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RESEARCH ARTICLE - EARTH SCIENCES

Subsurface Drainage System Performance, Soil Salinization Risk, and Shallow Groundwater Dynamic Under Irrigation Practice in an Arid Land

Zied Haj-Amor[1] · Salem Bouri[1]

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Abstract
In recent years, several arid lands have faced the major challenge of increasing risk of soil salinity caused by improper irrigation and drainage practices. Evaluating the relationship between soil salinity, drainage, and irrigation is therefore essential for understanding how to sustain the use of salinized soils in these lands. In this study, subsurface drainage performance, soil salinization risk, and shallow groundwater dynamic were evaluated under irrigation practice in a Tunisian arid land during two successive cropping years (2012–2013 and 2013–2014). Special attention was paid to the effect of subsurface drainage system on soil desalinization. Based on the analysis of the collected data, the following results were found: (1) frequent irrigation was a major factor in the rapid rise of shallow groundwater above critical soil depths; (2) inferior irrigation scheduling (i.e. large irrigation interval of 16–42 days) was the main cause of high soil salinization (EC_e) around crop roots ($EC_e > 4$ dS m^{-1}); (3) the installed subsurface drainage system in the studied area (i.e. perforated corrugated pipe at a soil depth of 1.5 m) resulted in a substantial soil desalinization rate from the first to the second studied year, the average decrease in EC_e was 23.3%; (4) the drainage system was unable to drain more than 27% of the salt introduced by the irrigation water due to the clogging of the gravel filter by sand. These results may provide a reference for appropriate restoration in the studied area and in other arid farmlands with similar condition.

Keywords Soil salinity · Irrigation · Drainage · Arid land · Desalinization

1 Introduction

Agriculture sustainability in many arid irrigated oases is threatened by several factors, such as the shortage of available water resources, the deterioration of irrigation water quality, and the persistent expansion of irrigated areas [1–3]. In Tunisia, the recent history of arid oases, such as the oasis of Kebili region, southern domain, is marked by an unpresented expansion of irrigated areas and a high consumption of irrigation water [4]. The farmland expansion coupled with the geomorphological factors of the region [2,5,6] has contributed to the creation of a shallow (depth $<$ 2 m) and saline (salinity > 4 g l^{-1} $\approx$ 6.2 dS m^{-1}) groundwater within many irrigated areas. This situation has, in turn, increased the risk of secondary soil salinity by capillary rise [7]. The salinity of irrigated soil is accentuated in several oases by inefficient management of irrigation and drainage water [8]. These factors are considered as the main contributors to the rapid deterioration of agricultural soil. This in turn affects date palm production, the dominant agricultural crop with a very high economic value in the Tunisian arid oases [9], and the sustainability of this unique agricultural ecosystems (i.e. oases).

To minimize the effect of shallow groundwater on soil salinization, the majority of Tunisian arid oases, which are prone to a potential rise of the water table, have been equipped with drainage systems. Agricultural sustainability in arid irrigated lands, as reported by several studies, requires more attention to drainage management to ensure that crop yield and soil quality are not negatively impacted [10–14]. All these studies confirmed that adopting effective drainage systems with appropriate irrigation practice can positively contribute to enhance the soil quality (e.g. low salinization level).

✉ Zied Haj-Amor
ziedhadj@yahoo.com

1 Water, Energy, and Environment Laboratory, National Engineering School of Sfax, 3038 Sfax, Tunisia

A network of surface drainage system in Tunisian arid oases was installed in 1995. The system consists of open ditches that were periodically dredged and maintained. As dredging operations are expensive and not always satisfactory, the surface network has mostly been replaced by buried pipe drainage system since 2007 [15]. As a result, about 90% of all date palm areas are now protected with these subsurface drainage systems. The aim of the system is to avoid water table rise to a critical soil depth that is fixed at 1.5 m based on the agro-climatic and soil conditions of the oases. As stated by [8], keeping the shallow groundwater depth deeper than 1.5 m can considerably reduce soil salinity level around the root-zone of date palms. Consequently, monitoring of shallow groundwater conditions (especially depth) as well as soil salinity is necessary to evaluate the performance of the installed drainage networks, and thus ensure the productivity of irrigated soil [16].

Some positive results concerning soil productivity amelioration have been reported by the farmers of Tunisian arid oases after the installation of drainage systems [15]. However, the performance of the installed subsurface drainage network is rarely evaluated to ensure effective performance. Numerous studies of Tunisian arid oases [17,18] have focused on the relationship between shallow groundwater depth and soil salinity as a function of environmental factors such as topography. However, the effect of irrigation practice on shallow groundwater level and soil salinization dynamics has been neglected in these studies. Indeed, the problems are often aggravated by changes in groundwater table and the mobilization of salts by irrigation [19]. In addition, as reported by [20], the consideration of irrigation practice in analysis of drainage system's performance, soil salinity, and water table dynamics is crucial for proper irrigation and drainage management and sustainable soil management. In this context, the present paper aims at assessing the irrigation practice to (1) analyse the performance of drainage systems, (2) evaluate the effect of subsurface drainage systems on soil salinity, and (3) quantify the effect of irrigation on water table dynamics. To achieve these objectives, field experiments were conducted for two agricultural years (2012/2013 and 2013/2014), in an arid Tunisian oasis named El-Hsay Oasis where a subsurface drainage system was installed in September 2013.

2 Study Area Setting

The study site is located in the El-Hsay Oasis (33°24'42.8"N, 9°01'17.6"E), which is a typical Tunisian arid oasis in the Kebili region, southwestern Tunisia (Fig. 1). The study was performed over two years from September, 2012 to August, 2013 and from September, 2013 to August, 2014. The oasis covers an area of 50 ha, which was divided into 100 equally sized arable plots. Each plot has rectangular shape, typically 100 m long and 50 m wide, and consisted of 40 irrigation basins (series of small level basins) where date palms (*Phoenix dactylifera*) are cultivated. The plots were irrigated by surface irrigation technique using saline water ($2.36\ \text{g l}^{-1} \approx 3.68\ \text{dS m}^{-1}$) provided from a deep aquifer. The soil is mainly sandy. The saline irrigation water coupled with the unfavourable agricultural sandy soil properties and high infiltration rates has led to a saline water table at less than 2 m depth [17]. The monthly averaged electrical conductivity of the shallow groundwater varied from $8.2\ \text{dS m}^{-1}$ in June to $11.9\ \text{dS m}^{-1}$ in August.

Since the beginning of the second study year (i.e. since September 2013), the study area has been equipped with a subsurface drainage system composed of lateral drains (perforated corrugated pipes) and collectors (open ditch outlets) (Fig. 2). The depth of the lateral drains was 1.5 m, whereas the depth of the collectors was 2.1 m. The spacing between the lateral drains was 50 m. The system was largely designed based on the experiences gained from other Tunisian arid oases, in terms of depth of the drains and spacing between drains, etc. Perforated corrugated pipes at 1.4–1.6 m depth are traditionally recommended for the Tunisian arid oases to prevent soil salinization and waterlogging at the root-zone of date palms [8,16].

Similar to other arid Tunisian oases, there is a limited number of disposal options for drainage water in the El-Hsay Oasis. In such areas, due to the lack of a treatment system or surface water courses such as rivers, lakes, or the sea, the common option is the disposal of drainage effluent into the natural depressions and low lands. Climatological data obtained from the Tunisian Meteorological Institute for the period 1993–2013 show that the climate of the studied oasis is hyper-arid with an annual rainfall of 79 mm and potential evapotranspiration of 1570 mm (Fig. 3). The surface air temperature reaches 37 °C in August and 11 °C in January. The geology of the studied oasis is characterized by sedimentary deposits (Plio-Quaternary formations) with silty and sandy lithology.

2.1 Features of the Investigated Plot

The monitored plot (MP) was situated at the highest elevation in order to avoid lateral groundwater flow from the neighbouring irrigated plots (see Fig. 2). Date palms (with age $>$ 10 years) were the only planted tree in the investigated plot. The adopted irrigation practices for the monitored plot during the study period (2012–2014) are summarized in Table 1.

A lateral drain with pipe length of 50 m and 0.3% slope was installed at a depth of 1.5 m within the MP. The perforated corrugated pipe has a diameter of 120 mm with a perforation size of 8 mm (Fig. 4). To prevent sediment clogging and to

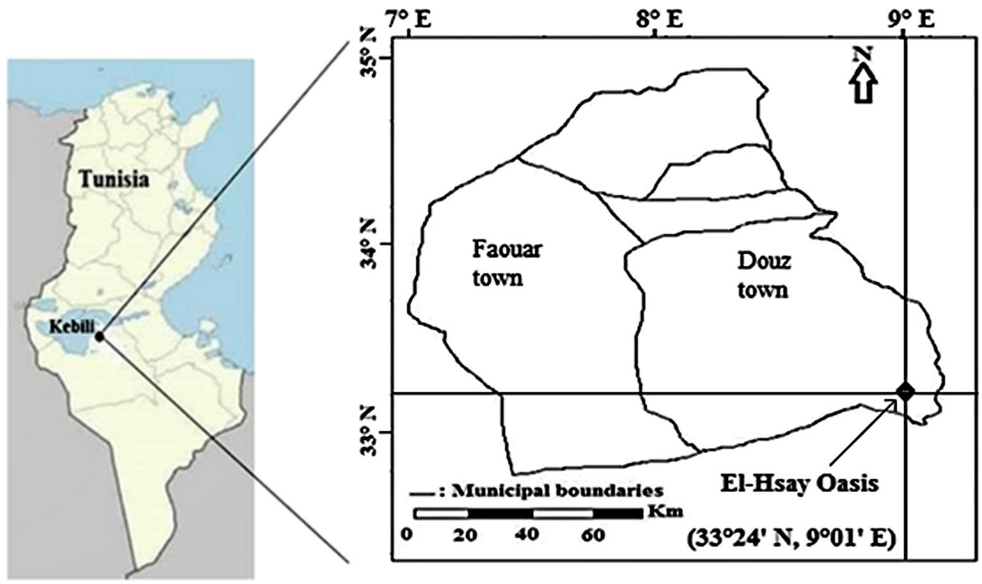

Fig. 1 The location of the study area (El-Hsay Oasis) in Douz town

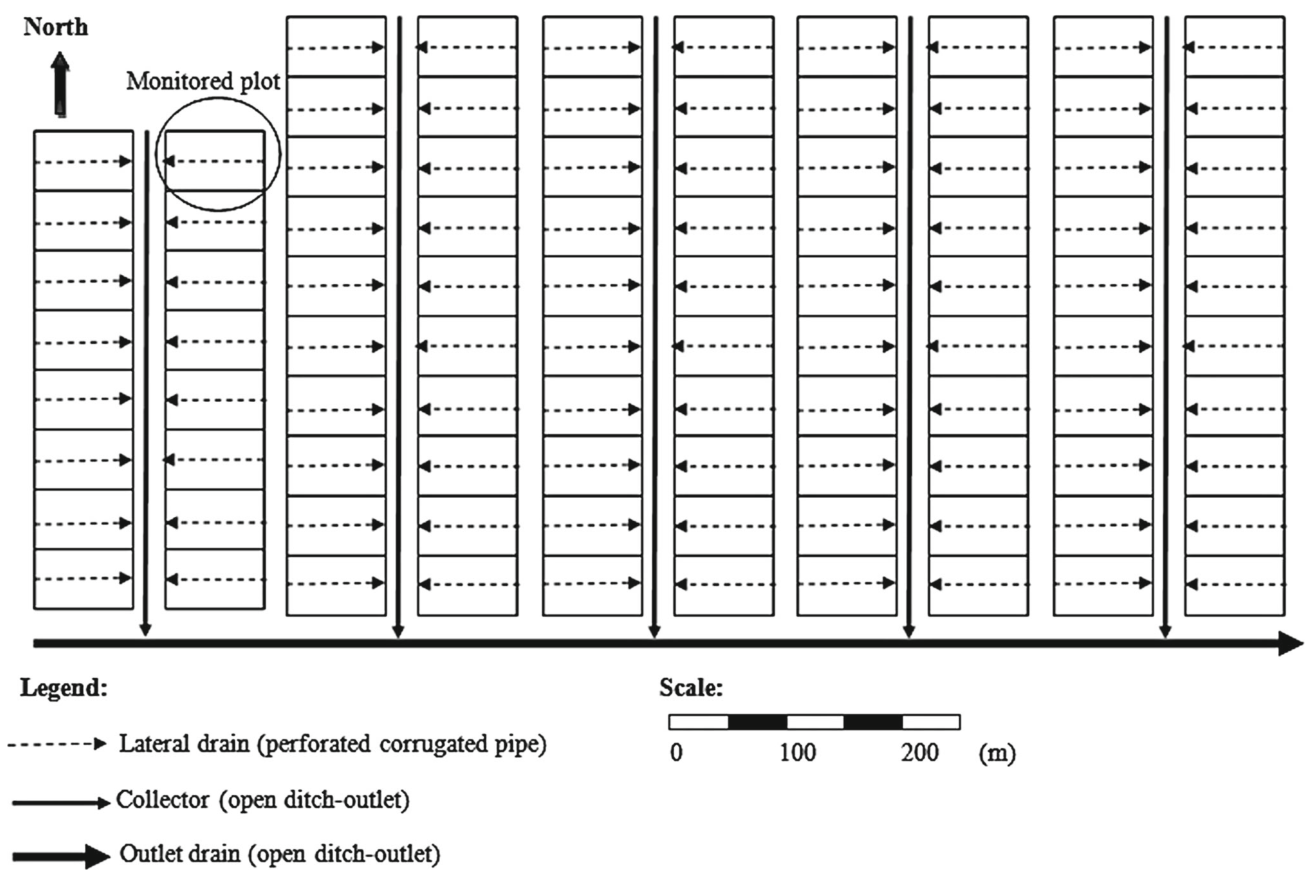

Fig. 2 Drainage network in the study area (El-Hsay Oasis)

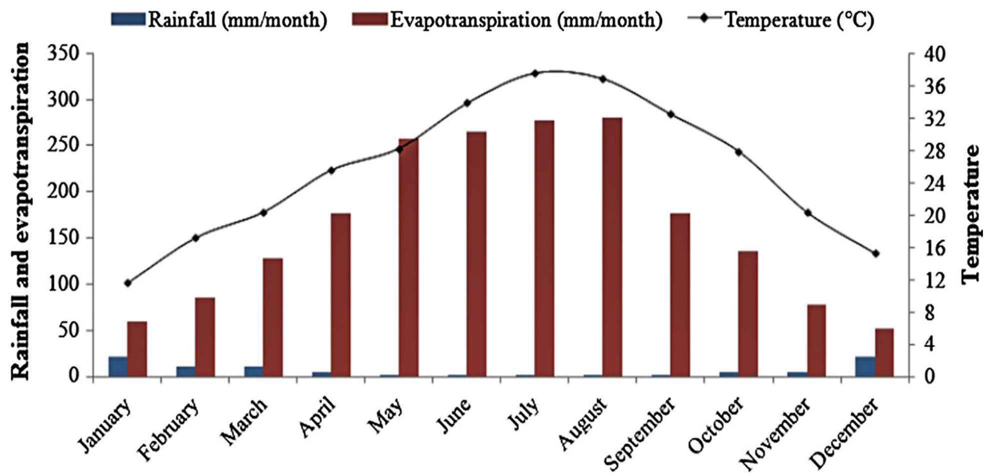

Fig. 3 Average monthly climatic data for the 1993–2013 period in the study oasis

Table 1 Irrigation practices in the monitored plot during the agricultural years 2012–2013 and 2013–2014

Study year	Irrigation amount (mm)	Irrigation interval (days)	Number of irrigation events (–)	Annual applied water (mm)
2012–2013	62	16–42	10	620
2013–2014	60	16–42	10	600

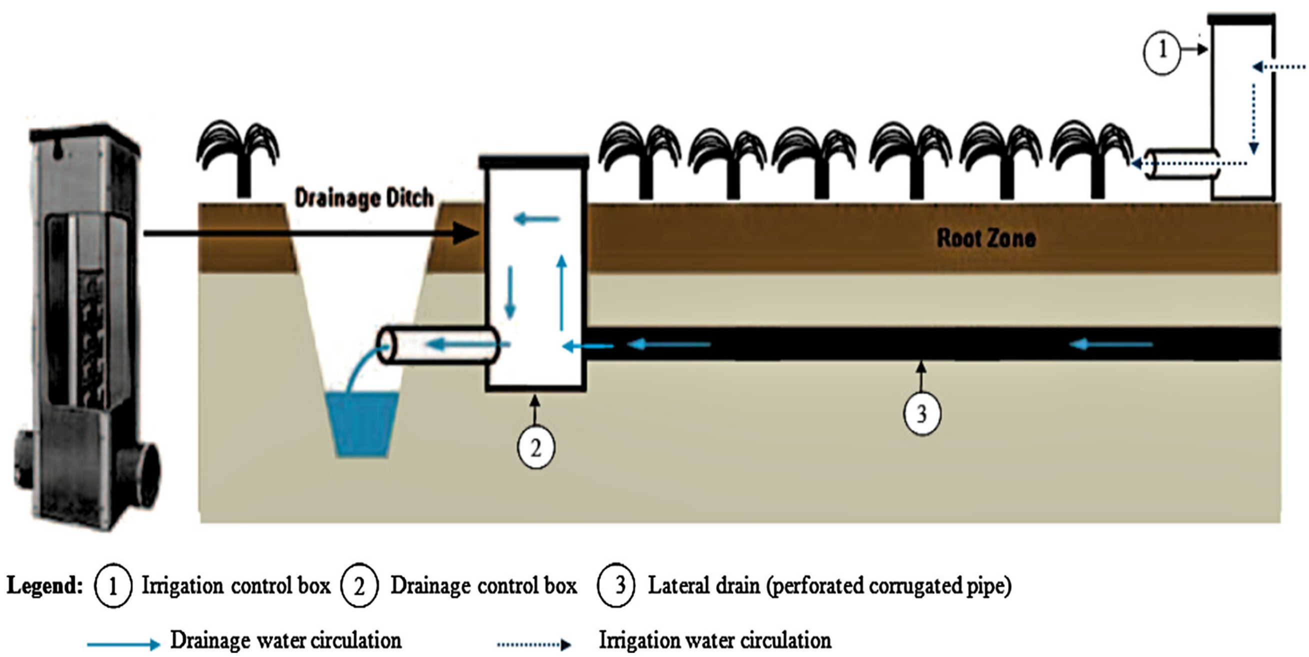

Fig. 4 Drainage management structure (lateral drain and open ditch outlet) in study plot

permit water circulation, the buried drain was embedded in filter material, i.e. gravel with a particle size of 12–22 mm.

3 Experimental Design and Data Acquisition

3.1 Pre-investigation

Before the initiation of the project, a pre-investigation was conducted in the MP. The aim of this investigation was to determine soil texture and soil saturated hydraulic conductivity (K_S) as initial values before irrigation. Two soil profiles with a depth of 1.5 m were excavated in the MP. Soil samples were collected at depths of 0.5, 1, and 1.5 m, each with three replications. The 18 soil samples were transported to the laboratory for soil texture and K_S measurements. The soil texture, i.e. relative proportion of sand, silt, and clay, was measured using the sedimentation method [21]. Based on the USDA textural classification [22], the soil texture of the studied plot was defined as sand. The K_s of soil was determined with the constant-head method [23]. No noticeable variability of K_s with soil depth was observed and the permeability tests yielded values of K_s around 0.99 m day^{-1}.

3.2 Experimental Design

The following sections present the experimental design and data acquisition for each stage of the present study.

(i) *Evaluation of drainage system performance*
During the second year, from September 2013 to August 2014, the performance of buried drains was evaluated with regard to salinization control in the MP with consideration of three assumptions: (1) due to the insignificant rainfall during the studied time period (< 80 mm), the rainfall contribution to the soil salinization balance was neglected; (2) the deep percolation of irrigation water was not considered; and (3) the contribution of evapotranspiration to salt outflow was neglected.

The salt balance in the MP was calculated based on the difference between salt inflow, which was introduced by the irrigation water, and salt outflow, which was removed by the drainage system. The required data to calculate the salt balance were determined as follows:

- *Salt inflow and salt outflow*
Irrigation and drainage control boxes were installed in the MP in order to measure the inflow and outflow of the salinity of the applied irrigation water (Fig. 4). During the studied period, ten irrigation events occurred. For each irrigation event, the salt inflow by the irrigation water was calculated as the product of the volume [l] and the salinity [g l^{-1}] of the applied irrigation water. The volume was measured by multiplying the flow rate (measured through a magnetic flowmeter [l s^{-1}]) by the irrigation duration [h]. The irrigation water salinity was directly measured in the field using a portable salinity meter (Aquaprobe AP-7000 device, Aquaread Instruments Company, UK).

The salt outflow from the drainage system was measured through drainage water monitoring in a drainage control box installed in the MP (Fig. 4). The same principles and techniques applied for measuring salt inflow were used to determine the salt outflow. The drainage water (flow rate, duration of drainage, and salinity) was continuously measured between successive irrigation events.

(ii) *Evaluation of drainage system on soil salinity*
The aim of this investigation was to evaluate the effect of the installed buried drain on soil salinization in the MP. To achieve this aim, the level of soil salinity after the drainage installation (2013–2014) was compared to that before the drainage installation. The soil electrical conductivity was used as an indicator for soil salinity level. During the studied period (2012–2014), soil samples were collected 24 h after each irrigation event from three different depths in the MP for soil electrical conductivity measurement. The soil samples were taken from 1 to 1.5 m soil layer. The samples were taken with maximum care because of the high density of date palm roots at this depth [24] and the risk of decreasing date palm production due to the root damages [25]. The soil electrical conductivity was measured in a 1:5 soil–water extract ($EC_{1:5}$) following the approach proposed by [26]. The obtained $EC_{1:5}$ values were converted to the electrical conductivity of saturated paste (EC_e) based on a linear regression (Eq. 1), which was established between $EC_{1:5}$ and EC_e for 90 soil samples collected from the studied oasis. $EC_{1:5}$ and EC_e are expressed in dS m^{-1}.

$$EC_e = 3.21 + 2.64 \times EC_{1:5} \quad (R^2 = 0.97) \tag{1}$$

(iii) *Evaluation of irrigation effect on shallow groundwater dynamic*
The shallow groundwater depth (D_{gw}) was measured throughout the year 2013 on a daily basis. D_{gw} was measured by a water depth sensor (PTM/N depth transmitter) in a hand-augured piezometer (i.e. an observation well) installed in the centre part of the MP. Because of the small area of the MP (0.5 ha), one piezometer was found to be sufficient for the shallow groundwater table due to the spatial homogeneity of the soil within the investigated plot.

4 Results and Discussion

4.1 Effect of Irrigation on Shallow Groundwater Dynamic

The effect of irrigation on shallow groundwater depth was analysed with and without consideration of the irrigation amounts applied in the MP during the second agricultural year (from September 2013 to August 2014). Shallow groundwater fluctuation in the observation well during this year is presented in Fig. 5.

The annual shallow groundwater fluctuation without irrigation-drainage practices was from 1.2 to 1.6 m. Strong seasonal variation of shallow groundwater fluctuation (D_{gw}) was observed throughout the agricultural year 2013–2014. A rise of water table was observed in winter season, i.e. from October 2013 to February 2014. This situation can be explained by the fact that the water loss through evapotranspiration decreased during the winter season, whereas a lower water table due to irrigation occurred in the summer season, i.e. from April 2014 to August 2014, due to the increase in the water loss through evapotranspiration process [27]. A similar seasonal variation was also observed in many other Tunisian oases [16,17,27]. The results reported in

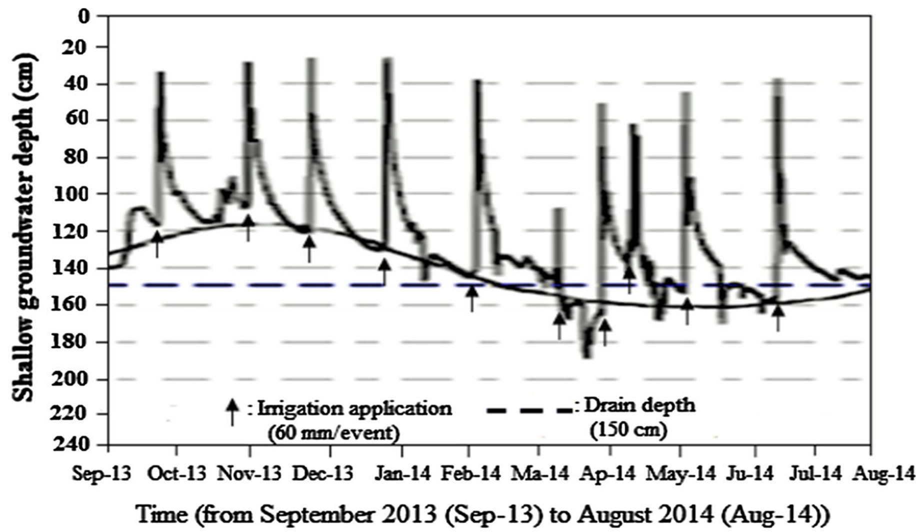

Fig. 5 Variation of shallow groundwater depth (i.e. depth to water table) during 2013–2014. The sinusoidal curve is the natural water table without irrigation

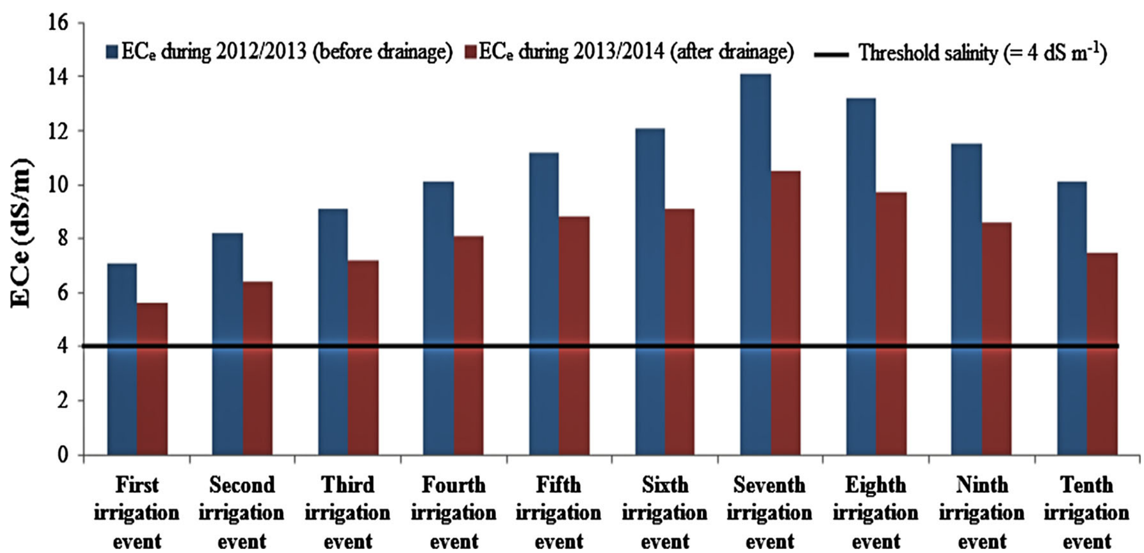

Fig. 6 Temporal variation of root-zone (100–150 cm layer) electrical conductivity (EC_e) during 2012–2013 (before installation of drainage system) and 2013–2014 (after installation of drainage system). EC_e was measured 24 h after each irrigation event

these studies indicate that water table fluctuation (declining and inclining phases) is mainly caused by seasonal variation of evapotranspiration.

During the second agricultural year, 2013–2014, ten irrigation events occurred. About 60 mm of irrigation water was applied at each irrigation event with a total of about 600 mm in the irrigation year (Table 1). As shown in Fig. 5, the shallow groundwater depth (D_{gw}) was quickly affected by these recharge events. For example, D_{gw} changed from 1.2 to 0.35 m immediately after the first irrigation event. During some irrigation events, D_{gw} rose above the critical soil depth into the respiratory zone of the date palm at 0–0.4 m soil depth [24]. It appears that the coarse soil texture (sandy soil) along with the high soil saturated hydraulic conductivity ($K_s = 0.99$ m day^{-1}) caused groundwater to rise rapidly after irrigation. The rapid rise in shallow groundwater was followed by a slow recession tail due to evapotranspiration and slow lateral movement to the installed buried drain.

4.2 Effect of Subsurface Drainage System on Soil Salinization

The measurements of root-zone electrical conductivity (EC_e) permitted to evaluate the decreasing rate of soil salinization due to the installation of drainage system in the MP. Figure 6 shows the monthly variation in EC_e before and after installation of the drainage system.

For the year 2012–2013, high EC_e values (from 7.1 to 14.1 dS m^{-1}) were observed in the MP. The observed EC_e were beyond the threshold salinity-tolerance level of the date palm estimated at 4 dS m^{-1} according to [28]. As reported by [29], an $EC_e >$ 4 dS m^{-1} has the potential to decrease

Table 2 Decrease in soil electrical conductivity (EC_e) due to the installation of drainage system in the monitored plot (2012–2013 and 2013–2014, each EC_e value was the average of three sampling points in the monitored plot)

Irrigation event number	EC_e before drainage* (dS m^{-1})	EC_e after drainage** (dS m^{-1})	Decrease in EC_e (%)
First event	7.1	5.6	21.1
Second event	8.2	6.4	22.0
Third event	9.1	7.2	20.9
Fourth event	10.1	8.1	19.8
Fifth event	11.2	8.8	21.4
Sixth event	12.1	9.1	24.8
Seventh event	14.1	10.5	25.5
Eighth event	13.2	9.7	26.5
Ninth event	11.5	8.6	25.2
Tenth event	10.1	7.5	25.7
Average decrease of EC_e (%)			23.3

EC_e was measured 24 h after each irrigation event
*EC_e during 2012–2013; **EC_e during 2013–2014

the date palm growth through osmotic effect and ion toxicity. However, other studies [30,31] revealed that the date palm can tolerate up to 9 dS m^{-1} without serious impact on its growth. Similar high EC_e values were also recorded in several Tunisian Saharan oases [17,32]. The causes of the noted soil salinization variation in the irrigated plot can be summarized as follows: (1) the absence of a drainage system within the irrigated plot; (2) the high salinity (2.24 g l^{-1}) of applied irrigation water; (3) the low amount of rainfall (80 mm $year^{-1}$) available for leaching; (4) the contribution of shallow groundwater to salt accumulation in the soil profile through capillary rise; and mainly (5) the large irrigation interval. Indeed, in some periods of the investigated year, the irrigation interval was more than 40 days (Table 1) because of the low capacity of irrigation network to satisfy the needs of all irrigation plots in El-Hsay Oasis.

The poor irrigation practices coupled with the uncontrolled extension of the palm trees could be the main causes of this low irrigation capacity [33]. Under salinity conditions (saline irrigation water and high salinity level of shallow groundwater) in arid irrigated areas, it is suggested that the irrigation interval should be reduced compared to natural conditions to decrease the soil salinization process [8,32]. Further, during the entire studied period (2012–2014), the root-zone electrical conductivity (EC_e) showed significant seasonal variation (Fig. 6). The EC_e was the lowest in the winter season from December to February, and the highest in the summer season from June to August. Two main reasons can explain this variation. First, the effect of salt leaching on soil salinization is more pronounced in winter than in summer due to the higher amount of rainfall. As shown in Fig. 3, the average rainfall was 53 mm in winter and 2 mm in summer. Second, the high soil evaporation rate during summer results in more upward flux of saline water from the shallow groundwater by capillary rise, thus leading to more salt accumulation around the date palm roots [7,34]. Severe salt accumulation from shallow groundwater may cause water deficiency in date palms and restrict the root water uptake leading to reduced crop growth [35]. A study conducted by [8] in Fatnassa Oasis (a Saharan Tunisian oasis) revealed that under saline shallow groundwater, frequent irrigation during the summer season is required to maintain high soil water content to assure a low salinity level in the root-zone of date palms. In addition, the EC_e level before the drainage installation (during 2012–2013) was generally higher than the EC_e level after the drainage installation (during 2013–2014) (Fig. 6). Thus, the installation of buried drain pipes in the MP resulted in a significant decrease in soil salinization around date palm roots.

During the 2014 winter season (January to December), the drainage practices decreased the EC_e close to the safe limit for date palm production of 4 dS m^{-1} [28]. It appears that the installation of a lateral drainage system in the MP is the main cause of EC_e reduction (Table 2). These results are consistent with those from several other studies [36,37] which revealed that the installation of drainage system has a substantial effect on soil salinization control in arid irrigated areas. As noted in Table 2, the average decrease of EC_e was 23.3%.

A similar percentage was identified by [16] for a Tunisian oasis. However, this percentage is low compared to other studies [36] indicating that the soil salinization can be decreased by more than 50% after the installation of a subsurface drainage system. [38] revealed that the decreasing rate of soil salinization depends upon two factors, i.e. the performance of the installed drainage infrastructure and irrigation management, especially applied water quantity and irrigation frequency. In this study, it appears that the poor irrigation scheduling (large irrigation interval) (Table 1) coupled with low efficiency of the installed subsurface drainage system

Table 3 Salt inflow, salt outflow, and drainage performance in the monitored plot during the agricultural year 2013–2014

Irrigation number	Irrigation date	Irrigation					Drainage					Salt balance (–)	Leaching fraction (%)
		Water salinity (g l^{-1})	Flow rate (l s^{-1})	Irrigation duration (h)	Water inflow (mm)	Salt inflow (t ha^{-1})	Water salinity (g l^{-1})	Flow rate (l s^{-1})	Drainage duration (h)	Water outflow (mm)	Salt outflow (t ha^{-1})		
1	22 September 2013	2.36	13.7	2.55	60	1.42	9.82	2.7	4.8	4.7	0.46	0.96	32.4
2	29 October 2013	2.32	14.1	2.53	61	1.42	9.81	2.6	4.9	4.6	0.45	0.97	31.7
3	22 November 2013	2.32	14.2	2.61	60	1.39	9.94	2.5	4.2	3.8	0.38	1.01	27.3
4	23 December 2013	2.31	13.8	2.58	60	1.39	10.14	2.3	4.7	3.9	0.39	1.00	28.1
5	01 February 2014	2.32	13.9	2.46	61	1.42	10.38	2.2	4.8	3.8	0.39	1.03	27.5
6	06 March 2014	2.45	13.8	2.41	60	1.47	10.65	2.1	4.7	3.6	0.38	1.09	25.9
7	27 March 2014	2.44	14.2	2.49	60	1.46	10.96	2.1	5.3	4.0	0.44	1.02	30.1
8	12 April 2014	2.41	13.9	2.51	60	1.45	11.86	2.0	5.7	4.1	0.49	0.96	33.8
9	02 May 2014	2.35	14.1	2.49	60	1.41	10.19	1.2	5.7	2.5	0.25	1.16	17.7
10	13 June 2014	2.34	14.3	2.55	60	1.40	10.08	1.1	5.8	2.3	0.23	1.17	16.4
(*) Cumulative value						14.23					3.86	10.37	**27.12**

Bold value indicates the cumulative percentage of evacuated salts

Salt balance: salt inflow–salt inflow; Leaching fraction: = (salt outflow/ salt inflow) ×100

*Cumulative value for 10 irrigation events

Table 4 Bulk density and hydraulic conductivity of gravel filter before and after drainage system installation. Source of data: SAPI Study Team, "Irrigation Perimeters Improvement Project in Oasis in South Tunisia"

	Bulk density ($g\ cm^{-3}$)	Hydraulic conductivity ($cm\ day^{-1}$)
Before drain installation	1.42	183
After drain installation	1.83	112

could be the main causes of the low soil salinization control in the studied plot. In this context, one of the main objectives of the present work was the evaluation of drainage system performance, which is presented in the following sections.

4.3 Performance of Drainage System

The performance of the drainage system was evaluated based on salt balance calculation (i.e. difference between salt inflow by the irrigation water, and salt outflow from the drainage system). Results of salt inflow, salt outflow, and drainage performance in the monitored plot during the agricultural year 2013–2014 are summarized in Table 3. The quantity of salt added by the ten irrigation events was estimated at 14.23 t ha^{-1} (cumulative value). The measurements showed a high concentration of salt in the irrigated soil which requires close attention and appropriate management of irrigation and drainage in the studied agricultural land [33].

Throughout the second studied year (2013–2014), the salt concentration in the drainage water varied from 9.81 to 11.86 g l^{-1} (Table 3). The minimum salinity of drainage water was reached in the spring season (February, March, and April), while maximum salinity was reached during the summer season (June, July, and August). Table 3 also shows that cumulative amount of salt removed by drainage water was about 3.86 t ha^{-1}. Comparing this value with the quantity of salt introduced by irrigation water (inflow salt) indicated that the installed lateral drain pipes within the MP were unable to evacuate more than 27.12% of the accumulated salt in the year 2013–2014 (Table 3). This low percentage, which reflects very low efficiency of the drainage system, appears to be one of the main driving factors for the low date palm yield observed in the studied oasis (El-Hsay Oasis). However, it is difficult to quantify the effect of drainage system on soil salinization compared to the effect of irrigation management.

The results presented in Table 3 show that there was a continuous decrease in the drainage flow rate during 2013–2014 with the minimum flow rates at the end of the studied period (ninth and tenth irrigation event). This outcome could be explained by the system clogging or limited capacity of the gravel filter of the lateral drain to discharge water [39]. However, the latter assumption is less probable for the MP as the lateral drain never reached full capacity during the measurements. On the other hand, the first assumption, clogging, was confirmed by the measured bulk densities of the gravel filter before and after installation of the lateral drain (Table 4). The differences between the bulk densities of the gravel filter (12–22 mm particle-size range) before and after installation of lateral drain within the MP showed that the gravel filter had been compacted, resulting in a decrease in hydraulic conductivity (Table 4) [39]. This observation confirmed that the sand clogging, which occurred in lateral drains at the end of studied period, was the main factor leading to low performance of the drainage system (27.12%).

An in situ diagnosis conducted in the studied area (El-Hsay Oasis) as well as other nearby oases (Jemna Oasis, Douz Oasis, Lazala Oasis, etc) indicated severe secondary sand clogging due to the fine texture of the sandy soil. The gravel filter that was originally installed failed to prevent clogging. The finding also confirmed a rapid sand clogging of gravel filter after a short period (1 year). It is clear that the use of gravel filters depends largely on soil conditions. It was noted that there is a need for using a geotextile envelope for avoiding sand clogging [40].

The rapid sand clogging of the drainage system as well as the low performance of drainage operation was essentially the main factors causing the low efficiency of the installed subsurface drainage system. According to above findings, there is a need for the design and development of a new drainage system including the standard guidelines, i.e. drain depth, spacing. Drainage modelling could be also a powerful tool to evaluate the efficiency of the installed subsurface drainage systems in the Tunisian arid oases.

5 Conclusion and Recommendation

Soil salinization due to the low performance of subsurface drainage system and saline shallow groundwater rise are common problems of all arid irrigated oases in Tunisia. The studied oasis (El-Hsay Oasis) is a representative example of these problems. In this study, irrigation practices and drainage system performances were considered to evaluate the soil salinization for two consecutive agricultural years (2012–2013 and 2013–2014) at the plot level (0.5 ha). Findings during this period revealed that the irrigation practices negatively contributed to the rise of shallow groundwater resulting in high salinization at the root-zone of the date palm. In the MP, the measured salt balance during the agricultural year 2013–2014 showed low performance of installed subsurface drain (27.12%). The sand clogging observed in subsurface drains at the end of studied period drastically decreased the overall performance of the installed drainage system. For the long-term sustainability of agricultural soils, advancing the current buried drain pipes to evacuate excessive salt from the irrigated soil is imperative. It is recommended to replace the current system with an adequate and more efficient technology such as geotextile envelopes to prevent sand clogging in the subsurface drainage system. However, the new system has to be tested in situ before extension of the new designed subsurface drainage. In addition to the rehabilitation of subsurface drainage, increasing the awareness of the local farmers and stake holders with regard to irrigation water management and soil practice is necessary to maintain a balanced extent of soil salinity by improving irrigation practice in the studied oasis. The results of this study can also have practical significance in other Tunisian oases with similar soil and groundwater conditions.

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