Chapter

Effects of Water Scarcity on the Performances of the Agricultural Sector and Adaptation Strategies in Tunisia

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Abstract

The chapter aims to develop a regionally disaggregated agricultural supply model for Tunisia in order to investigate the potential effects of increasing water scarcity on the performances of the agricultural sector in the country, and the structural adaptation strategies needed to face such a challenge. A set of scenarios combining future water availability, water use efficiency, and increasing producer prices were simulated using the developed model. Results show that the agricultural sector in Tunisia, particularly the agricultural employment, would be negatively affected in case of decreasing irrigation water availability, and mostly affected regions would be the north east, central west, and southern areas. However, it is always possible to mitigate such effects through a combination of structural adjustments (changing land use in different regions), enhanced water use efficiency, and support of producer prices. The model also provides recommendations regarding specific crops that should be promoted in specific regions in order to maintain an agricultural sector with high added value in Tunisia.

Keywords: agricultural supply model, mathematical programming, regional level, water shortage, Tunisia

1. Introduction

The impacts of climate change (CC) will be channeled primarily through the water cycle [1], with consequences that could be large and uneven particularly on the agricultural sector. Ref. [1] also entails that some regions could see their growth rate decline by as much as 6% of GDP by 2050 as a result of water-related losses in agriculture, health, income, and property. For the Mediterranean countries, reduction of freshwater availability is predicted to attain more than 40% by the end of this century along the coastal areas [2]. The North African region is one of the regions which will be affected the most by CC, as anticipated by different climate models [3]. The region is already experiencing low rainfall characterized by its high variability, which is influencing agricultural production systems and changing their determinants. Climate model simulations are providing converging results concerning the decreasing trends of rainfall with 10–20% across North Africa [4], with average median decrease reaching 12% [5]. For Tunisia, this rainfall trend will result in a decline of water availability with up to 28% in 2030 [6, 7]. Ref. [1] also reports that water management policies can exacerbate the adverse growth impacts of CC, while good policies can go a long way toward neutralizing them. While CC is one of the major challenges facing humanity nowadays, adaptation frameworks to its, reversible and irreversible, impacts on the natural and human systems have emerged as an urgent need. It is expected to intensify risks related to natural resources availability, particularly in areas where water scarcity is already a concern [8]. In most countries, freshwater scarcity is increasing, forest fires are more frequent because of high temperature, drought is omnipresent and persistent, and desertification rates are growing [9]. Previous reports and analysis have described the Mediterranean region as a CC "hot spot" [10] including the Intergovernmental Panel on Climate Change (IPCC). Agriculture is a climate-sensitive sector subject not only to adverse impacts of CC on natural resources but also on social and economic contexts. Changes in precipitation and warming patterns are witnessed having occurred during the last century [11]. All year round widespread warming and reduction in rainfall are predicted by scientific literature for the twenty-first century [10]. Reduction in precipitation in addition to an increase in evapotranspiration would lead to water shortages particularly in regions where resources are already at a critical level and irrigated cropping areas are increasing. CC is thus contributing to narrowing the gap between water supply and demand [12] which entails more complexity on water resources management in agriculture [8]. CC is reshaping not only agriculture activity patterns but also driving human existence standards, which requires a restructuration of an institutional framework and a policy plan that could be able to mitigate and adapt to CC impacts. Therefore, exploring adaptive pathways [13] and climate policy is becoming a cross-scale central focus for decision and policy makers [14]. Ref. [15] demonstrated the role of regional, national, and global policies and institutions in highlighting adaptation options and tools [16] and that the development of CC adaptation as a policy field is considered as a relevant application context for the establishment of the agriculture policy [17]. In order to assess the implications of potential policy actions and to assist stakeholders in developing adequate measures to improve resilience to CC, [17] prevailed that cost-benefit analysis is a useful assessment tool; bio-economic models are more useful for an ex-ante evaluation of policy interventions by simulating agents' (farmers') behavior on the farm level. However, analyzing CC impacts on agriculture (economic, social, and environmental) requires an approach that is able to provide a detailed picture of the sector, its constituents, and the interactions within it. Agricultural models, can be built on micro-level; bio-economic models or macro-level; studies entailing the whole agricultural sector such as agricultural supply models. Agricultural supply model (ASM) provides a presentation of the agricultural sector by a sequence of behavioral equations whose objective is to maximize regional income subject to technological, environmental, and institutional constraints [17–19]. They treat a wide range of issues in agriculture; ASM has been used to predict and assess the impacts of Europe's Common Agricultural Policy (CAP) or to estimate economic value of water and land [20]. Assessing CC impacts on Tunisian agricultural sector is a propitious research field; hence, by means of an agricultural supply model, it is possible to assess the impact of water scarcity, engendered by CC, on the agricultural sector in the country.

In this chapter, we suggest to look to strategic structural adjustments needed in terms of land use and irrigation in Tunisia to deal with future water scarcity. Structural change in agriculture is defined as being the adjustment of the agricultural sector to the changing conditions of demand and supply [21]. This complex and dynamic process constitutes a reallocation of land use and farm specialization, as well as repositioning of the agricultural sector as compared to other sectors of the economy [21–23]. Within this general framework, the objective of this paper is to simulate the scope of future water scarcity scenarios on the agricultural sector of Tunisia and to provide recommendations on how to reduce its effects through a CC adaptive policy plan. For the following sections, we particularly refer to structural change as being the reallocation of land use and crop specialization among different regions in Tunisia, as well as upon rain-fed and irrigated conditions. A regionally disaggregated agricultural supply model for Tunisia (ASMOT) was developed and used to simulate the effects of declining irrigation water availability on the development of the agricultural sector in different regions of Tunisia. Implications in terms of regional agricultural value added as well as employment in both irrigated and rain-fed sectors were assessed under different water-related scenarios. To our knowledge, ASMOT is the first attempt of disaggregated sector modeling in Tunisia which we aim to further develop and validate in the coming years.

2. Agricultural sector in Tunisia

Agriculture is an important sector in Tunisia contributing to 8.7% of the national GDP and employing around 16.2% of the total employment in the country [24]. Major crops, in terms of cultivated area, are tree crops (especially olives and dates) followed by cereals. While tree crops are strategic for exports (Tunisia is among the top 5 world exporters of olive oil and dates), cereals remain very important for human and livestock domestic consumption. Tunisia is also characterized by low rainfall and limited renewable water resources. It is influenced by the arid and semiarid climate that covers more than three-fourths of its area [25]. The agricultural sector is also highly dependent on water resources since it consumes more than 75% of total water use in the country [26, 27]. Climate variability has major effects on agricultural production in Tunisia which results on highly variable yields along years. Other sectors might also be affected but certainly with much less extent. In fact, according to the Tunisian regulation, urban, industrial, and touristic sectors are prioritized in terms of water use during shortage periods. As an example of this fluctuation, total cereal production went from 2.9 million tons in 1996 to 0.5 million tons in 2002 and again to 2.9 million tons in 2003 [26]. This trend is observed for all cereal crops where the yield of durum wheat varies between 0.5 and 2 tons/ha, soft wheat yield ranges between 0.5 and 2.5 tons/ha, and barley yield is between 0.4 and 1.5 tons/ha. Not only yields are variable, but the cereal and fodder cropped areas are also depending stochastically on the climate conditions. For the expected "bad" years, farmers usually avoid planting cereals which engenders a decrease of both areas and yields. As strategic response to climate variability, the country has started since the early 1970s to expand its irrigated areas in order to ensure more reliable supply of agricultural commodities over the years [28]. This strategy partly succeeded in developing around 450,000 ha of irrigated areas representing around 8% of total agricultural area in the country. Although irrigated area share is low, it reflects the highest surface that can be irrigated by the available water resources, given the current levels of irrigation water use efficiency (IWUE). However, despite their low share in total agricultural land, irrigated areas in Tunisia are producing 35% of the agricultural value added, and they are contributing up to 20% of total agricultural exports and 27% of agricultural employment [26]. Around 48% of these irrigated areas are irrigated from groundwater sources, including both superficial and deep aquifers, allowing the irrigation of 48% of the total irrigated area [28]. Overall water resources in the country are estimated to be only around 4700 million m^3 [7] including 650 million m^3 of nonrenewable resources (13.8% of the total water resources). Surface water is estimated to 2700 million m^3. Another major problem of the agricultural sector in Tunisia is the small farms' size. In fact, average farm size in Tunisia in 2005 was only about 10.2 ha [27]. Total farm number is 516,000 farms, managing an area of 5.3 million ha. According to the same source, in 2005, 54% of these farms have a size lower than 5 ha, and 75% of farms have a size lower than 10 ha indicating the main structural problem facing the modernization of the agricultural sector and the irrigated areas. In this regard, the stabilization of agricultural yields and the decrease of the sector dependency to climate variations are thus necessary for enhancing food security and agricultural trade balance in Tunisia. Many solutions have been proposed including the improvement of farmers' skills, financing, mechanization, intensification, and the extension of the irrigated areas. A structural change, however, is a broader concept that permits the adjustment of agricultural sector not only upon market features but also a more sustainable management of natural resources, land and water, to reinforce resilience to climate variability and food insecurity. This paper actually aims to determine which national structural readjustments are relevant for a more efficient reallocation of resources using a country- and context-specific agricultural supply model and scenarios. The following sections explain in details the model structuring and also present and discuss the outcomes of the study.

3. Methodology and analysis

The ASMOT model is an agricultural supply model that is built based on primary and secondary data of farming inputs and outputs for different crops, regions, and systems (rain-fed and irrigated). ASMOT is the first regionally disaggregated ASM developed for Tunisia. The model includes 21 of the most strategic crops of the country (including the most important cereals, trees/fruits, and vegetables). It also includes a representation of 67% of the total agricultural areas of Tunisia (around 3.34 million ha) and 78% of the total irrigated areas (around 352,000 ha). The ASMOT model is built based on regional disaggregated data, including 24 governorates of Tunisia. These governorates have been aggregated into five regions (North West (NW), North East (NE), Center West (CW), Center East (CE), and South (SO)) based on bioclimatic homogeneity (**Figure 1**).

The model was calibrated through Positive Mathematical Programming (PMP) [29] and using official 2011 data about observed crop areas by region and system (irrigated/rain-fed) as recorded by the Ministry of Agriculture, Hydraulic Resources and Fisheries of Tunisia [30]. Regional irrigation water availability was also included into the model based on official secondary data about existing water reservoirs in the different regions of the country.

Regional agricultural value added are optimized by ASMOT and aggregated into a national domestic agricultural value added. Various types of biophysical and economic constraints are considered in parallel to this optimization process. These can be found in the next section presenting the main mathematical structure of the model. The model also considers crop evapotranspiration and their respective effect on yield gaps. The different crops and regions included in the ASMOT model are shown in **Table 1**.

3.1 Structure of the ASMOT model

The aggregated agricultural supply (Eq. (1)) of the model calculates the aggregated gross value of agricultural supply (AS) in Tunisia as the sum of regional agricultural gross production values (RAS). Eq. (1) can be read as follows:

$$AS_{c,s} = \sum_{r} RAS_{r,c,s} = \sum_{r} \{[P_c * (Y_{r,c,s} - \Delta Y_{r,c,s})] - [AC_{r,c,s} + WP_r]\} * X_{r,c,s} \quad (1)$$

where ASc,s is the total agricultural supply of different crops (c) and systems (s). Systems can either be rain-fed (rai) or irrigated (irr). RASr,c,s indicates the regional agricultural supply by region (r), crop (c), and system (s). Pc is the producer price of crop c; Y is the yield expressed by region, crop, and system; and

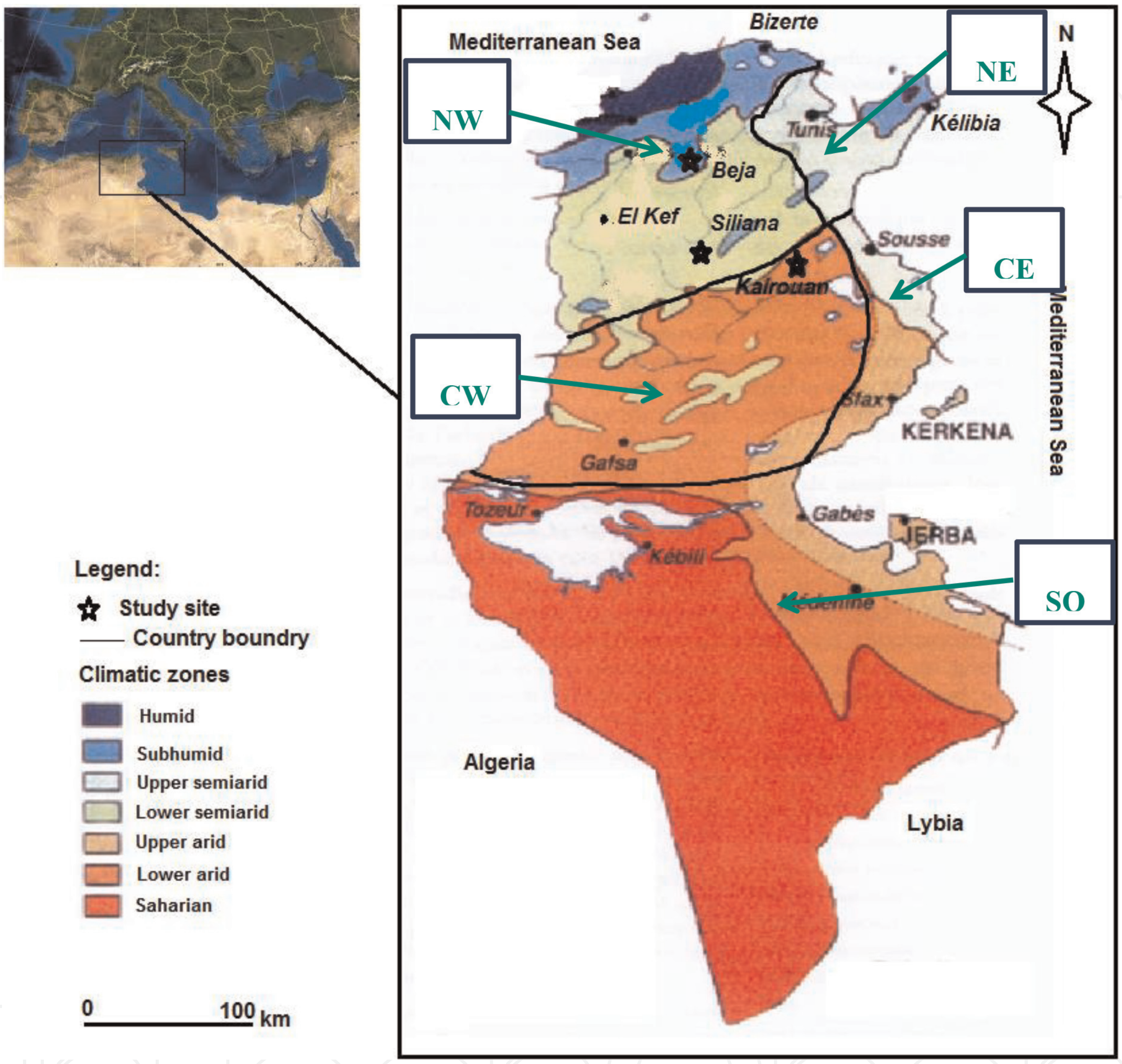

Figure 1.
Different bioclimatic regions in Tunisia.

Crops	Governorates and aggregated regions
Durum wheat, soft wheat, barley, olive, almond, palm date, citrus, grape, peach, apple, pear, grenade, tomato, potato, pepper, onion, garlic, artichoke, melon, watermelon, strawberry	North West (NW) (Bizerte, Beja, Seliana, Le Kef, Jendouba) North East (NE) (Nabeul, Ariana, Manouba, Ben Arous, Zaghouan) Center West (CW) (Sidi Bouzid, Kasserine, Kairouan, Gafsa) Center East (CE) (Sfax, Mahdia, Monastir, Sousse) South (SO) (Tozeur, Kebili, Tataouine, Médenine, Gabes)

Table 1.
Different crops and regions considered by the ASMOT model.

ΔY is the variation of yields which can be due to water stress (higher temperatures and evaporations). AC is the average cost of crop production excluding water costs. AC is expressed by region and system. WP is the irrigation water price in different regions. Finally, Xc,r,s is the positive variable of the total area for crop (c) under system (s) and in region (r). Observed Xc,r,s of the year 2011 was used for the calibration of Eq. (1). Once calibrated, X becomes variable and can be optimized under different scenarios. Yield variation ΔY is calculated as follows:

$$\Delta Y_{\mathrm{r,\,c,\,s}} = \mathrm{Y} * \mathrm{ky} * \left(1 - \frac{\mathrm{Eta}}{\mathrm{ETM}}\right) \tag{2}$$

where *ky* is the yield variation coefficient, which has a constant value for each crop, and Eta and ETM are, respectively, the real and maximal evapotranspiration:

$$\sum_{c,\,s} X_{r,\,c,\,s} \leq A_r \tag{3}$$

Constraint 3 is a land constraint, indicating that the total cultivated areas in each region should not, in the short term, exceed the currently observed agricultural areas (A_r):

$$\sum_{c,\,(s=irr)} X_{r,\,c,\,s} \leq IA_r \tag{4}$$

Constraint 4 indicates that the sum of crop irrigated areas in each region should not exceed the total irrigable areas (IA_r) available in that region:

$$\sum_{(c=trees),\,s} X_{r,\,c,\,s} \leq TA_r + (1 + \gamma_{c=trees}) \tag{5}$$

Constraint 5 bounds the annual tree area expansion to the observed annual growth rates of these areas in Tunisia during the last two decades which is about 5%. This constraint is also set at the regional level, where TAr is the current tree area in region r and γ is the annual growth rate of tree areas which is set to be equal to 5%:

$$\sum_{c,\,s} w_{r,\,c,\,s} * X_{r,\,c,\,s} \leq WA_r \tag{6}$$

Constraint 6 indicates that the sum of water requirement of all crops cultivated under different systems in a given region ($W_{r,c,s}$) should not exceed the water availability in that region (WA_r):

$$X_{r,\,c,\,s} \leq X^{o}_{r,\,c,\,s} * (1 + \varepsilon) \tag{7}$$

Finally, constraint 7 is a calibration constraint which was used in the first PMP step in order to estimate the cost function calibration coefficients ($\alpha_{r,c,s}$ and $\beta_{r,c,s}$). The average cost AC function is a nonlinear expression (Eq. (8)) estimated using two main calibration coefficients ($\alpha\alpha_{r,c,s}$ and $\beta_{r,c,s}$) which were calculated by solving Eq. (1) under the set of all considered constraints (3–7), including the calibration constraint [31, 29]. Coefficients $\alpha\alpha_{r,c,s}$ and $\beta_{r,c,s}$ were calculated using the dual values of constraint 7, and following the approach of [31, 32], where exogenous information about land rents was used for estimating the values of α and β. These PMP approaches have been widely validated and used for different sectors and other farm-type modeling and calibrations [33–39]:

$$AC_{r,c,s} = \alpha_{r,c,s} + \beta_{r,c,s} \, \mathrm{X}_{\mathrm{r,\,c,\,s}} \tag{8}$$

Eq. (8) was replaced by Eq. (1) which will generate a calibrated nonlinear objective function. To validate the calibrated model, we optimize Eq. (1) under all constraints while excluding the initial calibration in Eq. (7). If the resulting model will generate the same land allocation observed during the base year, then we can assume that our model is well validated and can be used for scenario simulations. ASMOT validation and calibration performances are presented in the result section.

3.2 Source of data

The data used for the ASMOT model was of different types and thus collected from various sources. Specific crop input and output levels for different regions and systems were collected through farmer questionnaires which were conducted for the season 2012–2013, in all regions of Tunisia in the framework of the Eau Virtuelle et Sécurité Alimentaire en Tunisie(EVSAT, funded by the IDRC) research project. Many focus groups with regional experts in crop production were conducted afterward in order to revise the average input and output values in respective regions and systems for all considered crops. Some coefficients of the model, such as the annual growth rates of tree crops, were calculated using FAO data [40]. Other secondary data regarding water availability, initial crop area distribution, irrigated areas, etc. were collected from official national datasets, especially available at the level of [30]. Water requirements in addition to evapotranspiration coefficients of different crops in different regions and systems were measured by the EVSAT research team through field experimentations.

3.3 Water scenarios

In relation to the overall objective of the chapter, our scenario development considers the current water scarcity situation faced by Tunisia, where water availability is expected to decrease by 28% at the end of the next decade [6]. Based on this, our first scenario suggests a cut of water availability by 25%, while second and third scenarios will consider improvements of IWUE and producers' prices as possible options to deal with this shortage and offer market incentives to enhance farmers' adaptation capacities. Only 69% of the total irrigated areas in Tunisia are fitted with water-saving technologies, thus leading to an average water use efficiency of about 55% at the national level [41]. This shows a wide scope to improve IWUE through appropriate investments in the farmer's skills and modernization of the irrigation networks. On the other side, it is well known that better integration of farmers along commodity value chains may offer enhanced producer prices [42], which can be considered as market incentives allowing farmers to enhance their technical investments and adaptation capacities [43, 44]. Based on these arguments, scenarios which were simulated using the ASMOT model can explicitly be read as follows:

- Scenario 1. Cutting total fresh water availability by 25%. This reduction is supposed to be the same across all regions of the country.

- Scenario 2. Cutting total fresh water availability by 25% and improving IWUE by 10%. The improvement of IWUE is interpreted in our modeling as a decrease of water volumes applied for different crops by 10%.

- Scenario 3. Cutting total fresh water availability by 25%, in addition to an increase of IWUE with 10% and higher producer prices offered to farmers. The suggested increase of producer prices are as follows: +5% for cereal prices and +10% for fruits and vegetable prices.

4. Results

After calibrating the model using real 2011 data and by estimating the calibration coefficients of the average cost function (Eq. (8)), the model was validated by running a status quo scenario and checking for consistency of the results compared to the observed values of land use. The result of this test showed that deviations of simulated land use variables ($X_{r,c,s}$) compared to the observed values of 2011 are all in the range of [−1%, +1%] (**Figure 2**) meaning that the model is performing well [37].

This validation test shows that ASMOT is performing well and can thus be used for scenario simulation. The next step is to reformulate and modify appropriate equations in the model in order to be able to simulate the scenarios presented in Section 2.3. Economic, social, and environmental outcomes of these scenarios are presented in the following sections.

4.1 Optimal land and water use under different scenarios

As discussed earlier, ASMOT optimizes the national agricultural value added and provides optimal regional land allocations for different crops and systems. These needed changes of land use in Tunisia allowing for optimal agricultural performances under a situation of water scarcity were purely calculated based on economic incentives corresponding to crop yields, costs, and incomes in the different regions and systems of Tunisia (**Table 2**). Results in **Table 2** show the overall trend of land use under different scenarios (SC1, SC2, and SC3).

Table 2 shows that trends of SC1 and SC2 are consistent but in most cases different from trends suggested under SC3. For the case of cereals, both SC1 and SC2 suggest important cuts of cereal areas in NW and CW and an increase of these areas in NE and SO regions. However, cereal areas are suggested to be reduced in all areas (except SO) under SC3. The same scenario 3 is also more favorable for expanding olives, almond, irrigated fruit trees, and vegetable areas in the different

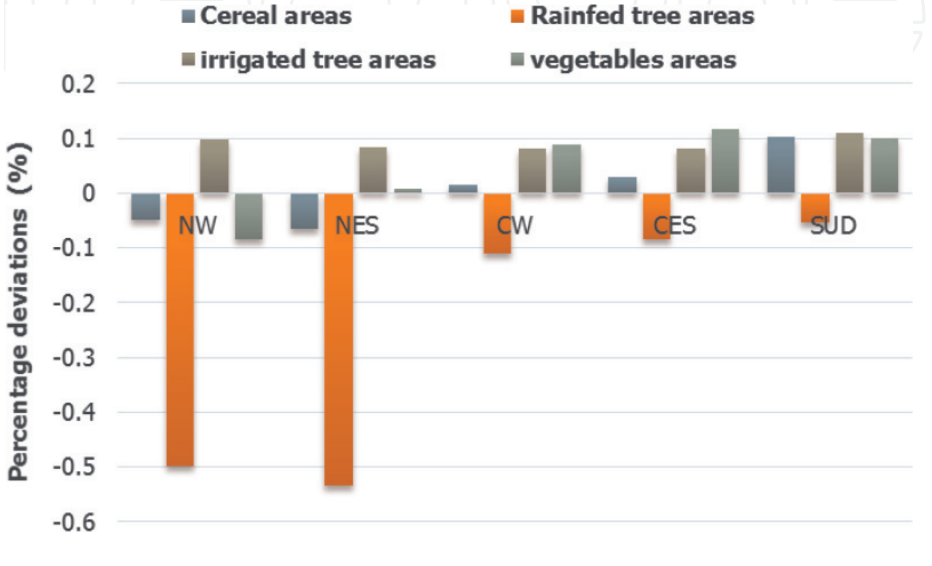

Figure 2.
Percentage deviation of simulated vs. observed crop areas in different regions included in the ASMOT model.

Type of crops	Regions	Percentage deviations compared to the status quo situation		
		SC1	SC2	SC3
Cereal crops	NW	−0.28	−0.06	−0.75
	NE	2.21	0.77	−1.39
	CW	−8.25	−3.37	−6.69
	CE	−0.01	0.03	−0.14
	SO	0.52	0.26	0.59
Olives and almond	NW	−0.8	−0.4	1.6
	NE	3.8	2.1	3.3
	CW	2.2	1.0	1.5
	CE	−0.1	0.0	−0.1
	SO	1.7	0.3	0.0
Irrigated fruit trees	NW	6.2	1.4	8.7
	NE	−8.0	−3.8	0.2
	CW	−5.2	−3.4	2.7
	CE	0.7	−0.6	3.4
	SO	−11.7	−2.3	−1.8
Vegetable crops	NW	8.0	2.9	4.8
	NE	−17.0	−7.3	−5.4
	CW	−4.1	−2.7	−0.6
	CE	7.5	2.7	7.5
	SO	4.6	2.2	8.1

Table 2.
Percentage change, compared to baseline situation, of the main crop areas under different scenarios (aggregated changes of rain-fed and irrigated systems).

aggregated regions. The highest area reductions recorded under SC1 and SC2 are these of cereals in CW; irrigated fruit trees in NE, CW, and SO; and vegetable crops in the NE. Under SC3, the highest area reductions were however recorded for cereals in CW and vegetable crops in NE.

4.2 Irrigation water demand under different scenarios

Total water use for irrigation under different scenarios in Tunisia was estimated based on optimal changes of land use as suggested in **Table 2** (see **Figure 3**). In the baseline scenario, around 2086.6 million m^3 of water is used for the total irrigated area considered in ASMOT (78% of the total irrigated areas, around 352.9 thousand ha) with an average use of 5912.1 m^3/ha (**Figure 3**). Under the first, second, and third scenario, total water consumption, respectively, decreases to 1876.5, 1818.1, and 1833 million m^3. By considering the new irrigated areas under each scenario, these decreases led to average water consumptions of 5949, 5349.7 , and 5385.8 m^3/ha. Total water saving under the second scenario is about 268.5 million m^3, which corresponds to around 13% of the total water use in the baseline situation. These numbers are showing that effective water management in the irrigated areas in Tunisia can mitigate the effect of water scarcity and even generate agricultural economic growth if accompanied by appropriate economic incentives.

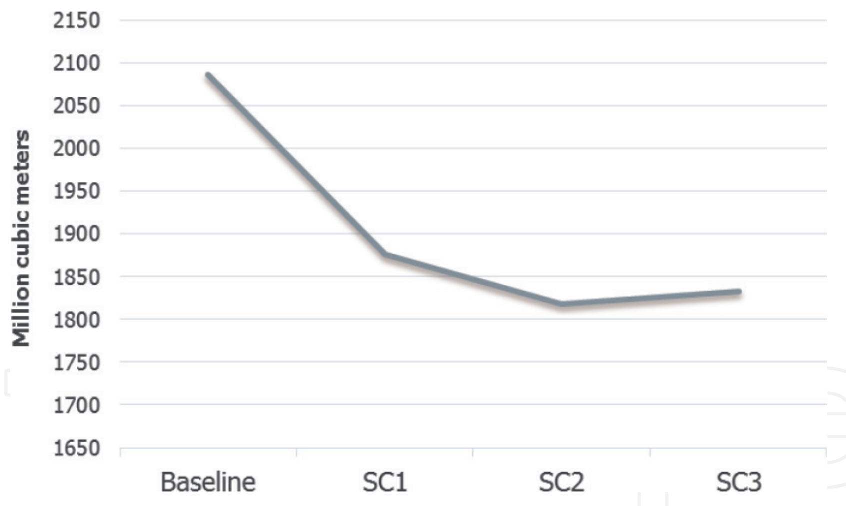

Figure 3.
Total water use for irrigation under different scenarios.

4.3 Impact on agricultural value added

ASMOT provides information about the total value added of its respective agricultural land area as the most aggregated results calculated based on optimization of these values at regional levels. This result can be calculated and presented for separate scenarios. For our particular case, the optimization process shows that Tunisia can overcome the problem of water scarcity (**Figure 4**) through specific structural changes of land use among crops, systems, and regions, as suggested in **Table 2**. **Figure 4** shows that agricultural value added in Tunisia will decrease with only 0.76 and 0.16%, respectively, under SC1 and SC2. However, these slight changes can only be possible if structural adaptations of the Tunisian agricultural sector, based on specific land use reallocations, are adopted as shown in **Table 2**.

Scenario 2 shows that with 10% increase of IWUE, the cut of water availability can be effectively mitigated, with an agricultural value added remaining almost equal to the status quo situation. If producer prices will further be supported (+5% for cereal crops and +10% for fruits and vegetable crops), the agricultural value added in Tunisia can even be 13% higher than the baseline situation, despite the sharp water cut considered. This higher value added of SC3 is not only due to the suggested price inflation but also to the restructuring of land use and the

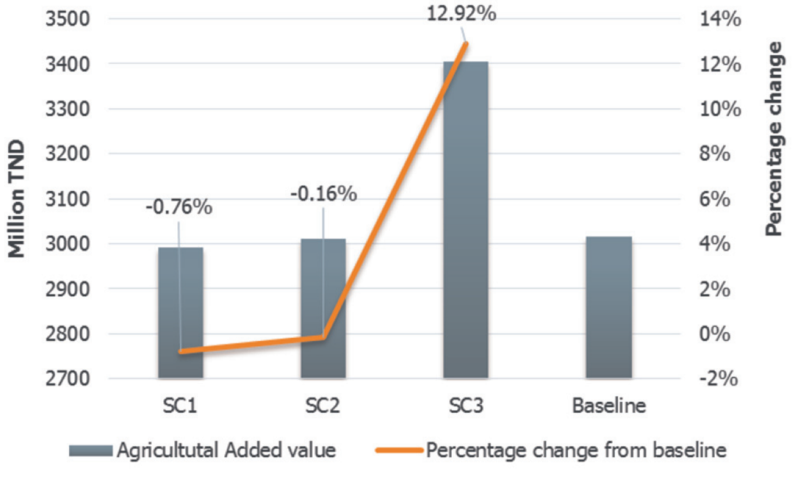

Figure 4.
Effect of water scarcity scenarios on the national agricultural value added.

decrease of total water use under this scenario. In fact, irrigated areas will decrease the most under SC3, and the average water use by hectare of irrigated land will also be 9.5% lower than SC1. Furthermore, the average price inflation considered under SC3 is only about 7.5%, with a maximum of 10% for vegetables and fruits. This price increase generated a higher and nonproportional increase of the value added (+13%), showing a relevant and positive and environmental effect of this price instrument.

Figure 5 shows a geographical distribution of changes in total agricultural value added among the considered regions, under different scenarios. It also shows the respective trends of these values among rain-fed and irrigated sectors. The figure shows that irrigated agriculture in Center West and North East of Tunisia is mostly affected by water scarcity. However, the contribution of the rain-fed agriculture in these two regions is also expected to grow which will partly overcome the negative effects of the decrease of irrigation value added.

4.4 Social effect of water scarcity scenarios

In this section we provide an overview of changes in labor demand under different scenarios compared to the baseline situation. **Figure 6** shows that despite the optimization of land use and agricultural value added, agricultural labor

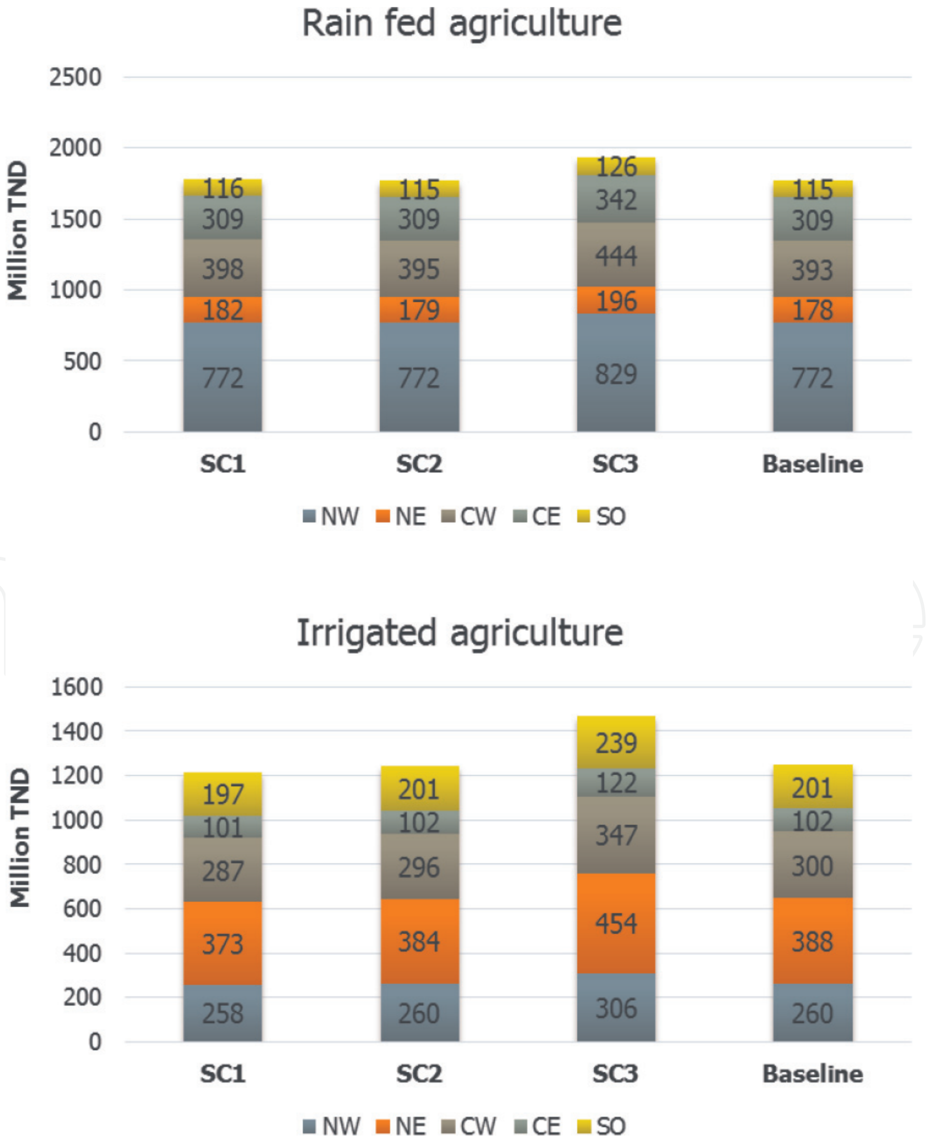

Figure 5.
Changes of regional agricultural value added under different scenarios in Tunisia (million TND).

demand will still be negatively affected under both SC1 and SC2, with respective decreases of 0.7 and 0.18% compared to the baseline situation. The same figure shows that this decrease of labor demand is exclusively recorded for irrigated areas and can reach–5.91% in these areas under the first scenario. The third scenario shows however that overall agricultural labor demand in Tunisia can increase with

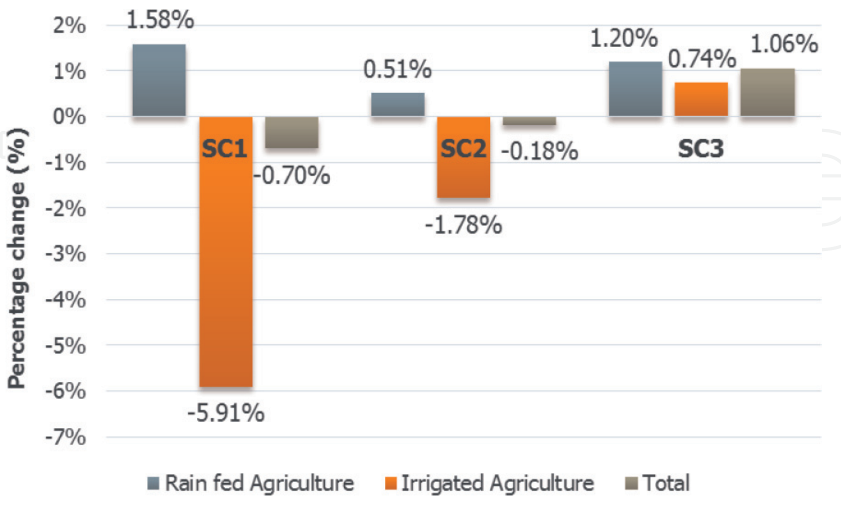

Figure 6.
Effect of different scenarios on regional agricultural labor demand (percentage changes compared to baseline).

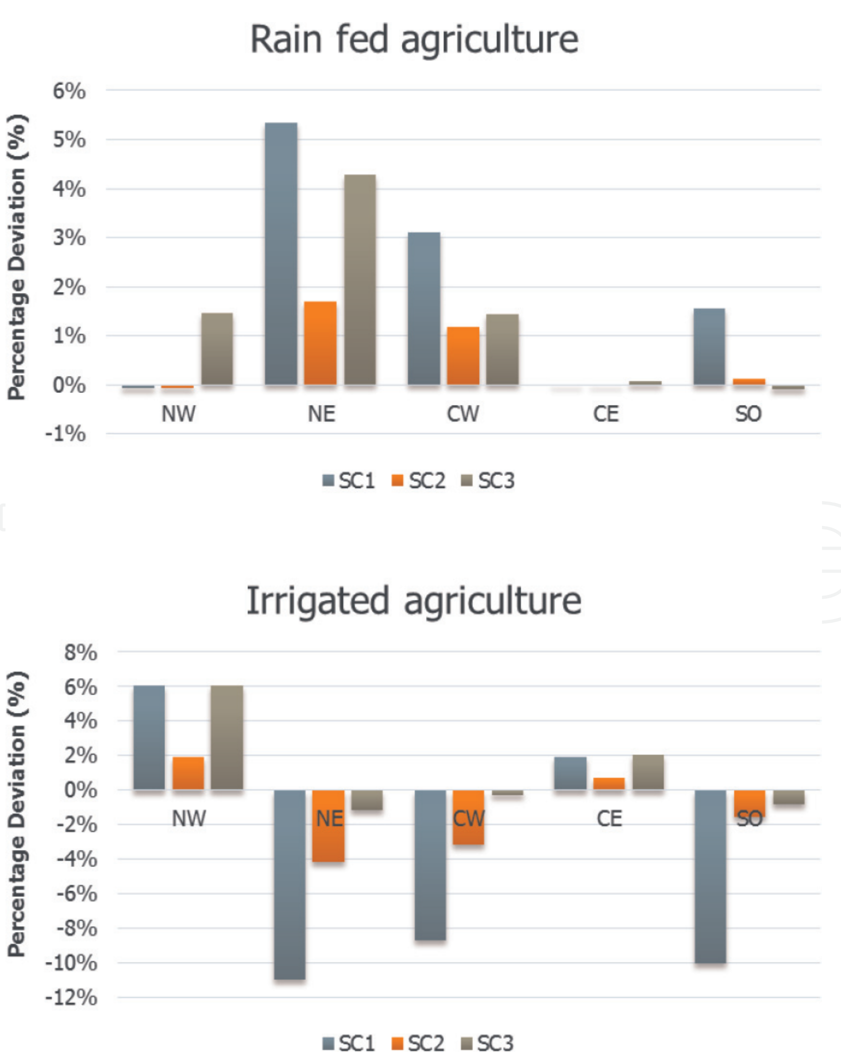

Figure 7.
Effect of different scenarios of regional agricultural employment under different scenarios (percentage change compared to baseline).

about 1.06% (around 8500 employment), despite the water scarcity situation. It is important to notice that, in opposite to SC1 and SC2, labor demand will increase under SC3 for the irrigation sector despite the decrease of the irrigated areas under this scenario (−3.6%).

Similar to the agricultural value added, labor demand in agriculture will disproportionally be affected along the different regions of Tunisia. **Figure 7** captures most of these regional effects for both rain-fed and irrigated sectors. Despite the negative trend of labor demand in the irrigated sector, the restructuring of irrigated areas in the North West and Central East of Tunisia may generate slightly higher employment while at the same time maximize the value added of this sector. Furthermore, results show that labor demand in irrigated areas of South Tunisia will be decreasing even under the third optimistic scenario.

5. Discussions

The scope of enhanced IWUE was proven through our analysis to be highly effective in mitigating the effects of water scarcity in the different regions of Tunisia. Better IWUEs (SC2) are allowed for lower decrease of irrigated areas than the no IWUE scenario (SC1). In the NE region, these decreases were, respectively, −15 and −6% under SC1 and SC2. At the national level, irrigated areas decreased with −10.6 and −3.7%, respectively, under SC1 and SC2. This is showing a wide scope of IWUE to improve irrigation performances and sustain irrigation. However, IWUE can be defined at different scales including user/scheme and basin levels. Through our modeling framework, we only captured benefits of IWUE in terms of water saving. However, in addition to the benefits captured by our model in terms of water saving, physical efficiency at the user/scheme level will also be translated into increased water productivity (or economic efficiency) [45]. Mechanisms to reallocate saved water elsewhere in the water economy will further be necessary to enhance basin-level efficiency. On the other hand, only improvement of IWUE through better technology and management can generate real water savings [45]. Hence, in order to improve IWUE, some measures could be considered such as assisting farmers by providing enhanced knowledge about better irrigation scheduling of optimal amounts of applied water. Another measure would be related to better management of irrigation systems at the field and the landscape levels.

Without substantial improvement in the productivity of rain-fed agriculture, and despite a considerable expansion of cropped area, irrigated area would have to increase close to 500 million ha globally to meet the expected food demand, entailing a doubling of water use [46]. However, it is unlikely that suitable natural resources for such expansion might be available and the increase of agricultural productivity in both rain-fed and irrigated agriculture is necessary to meet such a global food demand. In Tunisia, our results show that rain-fed agriculture might be a good alternative for mitigating the effects of future water scarcity. In fact, value added of this sector was stable over the different scenarios, and it also showed a good potential for absorbing unemployment from the irrigated sector.

The overall effect of the water shortage scenarios on employment is negative, but this negative effect can widely be mitigated and improved if producer prices can be increased. Increased producer prices do not necessarily entail higher consumer prices but can simply be implemented through enhanced management, regulation, and control of agri-food value chains. This is in line with the suggestion that better integration of farmers along commodities value chains may offer enhanced and more equitable producer prices [42], which can in turn be considered as a type of market incentive for farmers and can be used to promote specific agricultural productions [43, 44].

6. Conclusions

In this chapter, we used an agricultural supply model to simulate the effect of water scarcity on agricultural production in Tunisia. We simulated three scenarios related to (i) cutting irrigation water availability, (ii) cutting irrigation water availability accompanied by relative improvement of irrigation water use efficiency, and (iii) scenario 2 in addition to enhanced producer prices for farmers. Results were overall showing that mitigating a shortage of irrigation water in Tunisia is possible through readjustment of irrigated and rain-fed areas and better allocation of crops among regions and systems (irrigated vs. rain-fed). Results also show that the best scenario which has a significant effect on agricultural value added is the third one. Under this scenario, agricultural employment in the overall agricultural sector can even increase. We strongly recommend that the "national agricultural map" already developed by the Tunisian government could be revised using further socioeconomic data and applied for an optimal allocation of crop areas across the country. We further recommend that more work should be done on better performing the structure and the functioning of the strategic agri-food value chain in Tunisia, allowing better marketing margins for farmers which will thus be translated into higher adaptation capacities of farmers to climate change and water scarcity.

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