ASIAN JOURNAL OF AGRICULTURE
Volume 6, Number 2, December 2022 E-ISSN: 2580-4537
Pages: 103-108 DOI: 10.13057/asianjagric/g060207

Saline irrigation management in field conditions of a semi-arid area in Tunisia

ISSAM DAGHARI[1,♥], HEDI DAGHARI[1], NIHED BEN KHALIFA[2], MARIEM MAHMOUF[3]
[1] National Agricultural Institute of Tunisia, University of Carthage. Sidi Bou Said Av. de la République, Carthage 1054, Tunisia. Tel.: +216-71-749-100, ♥email: issam.daghari@gmail.com
[2]Faculty of Economics and Management of Nabeul. Route Hammamet, Nabeul, Tunisia
[3]Faculty of Economics and Management of Tunis, the University of Tunis el Manar. Campus Universitaire Farhat Hached, B.P. no. 94, Rommana, Tunis 1068, Tunisia

Manuscript received: 11 June 2022. Revision accepted: 26 July 2022.

Abstract. *Daghari I, Daghari H, Ben Khalifa N,, Mahmoud M. 2022. Saline irrigation management in field conditions of a semi-arid area in Tunisia. Asian J Agric 6: 103-108.* Tunisian saline soils occupy about 25% of the total irrigated area. The irrigated area of "Dyiar-Al-Hujjej" in Tunisia was considered because seawater intrusion took place and salinization of the aquifer reached a very high water electrical conductivity value of 15 dS/m in the 90s, which caused many local farmers to abandon land parcels and wells. In addition, salinity has reduced plant growth and water quality, leading to lower crop yields and degradation of stock water reserves. Excess salt affects overall soil health, reducing productivity. It kills plants, leaving bare soil prone to erosion. In this study, the electrical conductivity of the soil under several irrigated crops was evaluated for two soil layers (0-20 cm and 20-40 cm). Follow-up surveys of agricultural practices have shown that the irrigation water's quality has a considerable effect on the soil's electrical conductivity and, therefore, on the choice of crops. We also showed that crop rotation is a practice done by farmers to maintain and improve soil fertility by utilizing soil nutrient losses due to salinization. This study can be the basis of a valuation to allow farmers to have the best cultural practices to fight the salinization of their soils.

Keywords: Famers practices, irrigation, seawater intrusion, semi-arid, soil salinization

INTRODUCTION

Several recent publications on the Mediterranean show that agriculture in the Maghreb will be affected by the impacts of climate change (Chebil et al. 2022) mainly through the depletion of available water (Chebil et al. 2019) and degradation of local ecosystems (Ferjani et al. 2013) including soil salinization. According to the FAO, 7.3 million hectares of salinized irrigated area are located in Morocco, Tunisia, Spain, and Turkey, for a total of 27.3 million hectares for the entire Mediterranean region (Yacoubi et al. 2020). Within the irrigated area of Skhirat in Morocco, due to the use of high, very saline groundwater, an increase in soil salinity was observed, affecting yields, so farmers are left with the only choice of growing salt-tolerant crops (El Hamdi et al. 2022). In Algeria, in the fertile oasis of Biskra, an increase in soil salinity has led to the abandonment of several lands by farmers or the adoption of other more resistant crops to salinity (Abdennour et al. 2020). Tunisia has about 0.47 million hectares of irrigated land. Irrigation resulted in the deterioration or total sterilization of a considerable part of its soils (Khawla and Mohamed, 2020).

Indeed, in Tunisia, the main source of salinization in irrigated areas is water irrigation (Louati et al. 2018); nonetheless, agriculture is important in Tunisia (Ben Nouna et al. 2016a), it accounts for over 11% of the gross domestic product and employs about 22% of the workforce (Ben Nouna et al. 2016b). The irrigated sector accounts for over 35% of national agricultural production. Furthermore, some regions of Tunisia suffer from high salinity in the groundwater, as in Dyiar-Al-Hujjej. This coastal region has a large depression of its aquifer over 12 m under sea level, and seawater intrusion is the origin of several abandoned wells (Bani et al. 2021). High salinities were measured in several wells leading to their abandonment (Closas and Molle 2016), cessation of agricultural activity in these areas, and migration of farmers to outlying areas less affected by salinity (Yacoubi et al. 2018). On the road of Korba-Menzel-Temime, several abandoned well are seen on both sides. As an emergency, the Tunisian government did an expensive surface water transfer from the northwest of Tunisia via the Cap Bon-Medjerda Channel (CBMC) for almost a hundred kilometers. The volume of surface water supplied from the state supply network for this irrigated area varies yearly, depending on rainfall. The volume was 1,569,467 m^3, 1,714,603 $m^{3,}$ and 1,714,421 m^3 between 2000, 2011, and 2012, respectively. No water transfer was done in 2016 and 2017 (Daghari et al. 2019) due to a shortfall of rain in Tunisia. In Dyiar-Al-Hujjej irrigated area, farmers resorted to blending surface fresh water and saline aquifer water. Other farmers injected this surface water with an EC lower than 1.4 dS m^{-1} into wells to be blended with saline aquifer water. Drip irrigation was adopted throughout all the study areas. Drip irrigation is considered a water-salt regulation technology (Brahim et al. 2021). In this region, tomatoes and peppers are the most important in Tunisia. The main processing tomatoes and peppers factories are also located in this region. It is also the main strawberry-producing region in Tunisia. The area cultivated with summer tomatoes decreased from 450 to 210 ha between 1998 and 2011 (Daghari et al. 2021). A new crop combination of strawberry and pepper has become more and more widespread in this area. The Korba region is the main strawberry-producing area in Tunisia. Strawberry has become very popular and sought after by the agri-food industry for producing strawberry juice at all Tunisian festivities. Pepper is used in the culinary harissa process. Both crops are kept together in the same land parcel (on the same crop row) for two years, strawberry from September to May and pepper from June to August.

Usually, the largest consumption is recorded during April, May, and June, corresponding to the full growth period of tomatoes and strawberries. The CROPWAT model crop's water requirements calculation is 2.545 million m^3. According to the farmers' association, pumping saline water from the aquifer filled the gap between the surface water and the water requirement. All farmers are aware of the salinity problem in the irrigated area of Dyiar-Al-Hujjej. That is reflected in their practice of abandoning several wells and introducing rainfed crops. Although farmers' behavior as part of salinity management has not been studied before, it is only recently that attention has been given to this aspect in this irrigated area (El Zarroug et al. 2021). Our objectives are (i) to see the impact of irrigation with salt water on the electrical conductivity (EC) of the land parcels, (ii) to assess the feasibility of using different sources of irrigation water, (iii) to study whether cultural practices can be a reliable tool for controlling salinity in irrigated crops.

MATERIALS AND METHODS

Experiment and field measurements

Dyiar-Al-Hujjej is located in the delegation of Korba in the northeast of Tunisia, about 66 km southeast of the city of Tunis in the Cap Bon peninsula (Figure 1), having coordinates 36°35 'North and 10°52' East.

According to Ouelhazi et al. (2013), the most important geological outcrops in the studied area are mainly Mio–Plio–Quaternary deposits. The lower part of the Middle Miocene forms the detrital deposits known as the Beglia Formation. The Korba aquifer system comprises three geological units of marine Quaternary, Pliocene, and Late Miocene ages. The Tyrrhenian (Quaternary) is a 1.2-km-wide strip parallel to the coastline.

Investigating the history of the aquifer in Dyiar-Al-Hujjej, in 1969, the EC varied from 3 dS/m to 5 dS/m. In 2007, the measured EC varied between 4 dS/m to 15 dS/m, averaging 9 dS/m (Daghari 2016). The area is characterized by a semi-arid climate with an average annual precipitation of 420 mm (INM 2001). It has been observed that. Agricultural practices depend on the soil texture and structure. The remarkable thing in this perimeter is that the crops predominantly grown are vegetables (tomato, pepper, cabbage, etc.) or crops whose roots do not exceed 30 cm. Farmers in the discussions said it was impossible to grow other crops because the crust is very close to the ground. Indeed, soil profiles showed that the crust is often present from 60 cm depth, restricting farmers' choice of crops; therefore, no trees can be grown. After granular analysis, clay, silt, and sand percentages were 9.57%, 35.7%, and 55.35% (Daghari and Gharbi 2014).

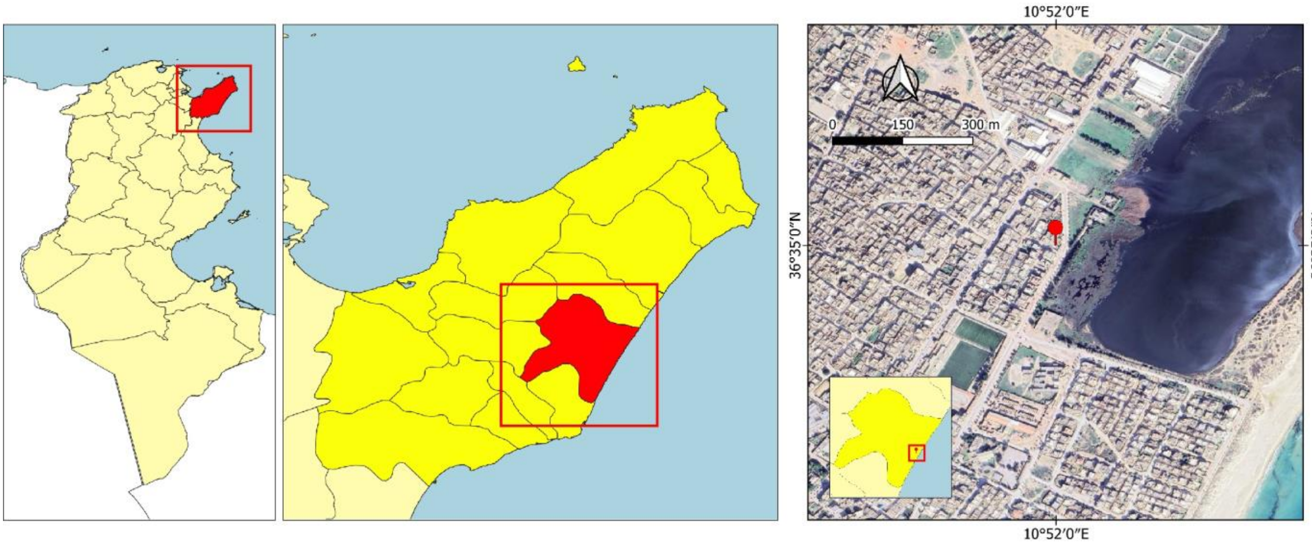

Figure 1. The geographic position of Dyiar-Al-Hujjej, Tunisia (36°35' North and 10°52' East)

Table 1. Farmer analysis questionnaire template

Distribution of crops				Irrigation water quality			Soil's EC
Sowing date	Crop	Area (ha)	Irrigated or not	Water sources	Irrigation water's EC	Aquifer depth	
-	-	-	-	-	-	-	-

Thanks to the availability of surface water from the state network supply, a strawberry high-return crop's growth are increasing yearly. That explains the increase in the area occupied by strawberries from 55 ha in 2000 to 160 ha in 2011. During almost the same period, the cultivated areas dedicated to tomatoes, a summer crop with high water requirement, decreased from 450 in 2000 to 210 ha in 2011. Sandy soils are ideal for growing strawberries (Daghari et al. 2020).

About 20% of irrigated area is allocated for strawberries. Transplanting is done in late September or early October, and harvest lasts until May but is only kept for two years. Crops' choices vary depending on available water resources. Farmers having only water from the state network supply and renting small land parcels do not practice rainfed crops. Farmers with both surface and well water blend the two water. These farmers grow a succession of irrigated summer crops (tomato, pepper) and winter-spring crops (strawberry, cabbage, cauliflower, lettuce, spices), but they are forced to leave their land to follow eventually. In the case of farmers that do not have access to surface water, they grow only rainfed crops in summer. In the winter, they lean on the preseason industrial tomato, sold at a good price, to take advantage of the rain for their water needs.

This study conducted a series of meetings with farmers and farmer associations, and in situ soil samples were taken. In addition, analysis questionnaires were provided to the farmers (Table 1) to answer certain questions for a full cropping season.

Statistical analysis

The statistical analysis was done by the Statistical Analysis Software SAS/STAT. The one-way ANOVA was performed using the F-test at a significance level of 5%. The data were obtained on a sample of 7 land parcels separated into three groups (1: use of land parcels irrigated with dam water/2: land parcels irrigated with a blending of dam water and groundwater/3: land parcels irrigated with only dam water). Fourteen measurements were taken to measure the salinity of water sources (0: 1st month of the agricultural season, 1: the end of the agricultural season). Thirty-six measurements were taken to measure the salinity of water sources (0: 1st month of the agricultural season, 1: the end of the agricultural season).

RESULTS AND DISCUSSIONS

Three sources of water are available: surface water (less than 1.5 dS/m) from the state supply network discharged into a local dam called Lubna (Lubna Dam), water source from the saline aquifer up to 5.37 dS/m and blended water source (surface water and saline aquifer water blended).

Experiment and field measurements

The water requirements of a crop do not vary if it is grown under the same weather conditions, so the same amount of water will be supplied to the crop. Thus, the salinity measurement under different crops is a good indicator of the correlation between the amount of irrigation water and the EC of the soil. In our study area, tomato cultivation is the most widespread. However, Strawberry cultivation has increased too if only surface water is available.

Electrical conductivity under tomato

The salinities were measured from soil profiles under tomato cultivation on different dates (Table 2) to know the temporal evolution of the salinity.

As F1, These are usually farmers with only surface water of good quality and do not invest in the creation of well. F1 was visited on 13 July 2021, having a small land parcel of two hectares. This farmer is a tenant that grows only vegetable crops with high income (strawberry - pepper in mixture and tomato) and no rainfed crops. In the whole irrigated area of Diyar Al Hujjej, this is a unique case where low EC was observed under tomatoes with an average of 1.8 dS/m (Table 2). A low EC under the tomato was possible using only surface water from the state supply network.

Farmer F2's land is too close to the sea, so the well has a high EC due to seawater intrusion. The farmer' has a single well (depth = 14 m as of 09/11/2021. Surface water was injected into the well and pumped out after blending with water from the aquifer. The EC of the blended water was three dS/m. This farmer's land parcel is about 30 Hectares, the largest in this area, so we found several crops in this land parcel. The average EC is 5.315 dS/cm under the tomato crop, an EC greater than F1 (1.8 dS/m), which only uses surface water.

Table 2. Soil electrical conductivity (dS/m) at different depths under different crops for different farmers

	F1	F2	F3	F4	F5	F6
Date	**12 July, 2021**	**11 September 2021**	**11 September 2021**	**11 September 2021**	**11 September 2021**	**11 September 2021**
access to surface water	Yes	Yes	No	No	No	No
EC water	1.5	3	5.37	3.72	5.2	5.7
EC soil overground	-	-	-	-	19.5	-
EC soil (0-20)	2	6.65	5.3	4.71	5.3	9.24
EC soil (20-40)	1.6	3.98	5.6	4.27	Crust	Crust

For farmer F3, his land is located close to the sea and is not supplied with surface water. On 09/11/2021, the well's EC was 5.37dS/m. Given this high salinity, the farmer grows industrial winter tomato, which has a good economic profit during the rainy season and can be harvested before the summer. However, soil solution dilution occurs, and salinity decreases due to the rain. Therefore, EC measurements were made in a land parcel where the tomato was almost harvested. EC values of 5.3 dS/m, and 5.6 dS/m, respectively, for the depth of 0-20 and 20-40 cm layers.

For farmer F4, he has a well close to farmer F5's well. His well is less saline (3.72 dS/m) and is localized in a low area that accumulates runoff water. This farmer cultivated tomato and pepper, having good yields. Measured salinities were lower than in the previous case (F3), which demonstrates the importance of rainwater harvesting. For F4, EC under harvested tomato was 4.71 dS/m and 4.27 dS/m for the layers 0-20 and 20-40 cm, respectively. For F2, EC under tomato was 5.35 dS/m and 5.6 dS/m for the layers 0-20 and 20-40 cm, respectively. For farmer F5, he has only one well to irrigate his crops. His well has an EC of 5.2 dS/m. A value of 19 dS/m was measured on a soil sample collected at the surface of cultivated soils with white spots, evidence of salts following a tomato crop that had just been harvested (Figure 2). Salinity under tomato was 5.35 dS/m for the layer 0-20 cm. For farmer F6, the measured EC in the well is 5.7 dS/m. EC reached 9.24 dS/m under finished irrigated tomato. Only rainfed crops or fallow are grown during the summer because of the high aquifer water EC. Irrigated pepper grown in the summer was abandoned because of the unmarketable and low small size of pods. Average EC was 1.8 dS/m and 5.26 dS/m, respectively, in the case of farmers F1 and F2 when only surface water or blended water was used. These values are lower compared to measured values for other Farmers.

Electrical conductivity under other crops

We also took soil profiles under other crops for more samples for statistical analysis. The F2 land parcel is about 30 hectares, which is the largest in this area, so we found several crops in this land parcel. Strawberry is a high-added value crop that all farmers want to grow on their land parcels. However, without a surface water source, it is impossible to have agricultural production. In our study area, two types of strawberries are grown. The 'Carmella' strawberry is sold at a high price but is very sensitive to water salinity, and the 'Tilda' strawberry is cheaper but more resistant to water salinity. For F2, EC measured from the soil profiles is 5.17 dS/m and 5.32 dS/m of soil under Strawberry "Tilda" for 0-20 cm and 20-40 cm, respectively. For another farmer, the EC measured for the "Carmella" strawberry is 3.24 dS/m (0-20 cm) and 3.82 dS/m for the "Tilda" strawberry. From 20 cm, there is a crust in this farmer's land parcel. Profiles were taken on 11 July 2021. The EC of the blended irrigation water is 3 dS/m and 5.37 dS/m for the latter two farmers.

Statistical analysis

For the layer 0-20 cm, the ANOVA results give an F value equal to 8.49, which means that there is an intergroup variation (between Water EC and Soil EC) 8 times greater than an intragroup variation. In other words, the differences in soil CE that we observe are indeed linked to the differences in the irrigation water EC and not to chance. The value of p is less than 0.05, which shows that the ANOVA test is significant and that the differences in intragroup means are not due to chance.

For the layer 20-40 cm, the value of F is 1.73, which shows that the difference in soil EC is not due to irrigation water quality. The value of p is more than 0.05, which confirms that the ANOVA test is not significant and that the differences in intragroup means are due to chance.

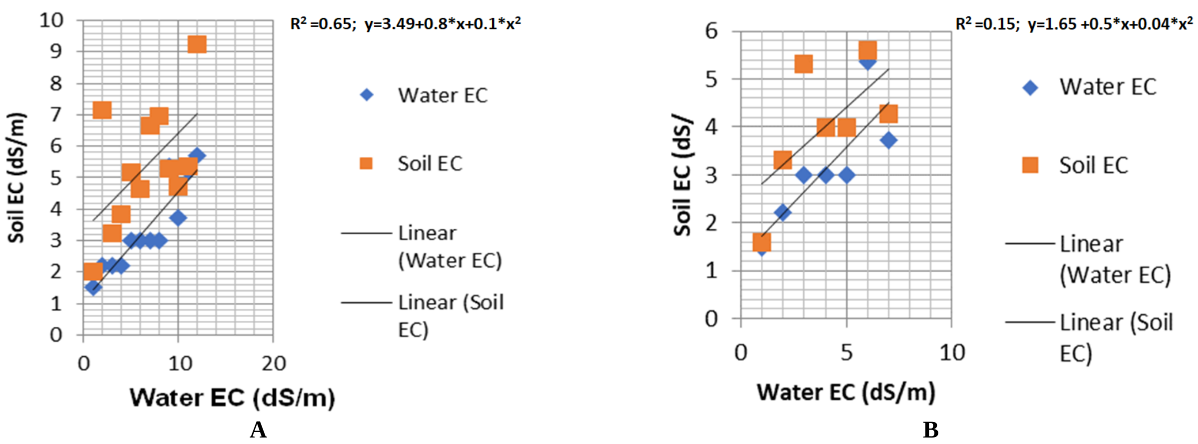

Figure 2. Effect of the water quality on the soil salinity at 0-20 cm layer (a), on the soil salinity at 20-40 cm layer (b)

We can deduce that irrigation in this irrigated area degrades the upper layer of the soil and that agriculture must be aware of these anthropogenic effects. With a soil depth of only 60 cm, farmers will soon be forced to leave this perimeter to practice agriculture. The presence of salt in this last layer is due to the accumulation of salts from previous irrigations. The leaching dose of salts is always taken into account by Tunisian farmers to get rid of salts in their land parcels (Saidi et al. 2018; Hammami and Zayani 2016). However, from a practical point of view (Besser et al. 2022), farmers cannot calculate the leaching dose and do so according to their intuitions (Dhaouadi et al. 2021a). In a future study, the leaching fraction must be calculated considering the interactions between the soil and the solution (Dhaouadi et al. 2021b). The geochemical approach is based on calculating the chemical balances between the solution and the soil minerals.

Discussions

In this study, a field experiment involving the dynamics of saline solutes observed the importance of irrigation water quality for farmers. ANOVA for measured values of salt concentrations was reliable for a root depth of 0-20 cm (R2 = 0.65) compared to a root depth of 20-40 cm (R2 = 0.15). These values showed the ability of agricultural practices to control salt levels and subsequently reduce the effects of irrigation with brackish water on the soil and the crop of tomatoes and strawberries. That was confirmed by Uddin (Uddin and Dhar 2007), who discussed the interest in introducing crop rotation. In other words, keeping the soil under rainfed crops reduces soil salinity and other benefits. In addition, crop rotation breaks the cycle of pests affecting crops by limiting pathogens and weeds.

For F2, irrigation with saline water with ECw = 3.5 $dS \cdot m^{-1}$ may be tolerable for the crop and induces a low risk of soil salinization. However, for F6, saline water with ECw = 5.7 $dS \cdot m^{-1}$ increases soil salinity in the short term and could be disastrous for the crop after several irrigation cycles. Using a drip irrigation system combined with appropriate management practices such as increased irrigation frequency or controlled deficit irrigation can mitigate these effects on soil and crops. Indeed, the sensitivity of crops to salinity depends on the vegetative stage; the effect of irrigation with saline water at the developmental stages is great and will surely harm the crop (Ashraf and Harris 2004).

In conclusion, our study area represents an exemplary case study of the effect of irrigation with saline water on soil and crops. Our studies have shown the importance of irrigation water quality for sustainable agriculture. However, repeating these experiments over at least three years can provide a solid statistic. The modeling approach can be considered, too, for the simulation of global salinity.

REFERENCES

Abdennour MA, Douaoui A, Piccini C, Pulido M, Bennacer A, Bradaï A, Barrena J, Yahiaoui I. 2020. Predictive mapping of soil electrical conductivity as a proxy of soil salinity in southeast of Algeria. Environ Sustain Indic 8: 100087. DOI: 10.1016/j.indic.2020.100087.

Ashraf M, Harris PJC. 2004. Potential biochemical indicators of salinity tolerance in plants. Plant Sci 166:3–16. DOI: 10.1016/j.plantsci.2003.10.024.

Bani A, Daghari I, Hatira A, Chaabane A, Daghari H. 2021. Sustainable management of a cropping system under salt stress conditions (Korba, Cap-Bon, Tunisia). Environ Sci Pollut Res 28: 46469-46476. DOI: 10.1007/s11356-020-09767-0.

Ben Nouna B, Rezig M, Barhouni H, Ben Ammar H. 2016b. Effect of partial root-zone drying irrigation technique (PRD) on the total dry matter, yield and water use efficiency of potato under Tunisian semi-arid conditions. J Agric Sci 8 (7): 129. DOI: 10.5539/jas.v8n7p129.

Ben Nouna B, Rezig M, Barhouni H. 2016a. Best irrigation practices designed for pesticides use to reduce environmental impact on groundwater resource in the Tunisian context. J Agric Sci 8 (7):142. DOI: 10.5539/jas.v8n7p142.

Besser H, Dhaouadi L, Hamed H. 2022. Groundwater quality evolution in the agro-based areas of Southern Tunisia: Environmental risks of emerging farming practices. Euro-Mediterr J Environ Integr 7: 65-78. DOI: 10.1007/s41207-021-00289-w.

Brahim N, Karbout N, Dhaouadi L. 2021. Global landscape of organic carbon and total nitrogen in the soils of oasis ecosystems in Southern Tunisia. Agronomy 11 (10): 1903. DOI: 10.3390/agronomy11101903.

Chebil A, Souissi A, Ben Nouna B, Frija Aymen. 2019. Analysis of the competitiveness of wheat and orange in Tunisia under water shortage scenarios. Arab J Geosci 12 (11): 355. DOI: 10.1007/s12517-019-4527-5.

Chebil A, Soula R, Souissi A, Ben Nouna B. 2022. Efficiency, valuation, and pricing of irrigation water in northeastern Tunisia. Agric Water Manag 266 (2): 107577. DOI: 10.1016/j.agwat.2022.107577.

Closas A, Molle F. 2016. Gourdwater Governance in the Middle East and North Africa. IWMI Project. DOI:10.13140/RG.2.2.11109.29922.

Daghari I, Abouaziza FB, Daghari H. 2021. Rethinking water and crop management in the irrigated district of Diyar-Al-Hujjej (Tunisia). Environ Sci Pollut Res 2021: 1-12. DOI: 10.1007/s11356-021-15155-z.

Daghari I, Bani A, Bousnina H, Chaabane A. 2020. On-farm water and salt management under a strawberry–pepper combination in the Korba area. Irrig Drain 69 (3): 1-7. DOI: 10.1007/s11356-021-15155-z.

Daghari I, Gharbi A. 2014. Modelisation by SALTMOD of leaching fraction and crops rotation as relevant tools for salinity management in the irrigated area of Dyiar Al-Hujjej, Tunisia. Intl J Comput Inf Technol 3 (4): 841-844.

Daghari I, Hammami M, Daghari H. 2019. L'irrigation localisée. Editions Universitaires Europeennes. Republic of Moldovia.

Daghari I. 2016. Gestion Intégrée des Ressources en Eau et Perception de la Salinité. Editions Universitaires Europeennes. Republic of Moldovia.

Dhaouadi L, Besser H, Karbhout N, Alomrane AR, Wassar F, Hamed Y. 2021b. Irrigation water management for sustainable cultivation of date palm. Appl Water Sci 11 (11): 171. DOI: 10.1007/s13201-021-01507-0.

Dhaouadi L, Besser H, Karbout N, El Khaldi R, Haj-Amor Z, Ben Maachia S, Wassar F. 2021a. Environmental sensitivity and risk assessment in the Saharan Tunisian oasis agro-systems using the deepest water table source for irrigation: Water quality and land management impacts. Environ Dev Sustain 2021: 1-33. DOI: 10.1007/s10668-021-01878-z.

El Hamdi A, Morarech M, El Mouine Y, Rachid A, El Ghmari A, Yameogo S, Chalikakis K, Yachou H, Kacimi I, Zouahri A, Dakak H, Bouramtane T, Valles V, Barbiero L. 2022. Sources of spatial variability of soil salinity: The case of Beni Amir irrigated command areas in the Tadla Plain, Morocco. Arid Land Res Manag 36 (3): 245-264. DOI: 10.1080/15324982.2022.2026531.

El Zarroug MR, Daghari I, Almabrok SH, Muanda C, Kompany JR. 2021. Over-exploitation of water and natural resources in Al-Hira, Libya. Open Acces Lib J 8 (8): 1-12. DOI: 10.4236/oalib.1107059.

Ferjani N, Morri M, Daghari I. 2013. Estimation of root-zone salinity using salt mod in the irrigated area of Kalaat El Andalous (Tunisia). J Agric Sci Technol 15: 1461-1477.

Hammami M, Zayanai K. 2016. An analytical approach to predict the moistened bulb volume beneath a surface point source. Agric Water Manag 166: 123-129. DOI: 10.1016/j.agwat.2015.12.020.

Khawla K, Mohamed H. 2020. Hydrogeochemical assessment of groundwater quality in greenhouse intensive agricultural areas in coastal zone of Tunisia: Case of Teboulba region. Groundw Sustain 10: 100335. DOI: 10.1016/j.gsd.2020.100335.

Louati D, Majdoub R, Rigane H, Abida H. 2018. Effects of irrigating with saline water on soil salinization (Eastern Tunisia). ArabJ Sci Eng 43 (7): 3793-3805. DOI: 10.1007/s13369-018-3215-1.

Ouelhazi H, Lachaal F, Charef A, Challouf B, Chaieb H, Jarraya-Horriche F. 2013. Hydrogeological investigation of groundwater artificialrecharge by treated wastewater in semi-arid regions: Korba aquifer (Cap-Bon Tunisia). Arab J Geosci 7: 4407-4421. DOI: 10.1007/s12517-013-1090-3.

Saidi A, Hammami M, Daghari H, Ben Ali H, Boughdiri A. 2018. Irrigation management evaluation and hydrosalinity balance within Kalaat El Andalous Irrigation District, North-East Tunisia: Irrigation management using low-quality waters and soil salinization. Irrig Drain 67 (4): 538-564. DOI: 10.1002/ird.2262.

Uddin MT, Dhar AR. 2020. Assessing the impact of water-saving technologies on Boro rice farming in Bangladesh: economic and environmental perspective. Irrig Sci 38:199–212. DOI: 10.1007/s00271-019-00662-2.

Yacoubi S, Slatni A, Zayani K. 2018. Analysis of saturation risk in sprinkler irrigation: Case of Cherfech Irrigation Perimeter in Tunisia. J Agric Sci 10 (2): 130. DOI: 10.5539/jas.v10n2p130.

Yacoubi S, Slatni A, Zayani K. 2020. Improvement of water and energy use in sprinkler irrigation under semi-arid conditions. Desalin Water Treat 176: 197-200. DOI: 10.5004/dwt.2020.25517.