Chapter 3
Innovation and Practical Experience of Using Saline Water at the Farm Level in Tunisia

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Abstract Tunisia is confronted, like several other countries, with water scarcity and salinity challenges. For salinity management, some activities are carried out. An alternative saline farming system is tried to find based to change the extensive rainfall crop system to a semi-intensive saline irrigated farming system, introduce new crops/cultivars, use localized irrigation, and develop more adapted farmer' practices. Concerning the adapted irrigation system under saline conditions, subsurface drip irrigation showed an improvement in water efficiency and a reduction in salt stress for different tomato varieties. Compatible organic molecular proline was tested to improve crop salinity tolerance. Foliar exogenous application of proline showed an increase in fruit yield. A new study has been carried out to evaluate the effect of the electromagnetic treatment (ET) of saline water on several aspects which as salts leaching, and duration of ET on the characteristics of drainage water and soil. The volume and the salts concentrations of drainage water were significantly higher under irrigation with electromagnetically treated saline water. This result was manifested by the improvement of salt leaching and the elimination of salt far from the root zone. The soil showed an increase in EC. The ET duration effect was also tested. The results indicated an increase in the volume and the salinity of drainage water when increasing the ET duration. The ET duration had also a significant effect on soil salinity which decreased under ET.

Keywords Salinity · Water · Management · Tunisia · Cultural practices

1 Introduction

Arid and semi-arid regions are characterized by scarcity of precipitation where evapotranspiration exceeds precipitation during the largest part of the year. Therefore, crop production is dependent on irrigation to achieve satisfactory yields. At the same time, one of the major constraints for environmental, social, and economic development

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in these regions is the shortage of freshwater resources (Bedbabis et al. 2014). The intensification of water scarcity is expected with rapid industrialization, fast population growth rates, and increased demand from the agricultural sector. Competition among user sectors will reduce the amount of freshwater allocated for crop production which, therefore, limits agricultural development. Consequently, there has been a growing interest in the use of nonconventional water, as alternative sources, such as agricultural drainage water, brackish water, or municipal and industrial effluent to meet its greater demands (Oron et al. 2002; Bixio et al. 2006; Khaskhoussy et al. 2019).

Although the use of saline water for irrigation is a strategy to mitigate water shortage, poor saline water management for irrigation has resulted in secondary salinization and a series of environmental problems (Kumar et al. 2015; Li et al. 2015). These problems will aggravate under climate change, unfavorable soil, overexploitation of groundwater, improper cropping patterns, and sea-water intrusion conditions (Heydari 2019).

Irrigation with saline water under strong evaporation, without taking into consideration the adequate application of water or conservation of the productive capacity of the soils, and associated with the absence of an efficient drainage system or the use of excessive amounts of fertilizers, leads to salt accumulation in the soil (Hue and Silva 2000; Wang and Qui 2004; Guilherme et al. 2019), salt accumulation in the upper soil layer negatively affects the soil properties. Indeed, high concentrations of sodium, calcium, and magnesium ions can affect the dispersion of clay particles, hydraulic conductivity, porosity, and soil aggregate stability (Guilherme et al. 2019). Therefore, the soil becomes degraded by salinization (Shrivastava and Kumar 2015). Consequently, soil salinization results in significant limitations to agricultural crop production which, in turn, negatively affects food security (FAO 2018).

High soil salinity levels decrease the osmotic potential of the soil, which results in the onset and the development of salinity stress at the whole plant level leading to reduced plant growth and finally biological or economic yield reduction (Dong 2012). Under osmotic stress conditions, various morphological, physiological, and biochemical changes in plants are mostly identical to drought (Munns 2002; Tang et al. 2007). Both drought and salinity stresses cause biochemical changes including inhibition of enzyme activities in metabolic pathways and accumulation of reactive species that play an important role in inhibiting plant growth and development (Nxele et al. 2017). Generally, salinity affects plants' growth, development, and survival in different ways such as water stress, specific-ion toxicity, oxidative stress, nutritional disorders, alteration of metabolic processes, reduction of cell division and expansion and genotoxicity (Munns 2002; Zhu 2007; Carillo et al. 2011).

Tunisia is among the semi-arid regions that face serious problems of salinization and water scarcity. Nowadays, about 10% of the national territory is affected by different degrees of salinity and about 25% of water resources have salt concentrations exceeding 3 g l^{-1}. As a result, about 50% of the total irrigated areas are considered at high risk of salinization. In this context, many experiences have taken place, since the sixties, in irrigated areas of Tunisia Center and at the experimental site of National Institute of Rural Engineering Water and Forests to evaluate the performance of different management practices including proper irrigation scheduling, drainage efficiency, appropriate irrigation systems, physical and chemical techniques (leveling, plowing, planting techniques, optimizers, etc.), soil amendments and introduction of salt-tolerant crops varieties and species for the sustainability of irrigated agriculture under salinity pressure were investigated.

To avoid such damage caused by these stresses and increase food production, it is necessary to develop innovative adaptation practices and different reclamation approaches including changes in crop management practices, agricultural water management strategies, and the adoption of new agricultural technology (Thong et al. 2019). In this context, farmers also play a crucial role, not only as receivers of innovations but also as producers and holders of knowledge (Goulet and Le Velly 2013; Tambo and Wunscher 2017).

As mentioned, various technological and biotechnological crop-soil–water salinity management practices, such as better water management, the introduction of alternatives crops, salt-tolerant plants, organic substances, and adoption of new irrigation practices at the field level, including methods for water use efficiency and innovative technologies for saline water treatment (Hanson et al. 2007; Pereira et al. 2002, 2009) were suggested.

There is a wide range of alternative crops for industrial, energy, and alimentation usages that can be used in salinity management which adapt well to arid and semi-arid region's climates and when using high salinity water for irrigation. These crops are generally salt-tolerant or/and well adapted to drought conditions. It has been reported that the yield of some salt-tolerant crops under saline water irrigation is similar to that under freshwater irrigation (Wan et al. 2010; Singh and Panda 2012). A variety of plants that seem to be well adapted to arid and semi-arid regions (Ashton et al. 2008) can be energetic, pseudo-cereal, cosmetic, etc., with high economic value (Gantait et al. 2014; Kaya and Attila 2015). Moreover, it has been reported that is possible to improve crop salinity tolerance by organic substances application, such as proline (Kahlaoui et al. 2016).

Proper choice of irrigation methods should create and maintain favorable salt and water regimes in the root zone such that water is readily available to plants for their growth and without any damage to yield (Minhas et al. 2020). In addition, it should ensure uniform distribution of water. Micro (Drip) irrigation methods are regarded as superior in improving efficiency and crop production under saline conditions (Hanson et al. 2008; Minhas et al. 2020).

Recently, new innovative practices, such as magnetic/electromagnetic treatment of saline water have gained greater importance. This physical treatment of water is an innovative approach that affects the behavior of inorganic and organic materials in water, including crystallization and biological processes, which, consequently, can positively influence the growth parameters of many crops (Selim and El-Nady 2011).

Considering these management strategies, many research studies have been done to develop appropriate management suitable for cropping with poor-quality waters under semi-arid Tunisian conditions, where salt-tolerant fruit trees, medicinal, aromatic, and other high-value crops are tested, and innovative technology systems were used.

This paper is an overview of the results of experiments conducted by the team of the Research Laboratory Valorization of Non-Conventional Waters, National Institute of Rural Engineering, Waters and Forests, Tunisia. An innovation represents "an idea, practice, or object that is perceived as new" and includes new agricultural technology and many other processes or the application of a new learning and teaching method (Spielman et al. 2011). Many research projects are conducted on salinity and efficient use of saline water issues under Tunisian climatic conditions by adapting innovative management practices that improve the efficient use of saline soil. The practices include new crops/varieties; new systems of irrigation; new technologies and more adapted farmer practices.

2 Selection of Salt-Tolerant Crops and Varieties

2.1 New Varieties of Olive Trees

Olive is a major tree crop in the Mediterranean region of which more than 90% of the world's olive oil is produced. In Tunisia, olive is the most representative, cultivated with about 1835 thousand hectares cultivated in a large agricultural area and there are approximately 82 million trees covering the land (DGPA, 2015). *Chemlali* is the major Tunisian cultivar that covers 2/3 of the Tunisian olive grove and contributes more than 60% of the national production of olive oil (Khlif et al. 2002; Ben Rouina et al. 2002). In comparison to other Mediterranean fruit trees, olive is considered to be a moderately salt-tolerant plant and the tolerance level depends on plant age and cultivar (Chartzoulakis 2011; Erel et al. 2019). It is suggested that olives can be irrigated with water with electrical conductivity (ECw) between 3 and 6 dS m^{-1} causing no effect on growth or yields, and irrigation water with 8 g l^{-1} NaCl has been found to be the tolerance limit for olive trees (Ayers and Westcot 1985; Chartzoulakis 2011). Mechanisms of salinity tolerance in olive trees include a strong ability to exclude potentially toxic ions such as Na^+ and Cl^- ions from aboveground tissues and its retention in roots (Chartzoulakis et al. 2002; Kchaou et al. 2010). To investigate and compare the effect of salinity on two olive trees cultivars, a field experiment was conducted, at the North of Bouhajla village located at the South of Kairouan city. This region has a typical Mediterranean semi-arid climate with an annual average precipitation of about 250 mm. Two olive trees cultivars: *Arbequina,* a Spanish cultivar, and *Chemlali,* a Tunisian cultivar, were used and a total of 120 olive trees were planted in the plot. Olive trees were irrigated with well water where TDS, EC, and SAR reached 3.7 g l^{-1}, 5.1 dS m^{-1}, and 11.4, respectively. The soil is characterized by a silty clay texture with about 50% of smectites, less than 1% of organic matter, 32% of total lime, 20% of active lime, pH of about 8.3, and a high initial salinity of about 5.0 dS m^{-1} in the surface layer and 6.5 dS m^{-1} at a depth of 1.5 m. Yield production and oil quality were evaluated after 6 years of planting. *Arbaquina* cultivar had a fruit yield (12 kg/tree) significantly higher than *Chemlali* cultivar (2 kg/tree). Fruit weight was significantly higher with the *Arbaquina* tree than with the *Chemlali* tree and this was mainly due to an increase in the olive weight. There were no differences among cultivars in acidy of oil, where acidy was about 2.64 and 2.71 for *Chemlali* and *Arbaquina,* respectively. According to this result, the oil of both cultivars looks to be regular virgin olive oil, which may be due to the collection, storage, and extraction of oil conditions. Oil fatty acid composition of these olives showed to conform with the International Olive Oil Council Standards (2019), except for two acids for *Arbaquina* cultivar and one acid for *Chemlali* that exceeded these criteria. It was found that *Arbaquina* oil absorption of UV radiation was more conforming to standard than *Chemlali* oil. Furthermore, *Arbaquina* cultivar looks to be a more salt-tolerant tree than the *Chemlali* Cultivar.

2.2 Energetic Plant: Jatropha

Jatropha curcas L. is a member of the spurge family (Euphorbiaceae), native to South America but now thrives in many parts of the tropics and subtropics in Africa and Asia (Kumar and Sharma 2008; Niu et al. 2012). It has emerged, among the species used to produce biodiesel from the oil extracted from their seeds, as one of the candidates with the greatest potential. It has increased in popularity in recent years due to its high ecological adaptability which allows it to thrive in a wide range of environmental conditions (Kheira and Atta 2009; Dorta-Santos et al., 2014). Jatropha is reported to be drought resistant due to its ability to grow under arid and semi-arid climates and without irrigation in a region where average rainfall does not exceed 300 mm $year^{-1}$ (Nui et al. 2012; Dorta-Santos et al. 2014). However, there is little information on its salt tolerance and no threshold has been assessed. While a number of researchers reported that Jatropha could successfully be irrigated with levels of salinity of up to 12 dS m^{-1}. FAO classified Jatropha as a sensitive crop (Dagar et al. 2006).

A greenhouse experiment was conducted to evaluate the growth responses of Jatropha to a range of salt concentrations. Jatropha was cultivated in three Tunisian soil types (clay loam, sandy loam, and medium textures) and irrigated with drinking water (C0 = 1.5 dS m^{-1}), saline water of 7.5 dS m^{-1} (C1) and saline water of 10.0 dS m^{-1} (C2). Stem length, diameter and number of leaves were recorded. Jatropha growth was significantly influenced both by water quality and soil texture (Fig. 1).

Indeed, the highest dry weights, d leaf areas, and stem lengths were observed in the sandy-loam soil under drinking water irrigation (Fig. 2).

Significant growth reduction observed in plants irrigated with saline soil could be due to the increase in Na^+ in different parts of the plant and especially in leaf tissues.

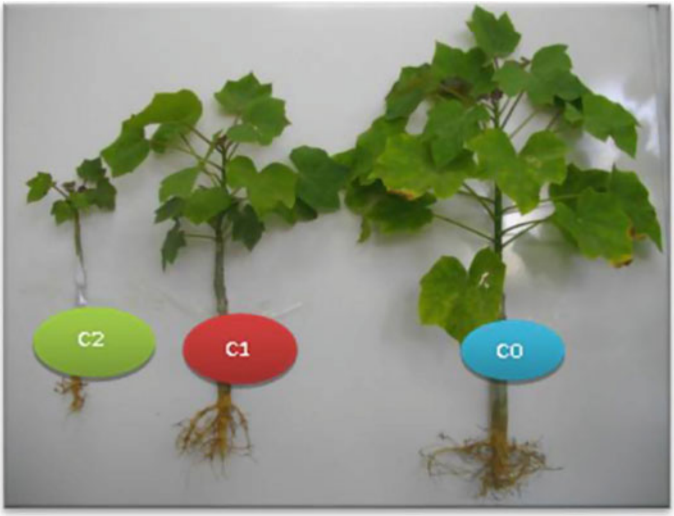


Fig. 1 Effect of saline water irrigation of different salinity levels on Jatropha growth. C0: Control; C1: 7.5 dSm^{-1}; C2: 10 S m^{-1}

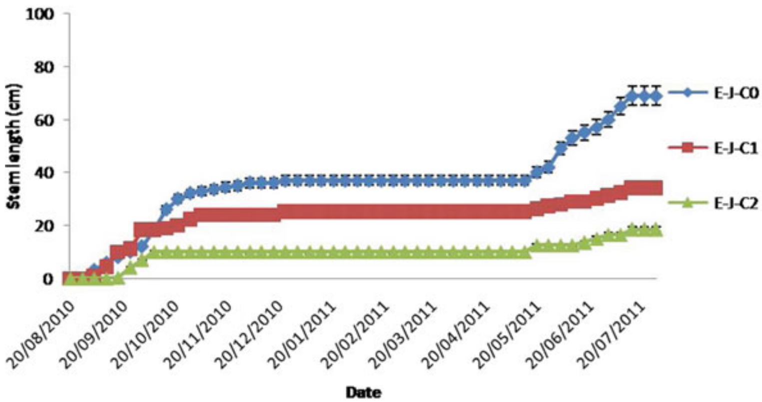


Fig. 2 Effect of saline water irrigation on stem length of Jatropha. C0: Control; C1: 7.5 dS m^{-1}; C2: 10 dS m^{-1}

Based on this finding, Jatropha cannot be considered a tolerant plant to salinity where its yield would be reduced when grown in a salt-affected area. This suggests that energy plants can only be adopted in areas with a shortage of water resources.

2.3 Pseudo-Cereal: Quinoa

Chenopodium quinoa Willd is an Andean species that shows a potential to enhance farm-level productivity and livelihoods in drought- and salt-prone areas. Quinoa is a salt-tolerant seed crop widely investigated due to its nutritional composition and gluten-free seeds (Kaya and Attila 2015). Field experiments (Rjeibi et al. 2015) were conducted to evaluate the response of quinoa, at different growth stages from seedling to maturity, to water deficit, and salinity stress under the Tunisian climate. The study highlighted the effect of irrigation with saline water at different salinity levels (1.25, 10, 25, and 40 dS m^{-1}) on morphological and physiological parameters of quinoa such as germination rate, length, diameter, leaf area, number of spikes, chlorophyll, and mineral element content. Stress conditions allow this plant to develop resistance mechanisms to water stress and grow under optimal conditions with a very limited quantity of water irrigation (250 mm). Quinoa also showed a tolerance for salinity with a seedling reduction of about 9% at 25 dS m^{-1}. Quinoa irrigated with saline water at a level of 10 dS m^{-1} showed the highest length, width, leaf area, number of branches, and weight. Moreover, the highest mineral contents were especially observed in leaves.

A germination test of quinoa seeds was performed for five varieties from the International Center for Biosaline Agriculture and from the University of Santiago of Chile. Among quinoa varieties, AMES 13,761 and *Ch.q. Willd* have the highest germination rates and consequently are more tolerant to salinity than other varieties. After the seed germination test, a field trial (Fig. 3) was carried out in the Cherfech research station to evaluate the response of quinoa to irrigation with saline water of two salt concentrations (6 and 12 g l^{-1}) and fresh water.

Fig. 3 Field experiment for quinoa seeds crop at Cherfech research station (north of Tunis City)

Growth parameters suggested a good adaptation of quinoa to drought stress. Results indicated also an increase of root biomass under deficit irrigation levels of 50% and 75% compared to full irrigation. The highest yield production was recorded under deficit irrigation levels of 75%, whereas, the lowest was recorded under the level of 100%. Generally, the highest yield production to the lowest were ranked as follows75% > 50% > 100. A comparison was performed on some growth parameters, such as shoot length and root biomass of plants irrigated with saline water of salt concentration 6 g l^{-1} and plants irrigated with deionized water (salt concentration = 0 g l^{-1}). Results suggested a good adaptation of Quinoa to salinity stress. The nutritional advantages of quinoa seeds and antioxidant components such as polyphenols are also evaluated, and the result showed that quinoa seeds cultivated under saline water irrigation (6 g l^{-1}) had the highest amount of proteins and polyphenols.

2.4 Medicinal and Cosmetic Plant: Aloe Vera

Aloe vera is a tropical, drought-resistant succulent plant of the Liliaceae family. *Aloe vera* (*Aloe barbadensis* M.), the most popular *Aloe* variety, has been cultivated for its beneficial properties, finding application in a wide range of medical and health products. It originates from the Mediterranean region, Eastern Africa, the Arabian Peninsula, India, and China. *A. vera* is a xerophyte with a strong drought resistance ascribable to its use of crassulacean acid metabolism photosynthesis, and a certain degree of tolerance to salt stress. It is highly appreciated due to its short growth period and its high economic value (Gantait et al. 2014). *A. vera* is a short-stemmed perennial that reaches a height of 60–100 cm. This succulent has elongated leaves that store large amounts of water. The leaf extracts latex and gel are the primary products used in *A. vera* industry. The original commercial use of the *Aloe vera* plant was in the production of a latex substance called Aloin, a yellow sap used for many years as a laxative ingredient. Later the gel, stabilized and marketed, gained respect as a product used as a base for nutritional drinks and as a healing agent. This gel has a complex chemical composition: amino acids, minerals, vitamins, enzymes, proteins, polysaccharides, and biological stimulators. The rich chemical composition of the plant depends, essentially, on the type of the aloe's species, conditions of cultivation, climate, harvest time, and the method utilized in harvesting (Giannakoudakis et al. 2018). It is attributable to its importance in the medical and healthcare fields, food industry, cosmetology, and nanotechnology (Soltanizadeh and Ghiasi-Esfahani 2015; Balaji et al. 2015; Rahman et al. 2015).

A. vera is being considered as an alternative crop for industrial applications in arid and semi-arid areas, where drought and salinization are preponderant. This suitable and environmentally safe solution shows an ability to survive in xerophytic conditions of the tropical, and subtropical regions as well as a salt tolerance even in infertile saline soils of coastal zones, although it is not usually taken as a halophyte (Zheng et al. 2009). Several experiments have been carried out for the assessment of growth, cations distribution, gel yield, and Aloin contents under different environmental conditions (Murillo-Amador et al. 2014). Many of these studies emphasized the beneficial role of moderate salinity stress for good growth, high yield of Aloe gel, and aloin content (Rahi et al. 2013).

Ascribed to its high market demand and export potential, *A. vera* farming is being encouraged by the Tunisian government. In order to occupy unproductive lands and preserve the water of good quality for domestic purposes, research was focused on either the Aloe cultivation in salt-affected soils or its irrigation with brackish water. In this context, an experiment has been conducted in the Kalaât Landelous region under hydromorphic and extreme saline conditions. The soil of the study area is distinguished by a high salinity level (16–24 dS m^{-1}) characterized by dominant Na and Cl ions. This salinity is mainly related to the presence of a shallow and highly saline water table. In fact, the water table depth is about 30 cm deep in the rainy seasons, and 142 cm in the dry seasons, and the salinity may reach 10.9 dS m^{-1}. Irrigations have been only performed during the summer season. Despite the elevation of the soil 1 m above the surface reducing as a result the effect of salinity in the topsoil, the soil remained very strongly saline with a genotoxic potential. *Aloe* plants showed an inability to resist the natural conditions prevailing in the study region. During the two years of monitoring, plants showed slow growth and low production (less than 12 leaves per plant) with signs of dryness (Souguir et al. 2013).

Simultaneously, the ability of *A. vera* to withstand salinity was tested under controlled conditions. Plants were cultivated in slightly alkaline ($pH = 7.6$) soil with low salinity ($ECe = 1.1$ dS m^{-1}). Salt stress was applied by NaCl addition in irrigation water: two salinity levels have been chosen: a moderate ($EC = 3.5$ dS m^{-1}) and a high ($EC = 12.0$ dS m^{-1}) level of NaCl. Irrigation frequency varied according to the season, and the cumulative water intake was about 1782 mm for each plant. 14 months of irrigation with saline water strikingly increased the soil salinity even under drinking water (Table 1). The most typical symptom of saline injury to plants is the reduction of growth. High concentration of salt significantly reduced growth parameters in terms of leaf number and length and fresh and dry matters with no significant modification in their water and gel contents. Growth changes occurred as a result of the Na accumulation in the leaf tissues, consequently dropping the K/Na and Ca/Na ratios when compared to plants irrigated with drinking water (Table 1). In addition, *A. vera* was a seat of high production of hydrogen peroxide (H_2O_2), a reactive oxygen species, generally associated, at a high level, with the development of the oxidative injury and the disruption of the metabolic functions in plants.

Malondialdehyde (MDA), a reliable indicator of oxidative injury and membrane lipid deterioration, also exhibited an enhancement of its content, proportionally to the toxic ion accumulation and/or H_2O_2 production (Table 1). In order to reduce oxidative damage, *Aloe* leaves have increased phenolic compounds biosynthesis (Table 1), which are the most abundant secondary metabolites in plants and play an important role in scavenging the free radicals (Mohamed and Aly 2008). On the basis of overall growth assessment and metabolic response at different salinity levels, *A. vera*, planted in soil affected by at least moderate salinity or irrigated with moderate salt water, can be attractive for industrial production in arid and semi-arid areas. High salinity negatively affects plant growth and its productivity.

Table 1 The salinity effects on the soil and on the *Aloe* plants. Irrigations were performed with different water qualities: drinking water (EC: 1.25 dS m^{-1}), moderate salinity (EC: 3.50 dS m^{-1}) and high salinity (EC: 12.00 dS m^{-1})

	Irrigation water quality		
	Drinking Water (EC: 1.25 dS m^{-1})	Moderate salinity (EC: 3.50 dS m^{-1})	High salinity (EC: 12.00 dS m^{-1})
Soil salinity-ECe (dS m^{-1})	5.77 ± 2.16a	11.4 ± 6.90b	20.55 ± 8.85c
Growth parameters			
Leaf number	14.45 ± 0.85b	12.91 ± 1.50b	9.09 ± 1.57a
Leaf length (cm)	30.46 ± 2.89b	29.76 ± 2.22b	22.22 ± 3.15a
Fresh weight (g)	369.16 ± 13.05c	255.22 ± 16.82b	163.26 ± 19.3a
Dry weight (g)	16.3 ± 1.23c	12.2 ± 0.05b	9.4 ± 1.67a
Water–gel content (%)	95.58 ± 1.92a	95.21 ± 1.18a	94.21 ± 1.45a
Cation content			
Na (%)	1.29 ± 0.04a	1.79 ± 0.09b	3.75 ± 0.22c
K/Na	1.04 ± 0.04c	0.72 ± 0.2b	0.47 ± 0.18a
Ca/Na	2.87 ± 0.10c	1.29 ± 0.40b	1.25 ± 0.09a
Oxidative stress-H_20_2 content (μmol g^{-1})	30.90 ± 12.96a	79.39 ± 42.48b	97.87 ± 14.12c
Lipid peroxidation-MDA content (nmol g^{-1} FW)[a]	6.41 ± 3.87a	12.96 ± 2.70b	31.54 ± 1.55c
Total phenolic compounds (U)[b]	1.22 ± 0.22a	2.68 ± 0.10b	4.30 ± 0.95c

Values represent means ± SE of triplicates
In each line, values followed by different letters are significantly different at $P < 0.05$ according to Tukey's test
EC lectrical conductivity of water, *ECe* electrical conductivity of the saturated soil-extract paste, H_2O_2 hydrogen peroxide, *MDA* malondialdehyde
[a]Fresh Weight
[b]Unit

2.5 Forage Legume: *Sesbania*

In order to find new crops tolerant to saline conditions and with high economic values, we were interested in *Sesbania aculeata*, a forage plant less studied in Tunisia. It is a leguminous shrub that belongs to the Fabaceae family and is one of the most potential legume fodder crops grown on saline and/or alkaline soils due to its halophytic nature (Parveen and Rauf 2008). Indeed, it can tolerate salinity up to 10 dS m^{-1} (Juzdan 2014). This plant plays an important role in the long-term maintenance of soil productivity because of its high nitrogen-fixing capacity. It can produce between

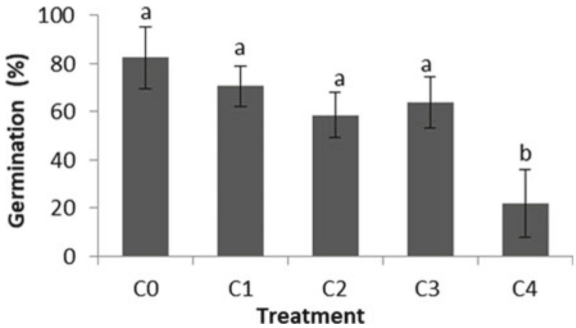


Fig. 4 Final percentage of germination of seeds of *S. aculeata* under salt stress (C0: distilled water; C1: 6 dS m^{-1}; C2: 12 dS m^{-1}; C3: 18 dS m^{-1} and C4: 24 dS m^{-1})

5.00 and 5.25 T ha^{-1} per year of dry matter and fix between 500 to 600 kg ha^{-1} of nitrogen per year.

Our study concerned the germination, the growth of this plant in a greenhouse and in the open field, and the effect of irrigation with saline water on the plant. In the first test, we tested the germination capacity of the seeds by applying different salt concentrations (6, 12, 18, and 24 dS m^{-1}) and we found that these seeds have a germination capacity of over 60% with irrigation water of up to 18 dS m^{-1}. Beyond this concentration, germination decreased significantly compared to the control seeds (Fig. 4).

Taking these results into account, a second test was carried out using only the concentrations 6, 12, and 18 dS m^{-1}. The test was carried out in pots and on loamy clay soil. In this soil, *Sesbania aculeata* was able to survive but with a significant decrease in growth especially under 18 dS m^{-1} (C3). This concentration affected the length of the plants and the fresh and dry matter of the roots and stems. The increase in salinity has no negative effect on the fresh and dry matter of *Sesbania* leaves (Table 2).

Based on the results obtained in this test, another experiment was conducted in the field using the concentrations 6 and 12 dS m^{-1}. Irrigation with saline water and even with drinking water has caused an increase in soil salinity with an accumulation of salts, especially in the deep layers (210 cm deep). The accumulation of salts in the soil seems to modify some growth parameters of the plants of *Sesbania aculeata*. In fact, salinity has no significant effect on the above and below-ground biomass (Table 3) as well as on the growth in length and diameter of the Sesbania stems (Fig. 5). These results do not agree with the results obtained by Mahmood et al. (2008) who showed that the fresh and dry biomass of the stems and roots of *Sesbania sesban* gradually decreased with increasing levels of salinity. However, Ben Naceur et al. (2001) show that irrigation of wheat varieties with 4 g l^{-1} saline water does not significantly affect height growth.

The root part seems to be the most affected by salinity with a significant decrease in lateral branching (Fig. 6) and the inhibition of the formation of nodules fixing atmospheric nitrogen at 12 dS m^{-1} (Fig. 7).

Tests of *S.aculeata* under salinity conditions showed a particular resistance at the germinative stage rather than at the growth stage. Two uses of *Sesbania aculeata* can

Table 2 Growth parameters of *S. aculeata* under salt irrigation. In addition to the control (C0), C1, C2, and C3, respectively represent the Electrical conductivity of irrigation water: 6 dS m^{-1}, 12 dS m^{-1} and 18 dS m^{-1}

	C0	C1	C2	C3
Fresh matter (g)				
Roots	5.49 ± 1.72a	4.06 ± 2.04a	3.06 ± 1.28ab	1.28 ± 0.72b
Stems	4.95 ± 2.40a	7.03 ± 3.57ab	5.42 ± 2.86a	2.24 ± 1.32b
Leaves	5.54 ± 1.70a	7.78 ± 3.43a	6.08 ± 3.27a	3.93 ± 1.02a
Drymatter (g)				
Roots	0.83 ± 0.23a	0.88 ± 0.37ab	0.76 ± 0.36a	0.35 ± 0.18b
Stems	1.57 ± 0.62a	2.14 ± 1.06ab	1.63 ± 0.82a	0.71 ± 0.45b
Leaves	1.84 ± 0.52a	2.27 ± 1.06a	1.7 ± 0.86a	1.05 ± 0.32a
Number of leaves	14.82 ± 2.89a	20.17 ± 5.20b	16.38 ± 5.12ab	14.43 ± 3.01a
Length of the aerial part (cm)	28.79 ± 4.94a	27.26 ± 4.69a	19.59 ± 5.07b	14.08 ± 3.41c

For each plant part (line), the different letters indicate significant differences by the Tukey test at $P < 0.05$

Table 3 Variation of fresh and dry matter of *S. aculeata* under irrigation with saline water. C0: 1.5 dS m^{-1}; C1: 6 dS m^{-1} and C2: 12 dS m^{-1}

	C0	C1	C2
Fresh matter (g)			
Roots	136.02 ± 38.97a	110.51 ± 57.66a	70.91 ± 20.50a
Stems	307.45 ± 101.92a	306.18 ± 94.64a	228.58 ± 103.87a
Leaves	49.63 ± 2.31a	28.78 ± 21.31a	24.95 ± 12.96a
Dry matter (g)			
Roots	48.06 ± 16.10a	52.333 ± 28.716a	38.35 ± 3.19a
Stems	193.10 ± 62.98a	152.30 ± 52.24a	111.64 ± 41.74a
Leaves	15.47 ± 0.64a	18.03 ± 16.06a	12.17 ± 9.31a

For each plant part (line), the different letters indicate significant differences by the Tukey test at $P < 0.05$

be considered. The aerial part can be used as fodder during the summer period. In this sense, *Sesbania* can also be irrigated with water having a salinity of up to 12 dS m^{-1}. In order to increase the productivity of crops and for nitrogen enrichment of the soil, *Sesbania* can be irrigated with water having a salinity of 6 dS m^{-1}. So, cultivating the Fabaceae *Sesbania aculeata* during the summer season is a better option than bare fallow to maintain the soil nitrogen reserve and decrease nitrogen fertilization rates, not only in arid and semi-arid countries but also worldwide.

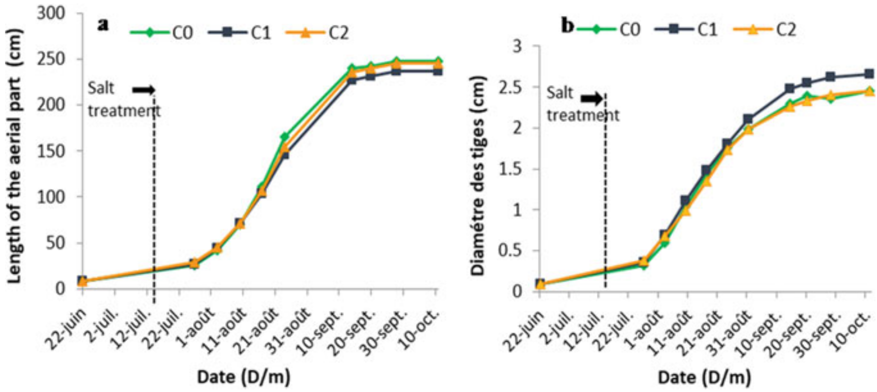


Fig. 5 Evolution of the growth (a: length; b: diameter) of the aerial parts of *Sesbania aculeata*. C0: 1.5 dS m^{-1}, C1: 6 dS m^{-1} and C2: 12 dS m^{-1}

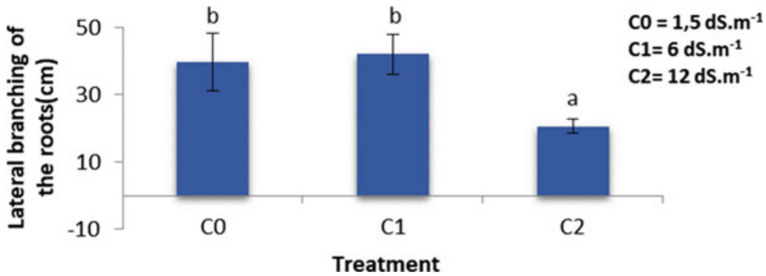


Fig. 6 Lateral branching of the roots of *Sesbania aculeate*

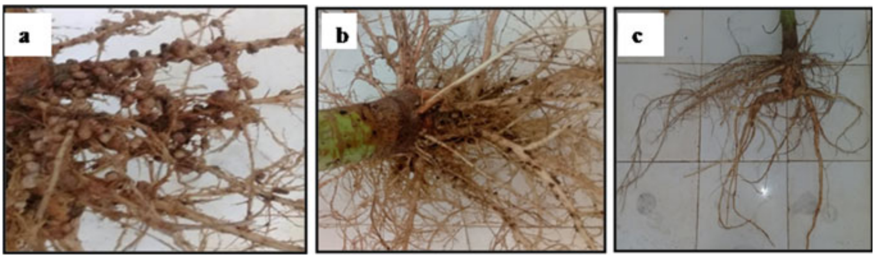


Fig. 7 Nodules on the roots of *Sesbania aculeata*. The roots show an abundance of nodules in the control C0 (**a**), a low number of nodules in C1 (**b**) and an absence of nodules in C2 (**c**). C0: 1.5 dS m^{-1}, C1: 6 dS m^{-1} and C2: 12 dS m^{-1}

3 Adapted Irrigation System Under Saline Condition

Water irrigation management is based on reducing salt accumulation in the active root zone and therefore the elimination of salt stress, especially during the critical growth stages of the plants (Minhas et al. 2020). To ensure proper water management, water distribution on irrigated land should be uniform by using the proper method of irrigation. Drip irrigation methods are regarded as superior in improving efficiency and crop production under saline conditions (Hanson et al. 2008; Minhas et al. 2020). With the purpose of improving salinity management and water use efficiency, an experiment (Kahlaoui et al. 2014) was conducted to study the effect of surface drip irrigation (DI) and subsurface drip irrigation (SDI) on three cultivars of tomato crop: Rio grande, Rio Tinto and Nemador under deficit irrigation levels of 85% and 70% and full irrigation. An increase in salinity was recorded under deficit irrigation levels of 70%. Results showed also a significant difference in the crop response to different treatments. Irrigation method with saline water affected the tomato growth (Fig. 8) of Rio Tinto and Nemador cultivars, in particular leaf area, dry and fresh matter, as well as chlorophyll contents and the mineral composition of leaves, stems, and roots. However, the effect on fruit quality was not manifested.

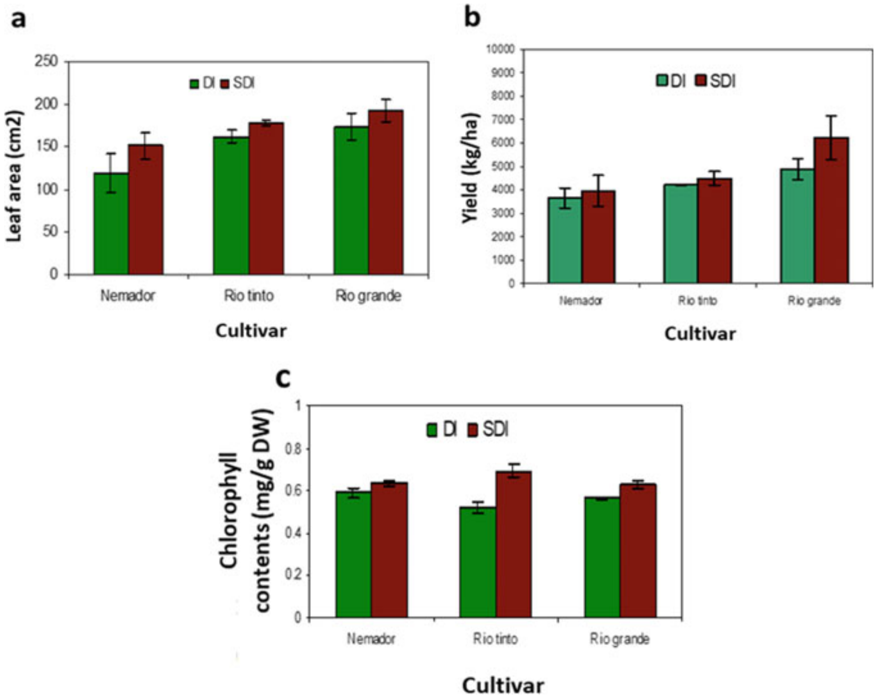


Fig. 8 Growth parameters variation among tomato cultivar and irrigation method (**a**: leaf area; **b**: yield production; **c**: chlorophyll content)

The accumulation of Na^+ and Cl^- was associated with a decrease in the contents of Ca^{2+}, K^+ and Mg^{2+} under DI irrigation treatment. The nutrient uptake, which affected by Na^+ and Cl^- accumulation, depends on mineral elements and tomato cultivar. Rio grande cultivar seems to be more suitable for water deficit under SDI. The more sensitive cultivar (Nemador) showed a low decrease in yield by SDI as a consequence of water efficiency improvement and saline stress reduction under using SDI.

4 Improving Crop Salinity Tolerance by Organic Substances: Proline

Proline (Pro) is an organic compound synthesized and accumulated in the cytosol and organelles of plants in response to salinity stress (Ashraf and Harris 2004; Sairam et al. 2006). It is also called a "compatible osmolyte" due to its accumulation in the plant without perturbing intracellular biochemistry (Sairam et al. 2006; Kahlaoui et al. 2016). Proline accumulation is considered as one of the adaptive plant mechanisms in response to salt stress and water deficit (Kumar et al. 2000; Ramajulu and Sudkakar 2000). Therefore, proline accumulation may be used as a clue for salt stress tolerance (Ramajulu and Sudkakar 2000). It has been reported that proline accumulation protects macromolecules against denaturation, contributes to osmotic adjustment, reduces cell acidity, acts as a storage compound and nitrogen source for an after-stress rapid growth, and protects plants against free radical-induced damage by quenching the oxygen single (Singh et al. 1973; Schobert and Tschesche 1978; Venkamp et al. 1989; Aziz et al. 1999; Teixeira and Fidalgo 2009).

Considering these findings, an experiment was conducted at Cherfech Station to investigate the effect of the exogenous application of two concentrations of proline on the physiological and biochemical responses of two cultivars of tomato irrigated and saline water ($EC = 6.57$ dS m^{-1}, $SAR = 12.8$) using subsurface drip irrigation (SDI) (Kahlaoui et al. 2012). The experiment was carried out, according to a randomized design with two factors (cultivar and Pro concentration), during the summer of 2009 (from 02/05 to 27/09). Two tomato cultivars (Solanum lycopersicum) were used: a salinity-tolerant cultivar, Rio Grande (Kahlaoui et al. 2011) and a salinity-sensitive cultivar, Heinz-2274 (Kahlaoui et al. 2012). Treatments were two exogenous applications of Pro (10 and 20 mg l^{-1}) and a control (without proline application) for each cultivar. Proline spraying was performed 6 times from 30% of the flowering state in June. It was shown that exogenous application of 10 mg l^{-1} of Pro was the most effective in promoting growth and productivity of both cultivars of tomato crops (Fig. 9) by increasing fresh and dry weight, leaf area, chlorophyll content, and improving mineral nutrition.

Exogenous applications increased proline accumulation, total soluble protein content, Guanine nucleotide-binding proteins (GS), and Guanylate kinase (GK) activities and decreased Proline Oxidase (PROX) activity. The increase due to proline

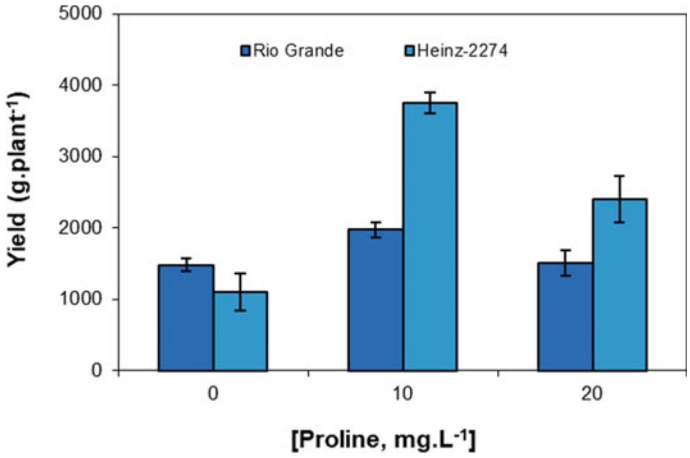


Fig. 9 Effect of the exogenous application of proline on tomato crop yield of two cultivars

accumulation was accompanied by a significant decrease in sodium and chlorine and the symptom of blossom-end rot. The increase of this physiological disease was the highest in the Heinz cultivar with a high concentration of Proline (20 g l^{-1}). With regard to the fruit quality, spraying with proline had no significant effect on acidity and on the total dissolved solids amount. In turn, the acidity raised in Heinz cultivar fruit at a high concentration of proline (20 g l^{-1}).

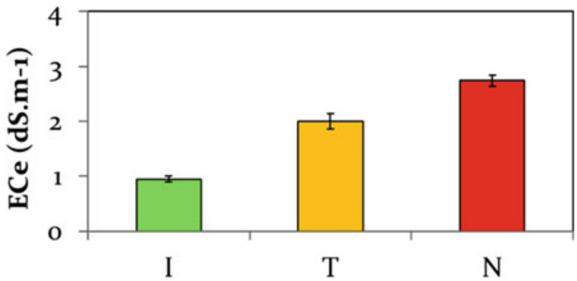
5 Reducing Water Salinity Effect by Electromagnetic Treatment

In order to improve yield production and manage low-quality soil and water, farmers of arid and semi-arid regions have been forced to implement innovative approaches. Among these approaches, some research studies have shown that magnetic/electromagnetic treatment (ET) of water can positively influence the growth parameters of various plant species and the soil properties (Esitken and Turan 2004; Turker et al. 2007; Selim and El-Nady 2011). The technology of water physical treatment by a magnetic/electromagnetic device that works with very low frequency and very low intensities permits to recreate a structure of natural and optimized water in its ability to dissolve and transport minerals (Hachicha et al. 2016).

In Tunisia, many electromagnetic and magnetic systems have been used by farmers for years, but research results on beneficial effects are still few. In this context, some studies were carried out, to evaluate the effects of the ET with Aqua-4D (Fig. 10) technology of saline water on the response of potato and tomato crops irrigated with saline water. Aqua-4D is a physical water treatment technology that acts on the structure of water, giving it properties that create a better dissolution and distribution

Fig. 10 Aqua-4D system used for experiments

Fig. 11 Effect of ET-treated water on soil salinity. I: initial; T: treated water; N: non treated water



of minerals in the water, better water retention in the soil, and better adsorption of minerals by plants without destroying the bacterial soil life and promoting a balance between the different elements of the living soil (Hachicha et al. 2016).

The first experiment was conducted under greenhouse conditions and repeated for two seasons (Autumn 2011 and Spring 2012). Potatoes "*Spunta*" crops were cultivated and irrigated by water characterized by a salinity level of about 4 dS m^{-1} (3 g l^{-1}), pH of 8.4 and SAR of 7.4. At the end of the irrigation cycle, soil irrigated with electromagnetic-treated water showed a significant decrease in its salinity level (Fig. 11).

ET of saline water increased yield production (25.7 T ha^{-1}) by about 11% as compared to untreated water (23.2 T ha^{-1}), with a slight improvement in the commercial volume (45 mm) (Fig. 12). Result showed also a slight increase on tuber caliber (>45 mm).

To test the performance of ET on water quality a pot experiment was carried out in a greenhouse. Soil was irrigated with saline water, treated, and non-treated at different salinity levels (1, 4.5, 9, 13.5 and 18 dS m^{-1}). After one irrigation cycle, volume and electrical conductivity salinity of drained water were measured. As presented in Fig. 13, the volume and salinity of drained water from treated water showed to be higher than the volume of drained and salinity water from untreated water.

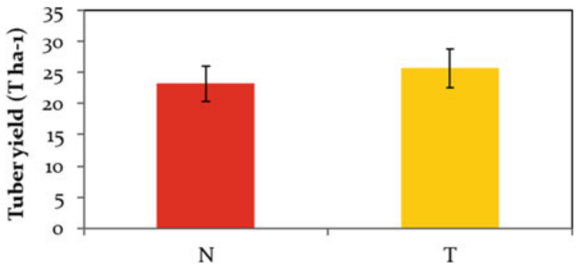


Fig. 12 Effects of electromagnetic treatment of saline water on tubers yield of potato. N: non-treated water; T: treated water

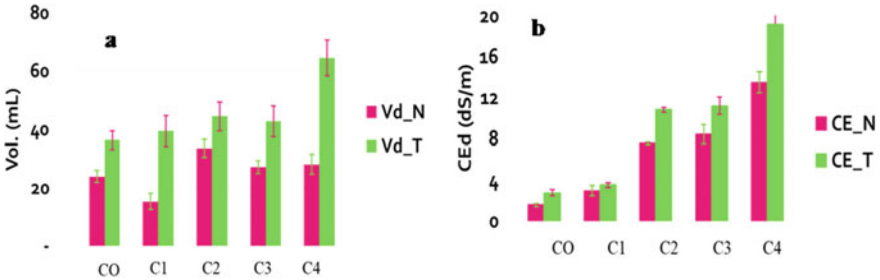


Fig. 13 Variation of volume (vol. a) and electrical conductivity (CEd, b) of drained water under electromagnetic treatment of saline water (CO: 1 dS m^{-1}; C1: 4.5 dS m^{-1}; C2: 9 dS m^{-1}; C3: 13.5 dS m^{-1} and C4: 18 dS m^{-1})

ET of saline irrigation water can be considered an effective method for soil desalinization. It has been reported that magnetic treatment of water decreases the hydration of salt ions and colloids, has a positive effect on salt solubility, and accelerates coagulation and salt crystallization (Hillal and Hillal 2000). It, consequently, increased the leaching of excess soluble salts, lowered soil alkalinity, and dissolved slightly soluble salts (Abedinpour and Rohani 2017). In this experiment soil water content and salinity were evaluated to test the beneficial effect of ET saline water on soil properties.

Soil irrigated with ET saline water showed a significant increase in its moisture (Fig. 14).

According to Surendran et al. (2016), irrigation with magnetized irrigation water caused higher soil moisture compared with the control for different solutions of saline and hard water.

The soil electrical conductivity (ECe) decrease was significant under irrigation with ET saline water as compared to non-treated water (Fig. 15).

Results revealed that the ET duration had also a significant effect on soil salinity (Fig. 16). Indeed, it helps to reduce salt accumulation and improve soil conditions around the plant's roots. The total removal of salts from the soil with electromagnetic water was greater than from untreated water.

ET water removes excess soluble salts and leaches salts further than the root zone (Aloutifi 2013; Mahmoud et al. 2019).

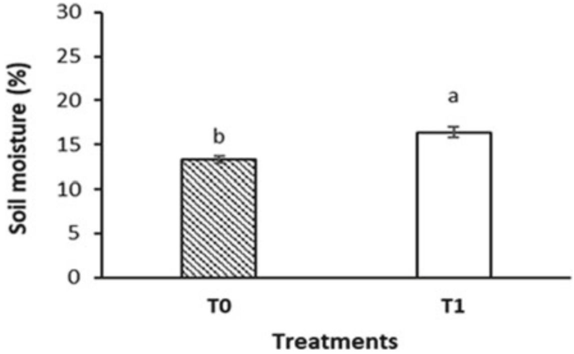


Fig. 14 Variation of the soil moisture (%) according to the treatment of irrigation water. T_0: untreated irrigation water; T_1: electromagnetically treated irrigation water

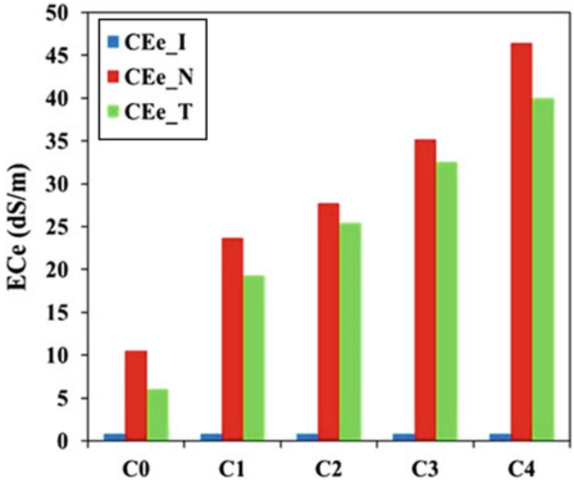


Fig. 15 Effect of electromagnetic treatment of saline water on soil electrical conductivity (ECe). CEe_I: initial soil salinity; CEe_N: Salinity of soil irrigated with nontreated water and CEe_T: Salinity of soil irrigated with treated water

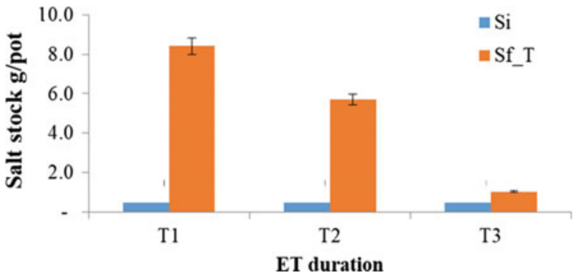


Fig. 16 Variation of salt stocks according to the duration of the ET. T1: water treatment duration of 5 min; T2: water treatment duration of 15 min; T3: water treatment duration of 30 min; SI: initial salt stocks; Sf_T: salt stocks after treatment

6 Conclusion

Water and soil salinity are the major factors limiting crop production and natural resources sustainability, especially in arid semi-arid regions including Tunisia. Based on the importance of facing salinity problems, many research projects covering some Tunisian regions are conducted to evaluate different adopted management strategies and performances in improving crop production under salt and drought conditions. Research studies related to soil salinity control (1) cultivation of alternative and tolerant-salt varieties such as new cultivars of the olive tree, Quinoa, Jatropha, *Sesbania,* and *Aloe vera*, (2) irrigation water management by using DI and SDI, (3) improvement of crop tolerance to salinity by exogenous application of proline substances and (4) the use of innovative technology systems such as Aqua4-D for ET of saline water. The results indicated the beneficial effects of different management strategies on the growth and yield of crops, on soil and water properties, and the tolerance of the majority of alternative crops to salinity and drought conditions, which confirmed the possibility of using low-quality water for agriculture. Further studies are required for more salinity assessment by the development of new tools, and more adaptation of biotechnology techniques in order to limit the salt stress effect and it will be important to better understand the mechanism of the magnetic field in order to turn it into a technology for sustainable farming.

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