Rethinking water and crops management in the irrigated district of Diyar-Al-Hujjej (Tunisia)

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Abstract

In Diyar-Al-Hujjej irrigated area, aquifer's over-exploitation, sea intrusion and abandonment of irrigated areas and wells were took place. A yield decrease for all crops was observed. Average aquifer water electrical conductivity (EC) jumps from 4 dS/m to 6.6 dS/m between 1969 and 2017. A fresh surface water transfer over more than 100 km was launched in 1998 to safeguard this irrigated area but this fresh water supply is not stable, it varies from one year to another (about 1,900,000 m^3 in 2015 and only 60,000 m^3 in 2018) while annual cops water requirements of the perimeter is about 2,500,000 m^3. An adaptation by farmers to this new situation of saline and water stress was observed. The follow-up surveys of the farmer's practices showed that: (i) new crops with high added-value grown during the rainy season were introduced in association with dry season crops (strawberry-pepper association), (ii) rainfed crops, fallow and water blending are common practices, and (iii) growing of rainy season crops in the aim to reduce water supply. The instability of fresh surface water volume transferred constitutes the main threat for this perimeter. The use of aquifer salt water must be stopped; it is the cause of the large quantities of salts supplied (over 13,000 kg / ha) and also of the low annual net income achieved. Net revenue was less than 2,000 US $/ha under salt water and reached even 8,000 US $/ha when sufficient surface water is available. An agrarian reform policy must be applied for this perimeter; only crops whose water requirements are partially met by rain should be grown. Introduction of another more sustainable water source should be initiated (as desalination) even at private farm level.

Introduction

The advanced degradation, limits and vulnerability of all natural resources are unanimous all over the world and especially in regions where high population density and intense economic activities are present. Competition between the different users of these resources is often observed. In Tunisia, good quality water is reserved for drinking water and in case of water shortage; irrigated areas receive quantities of water lower than their actual needs (even no supply sometimes for vegetable crops). In our irrigated area, fresh surface water supply was about 1,900,000 and 60,000 m^3during respectively2015 and 2018.

According to the FAO, 7.3 million hectares salted are located in Spain, Morocco, Tunisia and Turkey for a total of 27.3 million hectares for the entire Mediterranean region (Aragüés et al., 2011). Coastal aquifers around the Mediterranean and more particularly in North Africa are increasingly degraded and over-exploited. In Tunisia, salty soils occupy 1.5 million hectares (25% of the total area of cultivable soils (Hamrouni and Daghari 2010)). Agriculture will remain a key sector; it accounts for more than 11% of the gross domestic product and provides employment for more than 20% of the working population. The irrigated sector contributes to more than 35% of national agricultural production. Unfortunately, Tunisia is a country with very limited water resources. The quota of a Tunisian does not exceed 500 m^3 per inhabitant per year. A third of Tunisia's mobilizable water resources have salinity greater than 4.5 dS/m. Also, 50% of the sampled wells in Northern Tunisia have salinity higher than 3dS/m (Söderströmet al.1992). Furthermore, all regions of Tunisia suffer from high groundwater salinity; this is the case of our irrigated area and a lot of other regions such as all the south when average rain is about only 100 mm. Crops yield is very low due to salinity; in Tunisian oases, driving force of development for all of southern Tunisia, the average yield of irrigated date palms is 4.6 tons/ha while it's 41 tons/ha (9 times) in Egypt (El-Juhany 2010; Zafar 2020).

In the region of Diyar-Al-Hujjej, site of our study, aquifer over-exploitation combined with the rain's irregularity led to a drop in the water table level, sea intrusion and yields decline. A low tomato yield (less than 20 tons/ha) has been observed. Wells (EC) of more than 30 dS/m and depressions from sea level down to -13 m were measured (Chekirbane et al. 2014).

These highs (EC) have led to the abandonment of wells and farms and the migration of farmers to other areas less affected by salinity, often in the form of tenants. The average sodium adsorption ratio (SAR) was $8.6^{0.5}$ (meq L^{-1}) and the average electrical conductivity (EC) was 6.6 dS/m, (Mekni 2017). The number of abandoned wells increased from 1,268 to 3,200 between 1980and 2005 in Diyar-Al-Hujjej and surrounding areas (Cap Bon peninsula).

As emergency measures, there was recourse to the transfer of surface fresh water from another geographical region (north-west) of Tunisia, via the Cap Bon Medjerda canal over approximately 100 km with several pumping stations. This operation of water transfer is highly contested last years by the population living in the watershed from which the water transfer is made. On another side, feasibility of using seawater desalination shows its limit; besides environmental problems but renewable and clean energy usage can help sustain environmental conditions in the opposite of fossil fuel-based energy (Abbes et al. 2020). Desalinated water cost is very high (more than 0.5 US $\$/m^3$) while the selling price of surface water is 0.05 US $\$/m^3$ and the cost of pumped saline water is only 0.02 US $\$ /m^3$. The salt seawater desalination analysis showed clearly, that the application of desalinated seawater in the current situation leads to a negative net marginal value except for crops with high added-value (strawberry), (Daghari et al. 2020a). But no agro-industry exists for strawberries; the market is very limited and it is a crop that spoils in two or three days. As desalination is beyond the reach of farmers today, it was deemed more appropriate to analyze the farmer's practices.

In the irrigated area of Dyiar-Al-Hujjej, all farmers are aware of the salinity problem. Some new practices were adopted in the aim to manage salt, water and crops over time:

- water blending and over-irrigation with fresh water in the aim to drop soil salinity

- introduction of new and more profitable crops such as strawberry following this supply of fresh water and the practice of associated crops on the same site (strawberry-pepper combination), (Daghari et al. 2020b).

- growing of winter and spring crops in the aim to reduce water supply,

- adoption of crops rotation by the application of successions between irrigated crops, rainfed crops and fallow by all farmers in order to reduce soil salinity even if the farms size is very low; farms with an area of less than 4 ha represent 60%.

It is only recently that the behaviour of farmers and their perception of salinity have started to be studied. There is no clear agreement on what constitutes best practices for managing salinity in this region especially since the fresh surface water volume is very irregular (Table 1). Considering the heaviness of these experiments, only modeling was often used (Lahlou et al. 2000; Kaur et al. 2007; Arafat 2019) but field studies are lacking. Some studies were carried out over short periods and only looked at salinity (Daghari et al. 2020b), (Azza et al. 2020). Total amounts of salt brought, farmer's net revenue and salinity evolution for a long period (many years) were not studied before. The objective of this paper is to compare farmers' practices in an irrigated area whose irrigation water comes from a saline aquifer and very irregular transferred surface fresh water but certain prosperity is observed in this perimeter despite water and salt stress.

Materials And Methods

Study area

Dyiar-Al-Hujjej located in the Cap Bon peninsula of Tunisia (Figure 1) having as coordinates 36° 35' North and 10° 52' East.The average potential evapotranspiration and annual rainfall were respectively 1,166 mm and 441 mm for the period (1968 – 2020).   Dyiar-Al-Hujjej's aquifer (EC) was 6.6 dS/m in 2017, wells depth is about 20 m measured in 2011, 2017 and 2020 and it's the main region when strawberry is grown (more than 95%). Only localized irrigation is encountered and irrigation uniformity is about 90% (Daghari et al. 2020b).

Meetings with extension services, farmers and farmers' association called "izdihar" were carried out. The crops predominantly grown are vegetable crops (pepper, potato, strawberry, squash, tomato….).   Soil profiles showed that the crust is often present from 20 cm depth sometimes; after granular analysis, percentages of clay, silt and sand were respectively 9 %, 36% and 55%. Crops choice varies depending on available water sources. Thanks to the availability of surface water from the state network supply, the growth of a high added-value crop which is strawberry is increasing every year. Its agricultural production value is about 15,600 US $/ha while it's less than 3,000 US $/ha for all other crops. This explains the increase in the area occupied by strawberries from zero hectares in 1999, 55 ha in 2000 to 150 ha in 2011 and 121 ha in 2019. Cost production of strawberry is very high (0.2 USD/plant) and it isn't within the reach of all farmers; it's about 6,000 US $/ha while it's less than 2,000 US $/ha for all other crops. The cultivated areas dedicated to tomato which is a summer crop with high water requirement, decreased from 450 ha in 2000 to only 70 ha in 2019. The farms size is divided into two classes 0-4 ha and 4-10 ha, each occupying 435 ha with 185 farmers and 365 ha with 60 farmers, respectively.

The farmers were grouped according to three different scenarios: (i) farmers who use only fresh surface water from the state network, (ii) farmers who blend surface water and saline groundwater resulting in decreased water salinity, and (iii) farmers who use only saline groundwater. Each group has its own strategy regarding crops grown and crops rotation. (EC) measured on December 2th, 2020 were 2.4 and 4.4 dS/m respectively for fresh surface water and aquifer saline water. These values were respectively 2.82 and 4.36 dS/m on February 26th 2021.

Experiments

(EC) was measured using the method of saturated paste extract and Geonics conductivemeter (EM 38);. irrigation water amounts supplied were tracked by water-meter monthly. Also, wells (EC) and depths were measured by using conductivimeter, and piezometric probe respectively. For different crops rotations encountered, (EC) were measured during September 2017-February 2021.The last salinities measurements were carried out on December 2, 2020 and on February 2021 over an area after three important rains of about 30 mm each. During the years 2016, 2017, 2018, 2019 and 2020, the volume of surface fresh water supplied is very low and many areas were not occupied by irrigated crops. During 2019, the volume of surface water pumped was 780,389 while the volume distributed was only 620,000, a loss rate of 21%; the number of hydrants used was 138 for a total of 266 with a rate of 52%.

Main equations

- **Relative yield**

Relative yield (Y_r) is calculated by using the following equation (Maas and Hoffman 1977):

$Y_r = 100 – b\ (EC_s - a)$ (1)

where b = the curve slope expressed in percent per dS/m (equal to 14, 12, 10.5, 33 and 9.9 respectively for pepper, potato, squash, strawberry and tomato), a = the salinity threshold expressed in dS/m (equal to 1.5, 1.7, 4.9, 1 and 2.5 respectively for pepper, potato, squash, strawberry and tomato).

EC_s = the mean electrical conductivity of a saturated paste, measured in the root zone (dS/m)

- **Salt brought**

The quantities of salt brought (Q_s) are calculated using this equation:

Q_s = Volume of water (V) * water salinity (S)   (2)

with Q_s (kg/ha), V (m^3/ha) and S (g/l) = water electrical conductivity (EC)*0.64

- **Net revenue N:**

N = value of agricultural products (US $/ha) – (production cost (US $/ ha) + water cost (US $/ ha)) (3)

with production costs (US $/ha),(= product selling price (US $/kg) * yield (kg/ha)) and water cost (US $/ ha), (= volume of water (m^3) *selling price of water cubic meter (US $/ m^3)).

Selling prices at farm level of agricultural products, water prices or costs, production cost, crops yield considered are taken according to the Tunisian Ministry of Agriculture, Water Resources and Fisheriesdatabase.

Results And Discussion

In our irrigated area, crops grown and crops rotation depend mainly on available water sources; surface water is available on uncertain amounts. The volume of surface water transferred is irregular and varies from year to another (1,929,322 and 60,503 m^3 respectively for the years 2015and 2018) depending on the water volume stored in dams (Table 1). Average net crops water requirements calculated by the CROPWAT model, (Allen et al. 1998) are about 2,500,000 m^3 for this irrigated area. Tunisia is going through a dry period since 2016; the water stored volume in dams in Tunisia is less than 50% of their capacity; priority is given to potable water. Irrigated areas are very restricted during 2016, 2017, 2018 and 2019.

Table 1. Fresh surface water volume supplied to the irrigated area of Diyar-Al-Hujjej (Tunisia) (GDA (farmer's association, 2021)

Year	2000	2010	2011	2015	2016	2017	2018	2019	2020
Supplied water volume (m^3)	1,569,467	1,714,603	1,714,421	1,929,322	878,324	302,382	60,503	620,000	920,000

During the dry seasons April 2000-August 2000, April 2012-August 2012 and April 2019-August 2019, the volume of surface water supplied were respectively 1,085,510; 1,225,675 and 306,775 m^3 while the average crops water requirement is about 2,408,110 m^3.The availability of fresh surface water is the determining factor for cropping choices in this irrigated area.

In the irrigated area of Diyar-Al-Hujjej, for the year 2019, the number of irrigators was 150 with an area of 276 ha (about 39% of the total equipped area). The volume of water distributed in 2019 was 620,000 m^3 while the expected volume is 1,225,000 m^3 (about 200%). Even in 2020, fresh water supplied still low (920,000 m^3) and represent about 50% of the volumes supplied before 2015 (Table 1).

1. **Farmers having only fresh surface water**

These farmers are often tenants who do not invest in the drilling of wells and the built of tanks necessary for water blending. They grow only crops with high added-value; no rainfed-crops. Soil profiles (EC) measured was about 2 dS/m for the first year (1.6 under strawberry in May 2018 and 2.2 dS/m under pepper in August 2018), (line 4, Table 2), This relatively low salinity measured is the result of the use of good quality surface water and the leaching of salts under the effect of rain, especially since it is a light soil. Exceptional winter rains of 260 mm allowed the evacuation of more than 60% of the initial salt stock (Belouazi, 2010). The combination strawberry-pepper is maintained during a second year especially in September 2018, more than 200 mm have fallen, which further promotes salts leaching.

The (EC) measured at the end of the second year was 3.2 dS/m (line 4, Table 2) (Fig. 2, blue curve); so high for strawberry. For an (EC) of 3.2 dS/m, no yield can be obtained with strawberry while it's 100 % for squash by applying equation (1). Also, based on the database of the Tunisian Ministry of Agriculture, Hydraulic Resources and Fisheries, the amount of rainfall recorded is only 47 mm during all the dry and hot period (June 2019 - September 2019). At the beginning of the third year, strawberry-pepper association is removed, other less sensitive crops to salinity were grown (cabbage, potato, squash etc ...). At the end of the third year, (EC) was only 2.1dS/m in August 2018 under squash (Table 2).

With respective average net irrigation water requirements of 3,600 m^3 / ha; 6,000 m^3 / ha; 1,345 m^3 / ha; 7,174 m^3 / ha respectively for strawberries, pepper, potato and squash and with surface water's salinity of 1.5 dS/m, the quantities of salts brought calculated by using equation (2) were 9,600 kg/ha (= 3,600 kg/ha + 6,000 kg/ha) under strawberry-pepper and 8519 kg/ha (= 1345 + 7174) under potato-squash, the same amounts. Even if the quantities of salts added are almost identical for the three years, the crops grown during the third year are resistant to salinity; cabbage is poorly irrigated (or not). For squash, even with a (EC) of 5 dS / m, yield reduction is negligible. Considering the average (EC) between these measured at the beginning and end of each season (line 4, Table 1) and using equation (1), relative yield (Yr) drops from 80% to 47% for the strawberry and from 90% to 76% for pepper between the first and the second year; this is a significant drop in yields, especially for strawberry. Indeed, the yields really observed in the field during the second year are low compared to the first year. A reduction yield of 50% and 40% was observed respectively for tomato and for pepper for a water salinity slightly exceeding 3 dS/m, (CRUESI 1970). For fodder sorghum, watermelons and beans, irrigation water with a salinity of 5 dS / m leads to a yield reduction of 30% (Van Hoorn et al. 1968). Irrigation water productivity (kg of agricultural product / m^3 of irrigation water), decreases from 80 to 47% and from 90 to 76% respectively for strawberry and pepper between the first and the second year.

With (EC) of 1.95 dS/m at the end of the third year, transplanted strawberry yield reduction will be of 30% but the autumn rains will contribute to the desalination of the soil. Farmers over-irrigate if they see that the rains are poor; during sept1999-April 2000 and Sept 2017-April 2018, the fresh surface water amounts used by farmers were respectively 483,957 and 303,121 m^3 while average crops water requirement was only 137,595 m^3.

During the second year, costs production for strawberry and pepper are low (about 50% compared to the cost of a new facility); costs of tillage, seeds, transplanting were not considered; crops were kept during two years.

For the first and the second year, the net revenues were high (7,770 and 5,482 US $/ha respectively) compared to the third year (2,534 US $/ha), (last line, Table 2). It is for this reason that the strawberry-pepper combination is very coveted. Water cost is low by comparison to production cost (only 3% for strawberry).

Table 2. Measured (EC) and net revenue within the irrigated area of Diyar-Al-Hujjej during September 2017-August 2020 when only fresh surface water is available for different crops

Year	First year Sept 2017 – August 2018		Second year Sept 2018 – August 2019		Third year Sept 2019 – August 2020	
Cropping season	Sept 2016 – May2017	June2017 – August2017	Sept 2017 –May 2018	June2017 – August2017	Sept2016 – May2017	June2017- August2017
crops	Strawberry	Pepper	Strawberry	pepper	Potato	Squash
Measured (EC) under crops (dS/m)	1.6	2.2	2.6	3.2	1.8	2.1
Average (EC) during crops season (dS/m)	1.9		2.9		1.95	
Average (EC) during all crops cycle (dS/m)	2.25					
Net water requirements (m^3/ha)	3,600	6,000	3,600	6,000	1,345	7,174
Surface water cost (US $/ha)	180	300	180	300	67	358
Production cost (US $/ha)	6,000	700	3,000	350	1767	700
Crops yield	55	18	55	18	22	25
Relative yield (%)	80	90	47	76	99	100
Agricultural production (kg/ha)	44	16	26	14	22	25
Selling price	0.300	0.108	0.300	0.108	0.133	0.1
Value of agricultural production	13,200	1,750	7,800	1,512	2,926	2,500
Net revenue	7,020	0,750	4,620	0,862	1,092	1,442
Annual net revenue	7,770			5,482	2,534	

2. **Farmers using only saline aquifer water**

These farmers do not have access to surface water. They are located outside the irrigated area or they have not paid their irrigation water bill; agriculture is not their main activity. They have very small irrigated areas, coming from the heritage. They grow rainfed crops throughout rainy period (September-April). Thus, the soil observes desalination throughout this rainy period, which allows them to cultivate mainly tomato intended for processing and which are grown early between February and June to make the most of the rain while normal tomato is grown between May and August (dry season). The main Tunisian's tomato and pepper processing factories are located in this region and in neighboring areas.

Tomato has small shape and it's unmarketable and it's intended mainly for processing. Selling price is fixed in agreement with factories and it is lower than the selling price of tomato intended for fresh consumption but they have a guarantee for the sale of their production and waste is insignificant. Factories advance all operating costs (price of seeds, fertilizers, phyto-sanitary products). Pepper is not grown (no surface water); pepper pod is very small. (EC) measured during the rainy season under rainfed crops and fallow are less than 2 dS / m while under tomato grown during the dry season, (EC) reached 5.37 dS / m even at the end of the first year (line 4, Table 3); keeping the soil without irrigation during the rainy season or the second year allowed a notable reduction in salinity (Fig. 2, red curve), it's a light soil and crust is present at 20 cm sometimes. Average Measured (EC) of Diyar-Al-Hujjej's aquifer was 6.6 dS / m, (Mekni 2017). Tomato irrigation water requirements are 6,467 m^3 / ha. The amounts of salts brought are 13,658 Kg/ ha (6.6 dS / m * 0.64 * (6,467/2) m^3 / ha) under tomato assuming that only half of the water requirements are supplied in the form of salt water (50% of the water needs are met by rain) while the amount of the salts supplied is only 9,600 kg/ha for a whole year of irrigation under the strawberry-pepper combination when only surface water has been used. If all tomato water requirements were satisfied by saline water when tomato was grown during the dry season, the amount of salts brought was 27,317 kg/ha; which explains the farmers' choice for industrial tomatoes, the water requirements of which are largely satisfied by the rain. The areas intended for tomato growth fell from 450 ha to less than 100 ha between 2000 and 2019. Some farmers without access to surface water and observing low yields abandon their farms for one or two years to witness a desalinization of soil profiles under the effect of the rain; it's the case of all farmers located near the sea. In Gambia, faster germinating varieties of rice and peanuts have been developed to mature in a shorter rainy season and avoid the need for saltwater pumping as part of a challenge of adaptation to climate change (Yanl 2011).   Pinckson et al.(2020) indicated that it's necessary to develop new cereal crop varieties and suggest that the prices of agricultural products must be subsidize to improve cereal varieties production under climate change threat.

Table 3. Measured (EC) and net revenue within the irrigated area of Diyar-Al-Hujjej during September 2017-August 2020 when only saline water is available for different crops

Years	First year			Second year			Third year	
Copping season	Sept 2017 – August 2018			Sept 2018 – August 2019			Sept 2019 – August 2020	
Crops	Rainfed barly	Tomato intended for processing	Fallow	Rainfed barly	Tomato intended for processing	Fallow	Rainfed wheat	Fallow
Measuerd(EC) (dS/m)	1.26	5.37	4.27	1.59	5.2	4.3	1.63	1.89
Anual average (EC) (dS/m)	3.63			3.7			1.76	
(EC) for a complete cycle: Sept 2017-August 2020	3.03							
Net water requirements	-	6,467	-	-	6,467	-	-	-
Saline water cost	-	129	-	-	129	-	-	-
Crops production cost	negligible	1,808	-	negligible	1,808	-	negligible	-
Crops yield	negligible	75	-	negligible	75	-	negligible	-
Relative yield (%)	-	92	-	-	91	-	-	-
Agricultural production (ton/ha)	negligible	69	-	negligible	68	-	negligible	-
Selling prices	-	0.0045 (=0.75*0.06)		-	0.045 (=0.75*0.06)		-	-
Value of agricultural production	-	3,105			3,060			-
Net revenue	-	1,168		-	1,123	-	-	-
Annual net revenue	1,168			1,123			negligible	

Annual net revenue was very low (about 1,000 US$/ha) (last line, Table 3) while it reached more than 7,000 US$/ha when only surface water was used (last line, Table 2). Average annual returns simulated showed that fallow-wheat rotation was the most beneficial choice, compared to pearl millet-based sequences and pearl millet-wheat rotations (Kaur et al. 2007). Ahmed et al. (2019) indicated that Fallow increases water stored for the next year and found that planting lucerne in rotation with canola, wheat and triticale crops used more water, as did native vegetation. But here it's clear that in the irrigated areas, rainfed crops and fallow decrease soil salinity also because of no salt water supply.

3. **Farmers having access to 2 water sources (surface and saline waters)**

All farmers have in addition access to groundwater through private wells; reinforced concrete tanks or ground tanks for water blending are available also. Farmers prefer using surface water but a blending is done for salt-tolerant crops if surface water amounts are insufficient. They constitute the majority of farmers.

3.1 Case of farmers having a fair volume of surface water

These farmers are often owners and no tenant is interested in farms that do not contain surface water in large quantities. The strawberry-pepper combination is absent since surface water is present in small quantities. Water blending is done by injection of fresh water in wells which leads to an additional pumping cost. Unlike farmers who only have saline aquifer water who practice only rainfed crops during the rainy period, these farmers practice irrigated crops resistant to salinity during this same period. Three crops rotation are encountered:

- rainfed wheat or barley- tomato or pepper

- beans used as a green manure-potato- tomato or pepper

- cabbage-potato-squash-fallow

The crops grown till April are rainfed crops or irrigated by blended water and rain contributes to their water needs and to salt leaching.

In general, an increase in salinity is observed during the dry season following irrigation with blended water and/or groundwater; subsequently, during the rainy season, desalination took place. During the rainy periods (Sep 2017-Ap 2018 and Sep 2018-Ap 2019), (EC) varied between 1.26 and 2.5 dS/m under rainfed beans, cabbage and irrigated potato for the three years (line 4, Table 4). Subsequently, (EC) increased and reached even 5.36 dS/m in May 2017-August 2018, (line 4, Table 4); the field yield observed is low. Bani and al. (2020) found an (EC) of 3.8 and 5.5 dS/m under pepper irrigated with blended water. Saidi et al. (2010) reported that an increase of salt salinity from 2 to 8 dS/m was observed under tomato between the beginning (first May) and the end (August) of the dry irrigation season. Salt accumulation occurs mainly throughout the irrigation season. In the second year, the (EC) measured are the same (line 4, Table 4).

Table 4. Measured (EC) within the irrigated area of Diyar-Al-Hujjej during September 2017-August 2019 when surface water is available on little amounts for different crops

Cropping year		September 2017- August 2018				September 2018- August 2019		
Crops rotation number	Crops season	Sep 2017- Apr 2018		May - August 2018		Sept 2018 - Apr 2019	May - August 2019	
	Crops	Rainfed wheat		Tomato	pepper	Rainfed wheat	Tomato	pepper
First crops rotation	Measuerd (EC) (dS/m)	1.26		5.36	4.27	1.68	5.2	4.3
	Anual average (EC) (dS/m)	3.6				3.7		
	(EC) for a complete cycle: Sep 2017- August 2020	3.65						
	Crops season	Spt 2017– early January 2018	January - April 2018	May - August 2018		Sept 2018- April 2019	May - August 2019	
	Crops	Rainfed bean (as a green mannure) (not irrigated)	Potato	Tomato	Pepper	Rainfed barly	Tomato	Pepper
	Measuerd (EC) (dS/m)	1.47	2.2	4.6	4.9	2.3	4.4	5.1
Second crops rotation	Anual average (EC) (dS/m)	3.3				3.9		
	(EC) for a complete cycle: Sep 2017- august 2019	3.6						
	Crops season	Sptember 2017– early January 2018	January - April 2018	May - August 2018		September 2018- April 2019	May - August 2019	
	Crops	Rainfed cabbage (not irrigated)	Potato	Squash	Fallow	Fallow	Tomato	Pepper
	Measuerd (EC) (dS/m)	2	2.5	4.42	4.43	2	5.0	5.35
Third crops rotation	Anual average (EC) (dS/m)	3.34				4.16		

	(EC) for a complete cycle: Sep 2017- august 2019	3.75

Average measured (EC) are the same in the two cases, when only saline aquifer water was present and irrigation is done only during the dry season (Table 3) and when surface water is available on little amounts but irrigation is done during the rainy and the dry seasons (Table 4). In this last case, farmers' net revenue is better; they grow irrigated crops during the rainy season in addition. Simultaneous use of surface water and aquifer water is the most effective way to improve water use efficiency (reducing surface water diversions by 52%) and the depth of the underground water table increased to 79 cm (Weifeng et al., 2016).

By using equation (3), the net revenues were 826; 1,549 and 1,386 US $/m^3 respectively for potato, squash and tomato. For pepper the net revenue is negligible and it is rarely grown except in areas far from the sea; a reduced farmers' net income compared to those who grow strawberries when net revenue reached 7,770 US $/ha.

The amounts of salt added were 15,600; 1,345; 18,652 and 16,814 kg / ha respectively for pepper, potato, squash and tomato, very large quantities, except for the potato cultivated during the rainy season and for which a large part of the water needs is satisfied by rain. Ignoring salinity results in a 29% reduction in agricultural profits and an average deadweight loss of US $ 1,200 per year per hectare (Yehuda et al., 2020).

3.2 Case of farmers having medium amounts of surface water.

The strawberry-pepper combination is kept one year; subsequently, salt-tolerant crops are grown. For the strawberry-pepper combination, (EC) measured under strawberry in May 2018 is 1.6 dS/m (line 4, Table 5). Since strawberry is very sensitive to salinity, they are transplanted to soils that have been left fallow or occupied by rainfed crops the year before. Also a good part of its water need is met by rain and only good quality surface water is used for its irrigation. This is a light soil, salt leaching is also observed. For the pepper planted on the same lines as the strawberry crop but cultivated during the dry period and often irrigated with surface water or blended water, the (EC) increase and reach 3.5 dS/m in August 2018 (line 4, Table 5); it does not allow keeping the strawberry - pepper association for a second year. With an (EC) of 3.5 dS / m measured at the end of the first year, the relative yield (Yr) of the strawberry calculated by using equation (1) will be under 10%; farmers grow strawberry-pepper on other different lands due to its profitability.

Under the less salt-sensitive crops grown in the second year, the measured (EC) decreased and they were 1.15, 1.25 and 2.12 dS/m under respectively cabbage, potato and fallow (Table 5). For these crops grown during the rainy season, only surface water is used if irrigation is necessary; rain compensates a good part of their water needs. The highest (EC) was observed under pepper grown during the dry season (penultimate line, Table 5).

Table 5. Measured (EC) and net revenue within the irrigated area of Diyar-Al-Hujjej during September 2017-August 2019 when surface water is available on medium amounts for different crops

Years	First year		Second year		
Crops season	Sep 2017-May 2018	June –August 2018	Sept-dec 2018	Dec-April 2019	May-August 2019
Crops	Strawberry	Pepper	Rainfed cabbage	Potato	Fallow
Measuerd (EC) (dS/m)	1.6	3.5	1.15	1.25	2.12
Anual average (EC) (dS/m)	2.55		1.7		
(EC) for a complete cycle: Sep 2017-august 2020	2.02				
Net water requirements	3,600	6,000	-	1,345	-
Water cost	180	300	-	67	-
Crops production cost	6,000	700	-	1,767	-
Crops yield	55	18	-	22	-
Measuerd (EC) (dS/m)	1.6	3.5	-	1.25	-
Relative yield (%)	80	78	-	100	-
Agricultural production (ton/ha)	44	14	-	22	-
Selling price	0.300	0.108	-	0.133	-
Value of agricultural production	13,200	1,512	-		-
Net revenue	7,020	512	-	2,926	-
Annual net revenue	7,532		2,926		

The net revenues were 7,532 and only 2,926 US $/ha during the first and the second year (last line, Table 5), the profitability of the combination strawberry-pepper is clear. For farmers having only surface fresh water, the net revenues were 7,770 and

5,482 US $/ha respectively for the first and the second year (Table2). Salt brought under strawberry is 3,600 kg/ha while it is 6,000 kg/ha for pepper (three times) while the net income of strawberry is more than fourteen times that of pepper.

3.3. Case of farmers having an important volume of surface water and large irrigated areas

They are full time farmers and they are often large tenants of lands. They over-irrigate to leach salt as much as possible. The strawberry-pepper combination is kept often two years; there after more resistant crops are grown. (EC) measured under strawberry was only 1.53 dS / m in May 2018 (line 4, Table 6) because only surface water is used, the relative yield is about 80% calculated by using equation (1). The rains contribute to the water requirements and often salt leaching is present. A little increase in (EC) (2.2 dS / m) under pepper in August 2018 was measured (line 4, Table 6), the pepper being irrigated with surface water or blended water if surface water is missing. Farmers are aware that soil salinity must remain low to be able to keep the strawberry-pepper association for another year. For these farmers, given the medium (EC) measured and as the strawberry plants are expensive and are imported (plant cost is about 0.2 USD and the need of one hectare is about 30,000 plants), this combination was kept for a second year but (EC) measured during the end of the second year was high compared to the first year (4.7 dS/m under pepper in August), (line 4, Table 6), (Fig. 2, green curve). A reduction of field yield is observed. By using equation (1), relative yield is only 40% for strawberry. Already, in recent years, if a cycle of drought is observed and in the absence of heavy rains in September, the strawberry-pepper association has been removed at the end of the first year.

Given the high salinity, crops less sensitive to salinity such as cabbage, potato, squash or rainfed crops are grown in the third year; a decrease in salinity was observed. Average annual (EC) was 2.36 dS/m for the third year while it's 4 dS/m for the second year (line 5, Table 6). These farmers are all tenants and they have large irrigated areas; they don't stop practicing the strawberry-pepper association but on other parts of their irrigated area. One of the tenants, with whom we conducted the experiments, rented a total area of 33 ha and had 12 hydrants and 5 wells. He has access even to water from a nearby little dam (Lebna), which has very good water quality.

The profitability of the combination strawberry-pepper is clear; the net revenue for the second year is low compared to the first year but it's two times more than this of the third year; the net revenues were 8,331; 4,150 US $/ha for the first and the second year when strawberry is present while it was 2,094 US $/ha during the third year when only other crops were grown (last line, Table 6). This advantage in income under strawberry-pepper encourages farmers to keep this combination for a second year. Some farmers rent large land just to have several surface water hydrants at their disposal and they can practice the strawberry-pepper combination annually.

Table 6. Measured (EC) and net revenue within the irrigated area of Diyar-Al-Hujjej during September 2017-August 2020 when surface water is available on important amounts under different crops

Years	First year		Second year		Thirdyear		
Crops season	Sep 2017- May 2018	June August 2018	Sep 2018- May 2019	June- Aug 2019	Sept - Dec 2019	Dec – April 2020	May- August 2020
Crops	Strawberry	Pepper	Strawberry	Pepper	Rainfed cabbage	Potato	Squash
Measuerd (EC) (dS/m)	1.53	2.2	3.31	4.7	2.47	2.12	2.5
Anual average (EC) (dS/m)	1.86		4		2.36		
(EC) for a complete cycle: Sep 2017- August 2020(dS/m)	2.74						
Net water requirements (m^3/ha)	3,600	6,000	3,600	6,000	0	1,345	7,174
Water cost(US $/ha)	180	300	180	300	0	67	359
Crops production cost(US $/ha)	6,000	700	3,000	350	-	1767	700
Crops yield (tons/ha)	55	18	55	18	-	22	25
Relative yield (%)	83	88	42	58	-	85	100
Agricultural production (ton/ha)	46	15.8	23	10	-	18.7	25
Selling price(US $/kg)	0.300	0.108	0.300	0.108	-	0.133	0.1
Value of agricultural production(US $/ha/ton)	13,800	1,711	6,900	1,080	-	2,487	2,500
Net revenue (US $/ha)	7,620	711	3,720	430	negligible	653	1,441
Annual net revenue (US $/ha/year)	8,331		4,150			2,094	

4. **Synthesis analysis**

When surface water is available on medium or important amounts, average (EC) for a complete cycle is less than 3 dS/m while it's more than this value when only saline water or little amounts of surface water are available (fourth column, Table 7). Measured (EC) under tomato irrigated with saline or when surface water is present on little amounts were more than 5 dS/m (Tables 3 and 4). Even if salinities increase during the irrigation season and decrease during the rainy season; very high (EC) were measured under crops during the irrigated season and which are the cause of drop in yields. (EC) increases from 3 to more than 8 dS/m within the surface layer between the start and the end of the tomato irrigation season (Saidi et al. 2018). Salinity management is directly linked to irrigation management and scheduling. In our irrigated area, (EC) was measured on February 26th, 2021, within two irrigated plots, (i) in the first plot, crops rotation (irrigated crops, rainfed crops and fallows) were applied during 2016, 2017, 2018 and 2019 but surface water was used with a low (EC) of less than 1 dS / m, and (ii) in a neighboring rainfed area (during all the cycle 2016-2019). (EC) varied between 1.7 and 1.9 dS / m for the first case and it's about 1.5 dS / m for the second case; not so different when salt tolerant crops were grown. Farmers need to be convinced that rational irrigation water management is important both to the welfare of farmers and the environment (Lazaridou et al. 2019). Even if (EC) measured under crops reached almost 6 dS/m, we see that for total crops cycle, the (EC) was less than 4 dS/m in all cases (fourth column, Table 7); hence the interest of the introduction of crops rotation. Keeping soil under rainfed crops reduce soil salinity, besides other advantageous. Crops rotation breaks the cycle of harmful organisms affecting crops by restricting pathogens and weeds (Leteinturier et al. 2007). In our irrigated area, potato grown after a cabbage is of good quality compared to the potato grown after the strawberry-pepper combination (it has blackish spots) after the Diyar-Al-Hujjej framers and some samples were noted by ourselves. During the last five years (2016-2020) surface water transfer is negligible (Tab. 1) compared to crop water requirements (2,500,000 m^3). The water table depth is 20.5 m; measured surface water and groundwater (one well) (EC) were respectively 2.2 and 4.42 dS/m on 2th December 2020. No significant change in water table depth since 2000. On February 26 th, 2021, (EC) of surface water, blended water and wells are respectively 2.82, 3.08 and 4.63 dS/m.

Growing strawberry-pepper on second year leads to high salinity (4 dS/m, (penultimate line, third column, Table 7) even if surface water is available on important amounts but farmers opt for this solution saw the net income achieved when strawberry is grown (last column, Table 7). Net revenue obtained with 50% of strawberry yield is higher than any other net revenue obtained with other crops even under low salinity. When only saline water or surface water is available on little amounts, not only net revenue is less than 1,850 US $/ha but also quantities of salt brought were high, reaching 18,102 kg/ha/year (columns 5 and 6, Table 7). In San Joaquin Valley, only 2,000 kg salt/ha is added to irrigate summer crops (cotton, alfalfa) if a high quality irrigation water is used (Kenneth et al. 1986). Extension services should recommend stopping this type of irrigations; over-exploitation of the aquifer leds to sea intrusion.

The net annual revenue is generally greater than 5,000 US $/ha/year when strawberry is present while it is less than 2,000 US $/ha/year when this crop is absent (last column, Table 7). For this crop, a large-scale processing industry must be set up to absorb the over-production of a rapidly deteriorating crop.

Table 7.Measured (EC), salt brought and net revenue within the irrigated area of Diyar-Al-Hujjej during September 2017-August 2020 under different crops rotation and for different water sources

Source water available	Crops rotation	Annual (EC) (dS/m)	(EC) for a complete cycle: Sep 2017-August 2020 (dS/m)	Quantities of salt brought (tons/ ha)	Average annual quantities of salt brought (tons/ ha/year)	Net revenue (US $/ha)	Average annual net revenue (US $/ha/year)
Only surface water	Strawberry-Pepper(2017/2018)	1.9	2.25	9,600	9,240	7,770	5,262
	Strawberry-Pepper(2018/1019)	2.9		9 600		5,482	
	Potato-squash (2019/2020)	1.95		8,519		2,534	
Only saline water	Rainfed barly-processing tomato - fallow (2017/2018)	3.63	3.03	13,658*	13,658	1,168	1,145
	Rainfed barly - processing tomato - fallow (second year) (2018/1019)	3.7		13,658*		1,123	
	Rainfed wheat - Fallow (third year) (2019/2020)	1.76		-	-	negligible	
Saline water + surface water on little amounts	Rainfed wheat- (Tomato or pepper) (2017/2018)	3.6		16,207(= (15,600 +16,814)/2)	16,207	1,386	1,386
	Rainfed wheat- (Tomato or pepper) (2018/1019)	3.7	3.65	16,207(= (15,600 +16,814)/2)		1,386	
	Rainfed bean (as a green mannure) - Potato- Tomato or Pepper(2017/2018)	3.3		17,552(=1,345+ 16,207)	17,183	2,212 (=826+1386)	1,799
	Rainfed barly-Tomato (2018/1019)	3.9	3.6	16,814		1,386	
	Rainfed cabbage - Potato- Squash-Fallow(2017/2018)	3.34	3.75	19,997 (=1,345+ 18,652)	18,102	2,375(= 826+1549)	1,850
	Fallow- (Tomato or Pepper) (2018/1019)	4.16		16,207(= (15,600 +16,814)/2)		1,326	
Saline water + surface water on medium amounts	Strawberry-Pepper(2017/2018)	2.55		9,600	5,473	7,532	5,229
	Rainfed cabbage - Potato-	1.5	2.02	1,345		2,926	

	Fallow(2018/1019)						
Saline water + surface water on important amounts	Strawberry- Pepper (2017/2018)	1.86	2.74	9,600	9,240	8,331	4,858
	Strawberry- Pepper (2018/1019)	4		9,600		4,150	
	Rainfed cabbage - Potato-Squash(2019/2020)	2.36		8,519		2,094	

(*) for processing tomato grown on early season, only half of these water requirements are assumed to be supplied by groundwater, the other half is supplied by rain.

All the dry season crops must be discarded and replaced by crops whose water needs are partly met by rain such as artichoke, a crop very tolerant to salinity and highly sought after for export. Also, the sensitivity of crops to salinity depends on the vegetative stage; the effect of irrigation with saline water in development stages is low (Ashraf and Harris 2004). Tomato and pepper under green house can constitute another alternative especially as these crops are profitable even if desalination is introduced and this is a region where the greenhouse activity already exists. Other irrigation techniques must be introduced. Subsurface drip irrigation (SDI) reduce evaporation losses during the pre-plant and early-season periods and improve water storage efficiency and crop yield even at low irrigation capacity (Bordovsky 2020). A significant impact in conserving groundwater can be obtained when improved irrigation at a farm level is applied (Ajaz et al. 2020). Additional effort is required from extension services; the profitability and productivity of Boro rice, as well as water productivity, were comparatively higher for focal farmers compared to control farmers (Uddin et al. 2020). The social benefits must be taken in consideration; Ryu et al. (2019) found that when only economic costs and benefits were considered, the benefit-cost ratio for the public system (0.02) was smaller than that for the private system (0.264) while, the results of the two alternatives changed when social benefits were considered. New technologies can also improve water productivity (Mansour and al. 2016).

Conclusion

This perimeter is still managed with old reflexes when only salt water was present; low-income crops (squash, tomato) tolerant to salinity are still grown even though they are the source of strong soil salinization, aquifer over-exploitation and sea intrusion. Choice of crops must be reviewed.

Crops grown during the rainy season (strawberry, potato) and for which a good part of their water needs are met by rain have led to a high net income and a low amounts of brought salt (about 7,000 US $/ha and 3,600 kg/ha for strawberry) compared to the crops grown during the dry season when salt brought amounts were more than 13,000 kg/ha and net revenue was less than 2,000 US $/ha. In the presence of salty water, irrigation management is the key of success of any irrigation project.

The practice of rainfed crops and fallow during the rainy season allowed a salinity reduction within the soil profiles. The salinity measured under irrigated tomato is greater than 5 dS / m while that measured under rainfed wheat or barley is less than 2 dS / m in the same farms.

The economics of natural resources must answer these complex questions, what is better if surface water is missing? (i) growing crops that coincide with the rainy season and/or faster germinating varieties but often with low net revenue (as processing tomato), (ii) accepting a low net income and protect the soil against salinity by growing only rainfed crops and stop sea intrusion but we must think about compensating these farmers, and (iii) are present crops rotations maintain or degrade soils proprieties; an interdisciplinary research is needed?

However, other durable solutions need to be examined on a larger scale, can desalinated water be an alternative if a water social price subsidized by the state will be applied. The case of this perimeter can constitute a roadmap for several other perimeters suffering from lack of water and excessive salinity.

Declarations

Ethics approval and consent to participate

Ethics clearance was granted by Research and Innovation, Office of the Director, University of Venda, Project No: SMNS/19/ZOO/02/0307.

Consent for publication

Not applicable

Availability of data and materials

The datasets used and/or analysed during our study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

DCT conducted the fieldwork and wrote the manuscript. PJT supervised the project, IEJB co-supervised the project. Both PJT and IEJB reviewed and provided invaluable feedback on the manuscript. All authors reviewed the manuscript.

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Figures

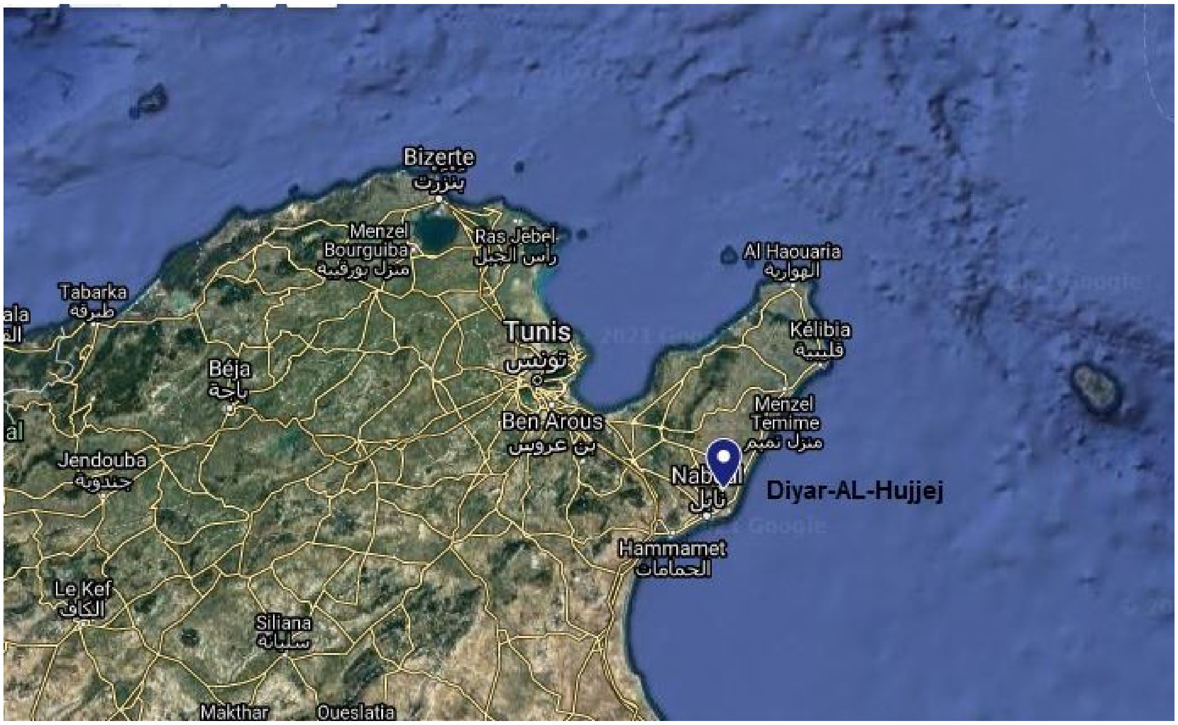

Figure 1

Geographic position of Diyar-Al-Hujjej (Tunisia) (google maps). Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

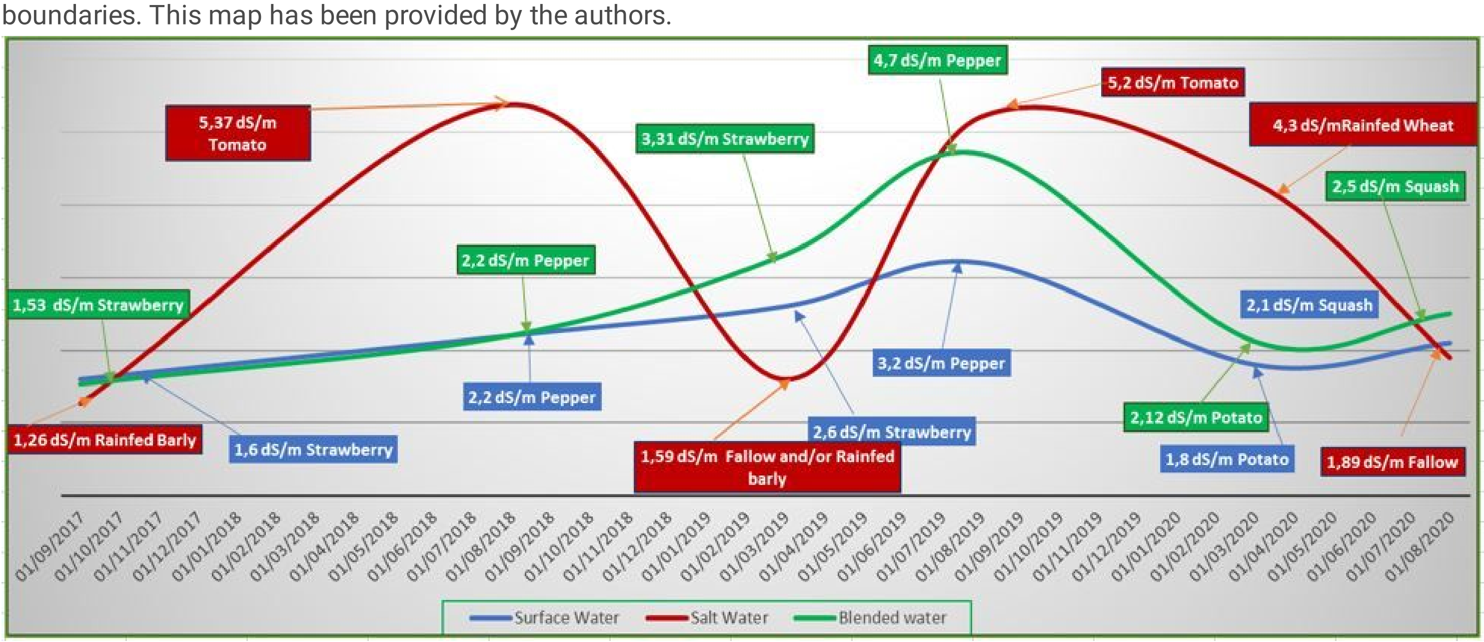

Figure 2

Electrical conductivity (EC) in dS/m measured under irrigated, rainfed corps and fallow in Diyar-Al-Hujjej (Tunisia) during 2017-2020.