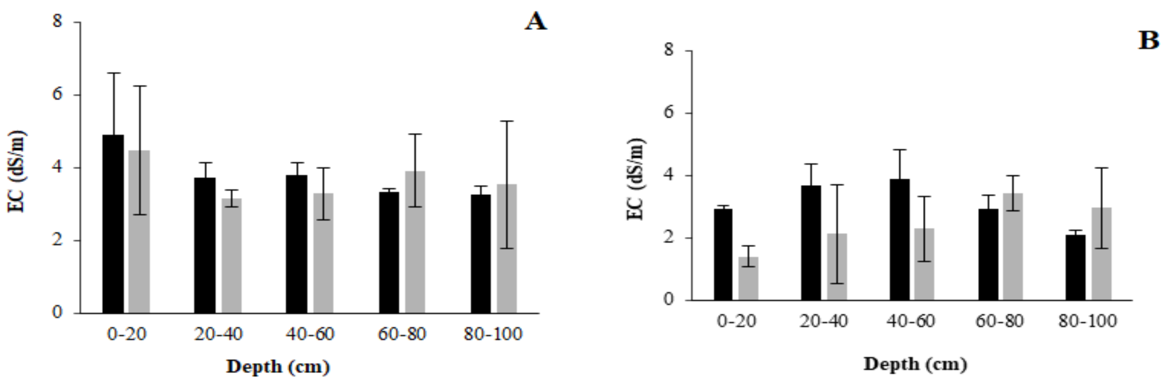
This irrigation water has a fairly low sodium content compared to the divalent cations (Ca^{2+} and Mg^{2+}), confirmed by the low SAR values. It has little sodification, especially for light-textured soils. The magnetization would apparently not affect the total ionic composition of the water in these analyzes. Zlotopolski (2017) affirmed that magnetic water treatment did not change chemical water parameters. However, it changed physical parameters [18].

B. *Soil Granulometry*

The soil had a sandy-loam soil texture (Sand = 77.82%, Silt = 6.52% and Clay = 15.66%) [19]. It displayed low total limestone content (< 5%) and poor rate of organic matter (< 1%). The EC values of the soil solution varied between 0.49 to 7.68 dS/m. According to USSL (1954) standards, the soil studied was non-saline to moderately saline [15].

C. *Effect on Soil Electric Conductivity (EC)*

In the summer sample of 07/16/2019, the soil surface appeared to be more concentrated in salts compared to the medium and the bottom of the profile (Fig. 1A). At the non-magnetized site, the salts tended to decrease with depth. In the point irrigated by magnetized water, the EC was slightly higher than in the previous site. It can be concluded that the water magnetization could have a positive effect on the deep salts driving, thus acting to reverse the usual movements of upward salts to the surface, especially in the hot season.



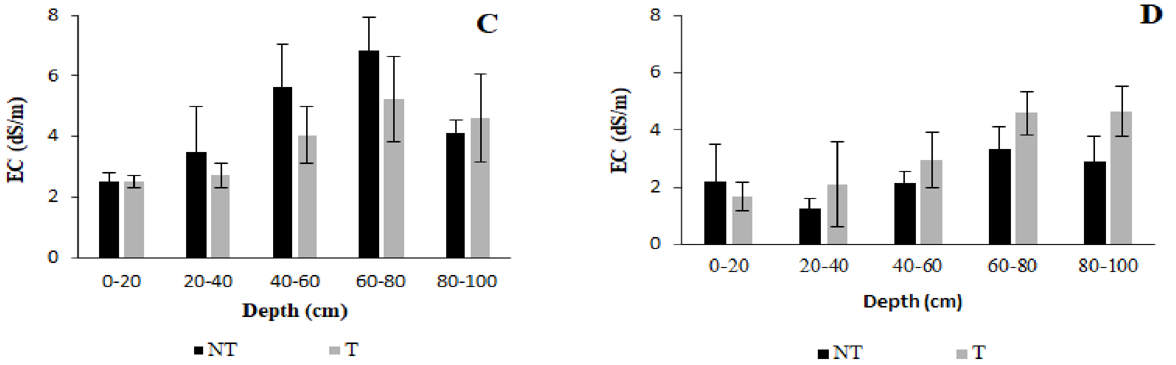


Fig. 1. Evolution of the soil electrical conductivity EC (dS/m) according to the depth and the mode of irrigation water treatment on 07/16/2019 (A), 10/10/2019 (B), 12/12/2019 (C) and 02/20/2020 (D). (NT: not treated; T: treated)

In the sample of 10/10/2019, the in-depth driving of the salts on the magnetized site was confirmed, with a strong leaching of the surface horizons (0-20 and 20-40 cm). Conversely, the non-magnetized site concentrated more salts in the surface horizons with a maximum in the 40-60 cm range (Fig. 1B). A partial and incomplete training of salts on this site was observed; it may have occurred after a fall rain that had a partial effect on leaching. This different distribution of salts between the two sites would maintain less concentrated solutions on the soil irrigated by magnetized water, especially in the area with strong root distribution (0-60 cm), and would act favorably on a better water supply and a more efficient absorption of nutrients.

In winter, irrigation frequencies decreased and the rains pushed the salts deeper; this was especially true for the site irrigated with non-magnetized water where the maximum amount of salts accumulated in the 60-80 cm horizon (Fig. 1C). In the horizons of soil irrigated with magnetized water, salts were less abundant and were distributed with a downward gradient.

During February 2020, the salt profile of the magnetized site changed little, but it was the non-magnetized site that had lost many of its salts (Fig. 1D). It was probably with holding irrigation or lowering the frequencies that would help carry the salts deep down.

It can be concluded that the results of the analysis of the electrical conductivity of the saturated paste extract of the soil profiles of the Beni Khalled confirmed an improvement in the salinity of the surface horizons first by the operation of magnetization of the irrigation water then by the winter leaching ensured thanks to the pluviometry and the reduction of irrigation frequencies. Zlotopolski (2017) showed that magnetic water treatment changed the distribution of salts between soil layers reducing their content in the upper horizons which are more important for agriculture [18]. On the other hand, recent studies have reported that magnetized water could increase salt movements to depths beyond the rhizosphere [20].

D. *Effect on Crops*

(a) *Nutrient Composition of Plant Leaves*

The effect of the magnetization of the irrigation water favorably affected the absorption of nitrogen and phosphorus. For nitrogen, the quantities absorbed are very clearly greater than those of the plant irrigated by non-magnetized water (Fig. 2A). The nitrogen contents varied between 4060 ppm (0.40%) and 17000 ppm (1.70%) for the control leaves and between 17605 ppm (1.76%) and 25456.67 ppm (2.55%) for the leaves irrigated with treated water.

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For phosphorus, the levels in the plant at the magnetized site are higher than those in the plant at the non-magnetized site, but in a more moderate manner (Fig. 2B).

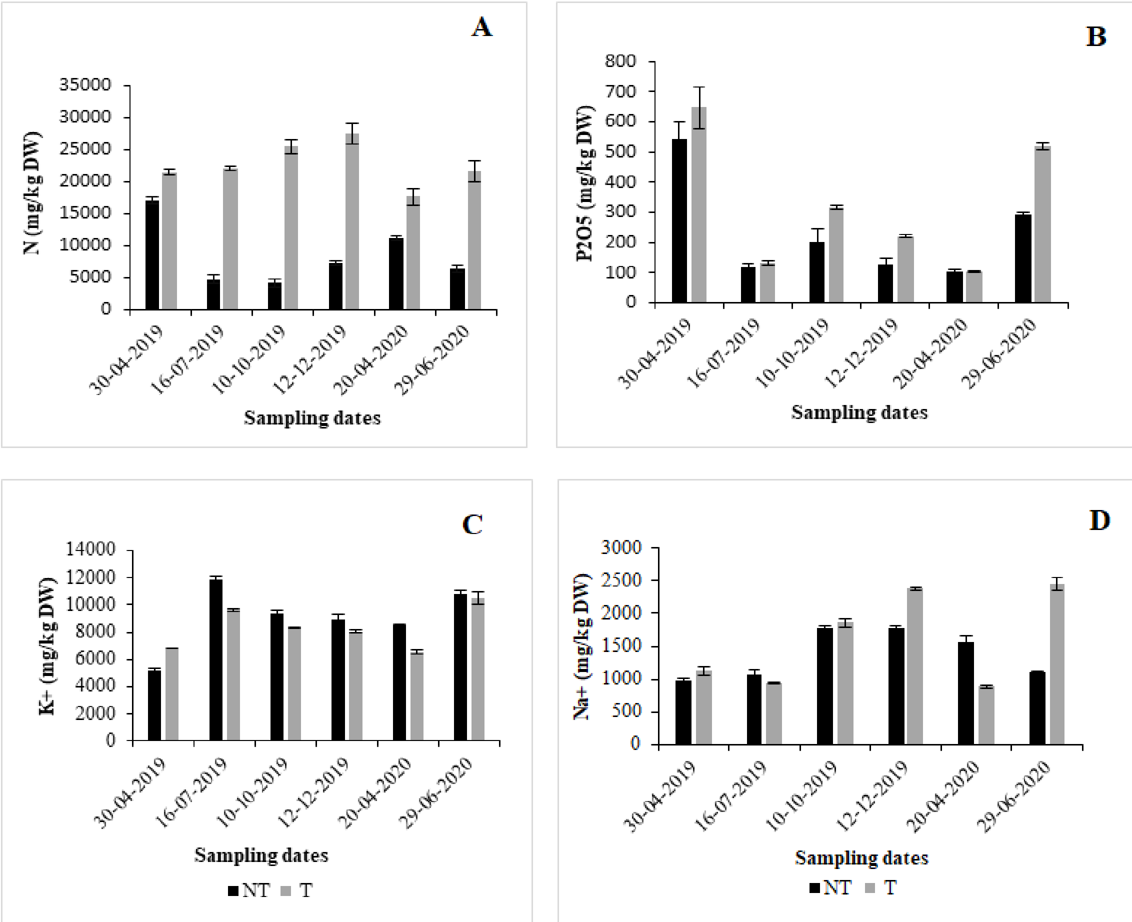

Fig. 2. Total nitrogen (A), P_2O_5 (B), K^+ (C) and Na^+ (D) analysis results, in citrus leaves, before (NT: non treated) and after magnetic treatment (T: treated) of irrigation water.

Magnetization does not seem to have had an obvious effect on potassium absorption (Fig. 2C) since during the six sampling dates; the differences between the two sites are not obvious. Conversely, sodium is better absorbed by plants irrigated with magnetized water (Fig. 2D).

Thus, we can draw from these results that the magnetization of the irrigation water acts favorably on the mineral nutrition of the plant, knowing that the two sites are treated under the same conditions of agricultural practices. These analyses show that the plant irrigated by magnetized water accumulates elements better. Aly et al., (2015) reported that magnetic water caused an increase in nitrogen%, phosphorus%, potassium%, calcium% and magnesium% in Valencia orange leaves [21]. These increments may be due to that the magnetized water showed higher values for mobile forms of nitrogen, improved fertilizers' dissolution in irrigated soil with this treated water and increased rate of water absorption.

(b) *Correlations between the Quality of Irrigation Water and Some Mineral Elements Quantified in Citrus Leaves*

For well water (before the magnetic treatment NT), we could identify a positive correlation between the SO_4^{2-} concentration of the irrigation water and the K content of the leaves at the 0.05 threshold, with a correlation

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coefficient r = 0.781 (Fig. 3A). In addition, a negative correlation could be obtained between the Cl concentration of the irrigation water and the Na contents of the leaves (Fig. 3B). The presence of chlorides in solutions would inhibit the absorption of cations by citrus plants.

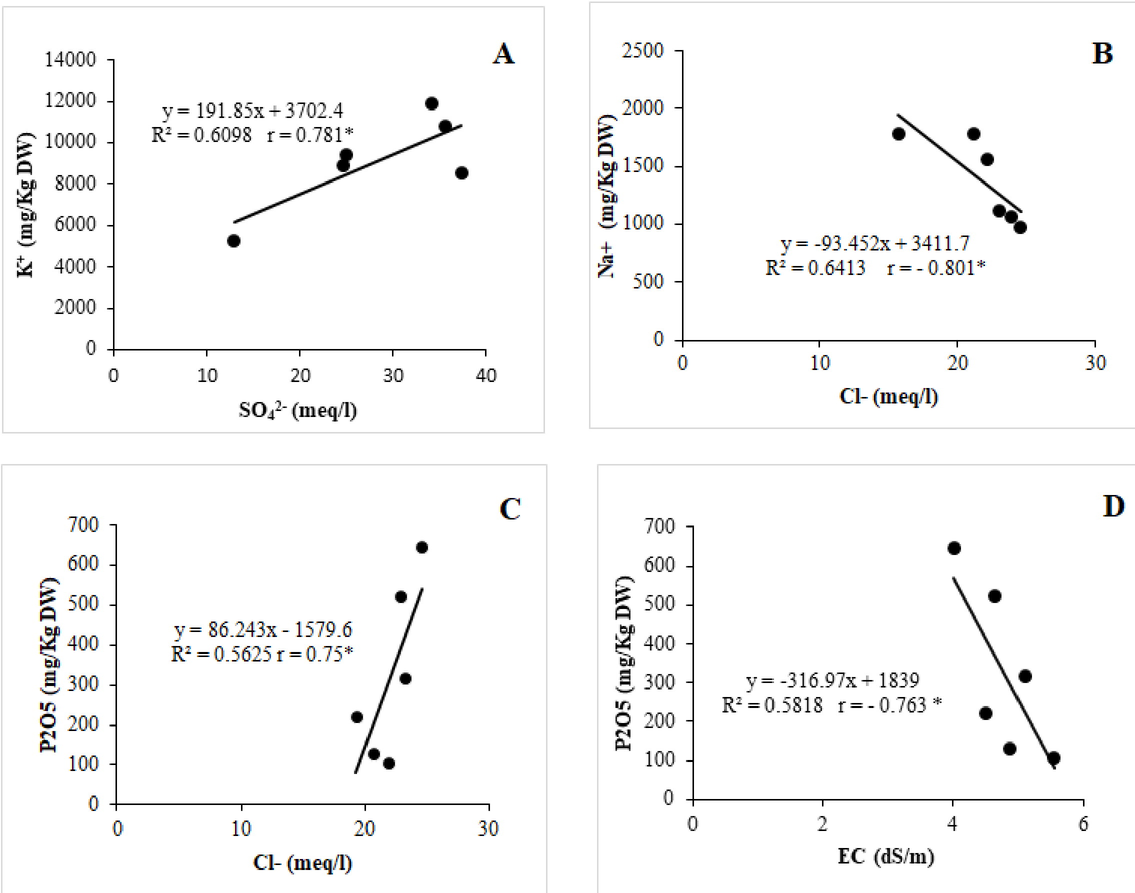

Fig. 3. Correlation between SO_4^{2} in untreated water and K^+ in leaves (A), Cl^- in untreated water and Na^+ in leaves (B), Cl^- of treated water and P_2O_5 of leaves (C), and EC in treated water and P_2O_5 in leaves (D) (*: $p < 0.05$). DW: dry weight; R^2: R-squared = (Correlation coefficient)^2; r: Correlation Coefficient.

For water treated by magnetization (T), available data have identified a positive correlation between the chlorides in irrigation water and the phosphorus absorbed by the leaves (Fig. 3C). It is concluded that magnetization would reduce the effect of chlorine and make it less antagonistic to phosphorus; the two ionized elements behave like anions, so a possible incompatibility could exist between them.

On the other hand, a negative correlation was observed between the EC of the irrigation water and the P2O5 of the leaves (Fig. 3D); this seems ordinary and expected result since the EC increases the hydrostatic tension of the water and would inhibit the absorption of nutrients, one of which is phosphorus. The magnetization would not act on strong salinities. The beneficial effects of water magnetization could be mainly attributed to the reduction in surface tension of magnetized water that improves the ability of roots to absorb water and nutrients, and thus improves different biosynthesis processes [22].

IV. Conclusions

Magnetic water treatment has opened new research avenues in agriculture. Safety, compatibility and simplicity, environmentally friendliness, low operating cost and not proven harmful effects are the main advantages of this technique. Improvements of irrigation water quality and quantity, crop yields and quality, soil improvement, scale prevention/elimination in water using systems, and water saving are some of the reported benefits of magnetic water treatment in agriculture. Regarding the chemical properties of irrigation water, calcium was the most predominant soluble cation whereas sulphate was the predominant anion followed by chloride.

The magnetization of the irrigation water showed insignificant variations of the cations and anions analyzed. The magnetic treatment caused a slight decrease in pH although it had no direct effect on electrical conductivity.

Water magnetization of the water could have a positive effect on the driving of salts at depth, thus acting to reverse the usual movements of upward salts to the surface, especially in the hot season.

The electrical conductivity of the saturated paste extract of the soil profiles of the Beni Khalled confirmed an improvement in the salinity of the surface horizons first by the operation of magnetization of the irrigation water then by the winter leaching ensured thanks to the pluviometry and the reduction of irrigation frequencies.

Irrigating with magnetically treated water significantly increased total nitrogen concentrations of citrus leaves. Finally, irrigated plants by magnetized water seemed to better accumulate nutritive elements.

ACKNOWLEDGMENT

Thanks to Mr. Habib Ben Hassine, former professor of higher agricultural education Head of Agricultural Production Systems and Sustainable Development Research Laboratory "SPADD" (LR03AGR02) for reviewing the paper and to Mrs. Nadia Abdelli, Amiral-Agro Company, Tunis, Tunisia.

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