Potential adaptations of the Tunisian agricultural sector to water scarcity

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Abstract

In this paper, we developed a regionally disaggregated agricultural supply model for Tunisia to investigate the potential effects of increasing water scarcity on the performances of the agricultural sector in this 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, might be negatively affected in case of decreasing irrigation water availability. The north east, central west, and southern regions will be the most affected. 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 producer prices support. 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. *Motivation and Outline*

The impacts of climate change (CC) will be channeled primarily through the water cycle (World Bank, 2016), with consequences that could be large and uneven particularly on agricultural sectors. According to the same source, some regions could see their growth rates decline by as much as 6 percent of GDP by 2050 as a result of water-related losses in agriculture, health, income, and property. For the Mediterranean, more than 40% reduction in freshwater availability is suggested by the end of this century along the coastal areas (Abdulla et al., 2009). The North African region is one of the regions which will be affected the most by CC, as predicted by different climate models (Rochdane et al., 2014; Seif-Ennasr et al., 2016). The region is already experiencing low and highly variable rainfall, which are shaping much of its agricultural production systems. Climate models simulations are providing converging results concerning the decreasing trends of rain fall with 10 to 20% across North Africa (Schilling et al., 2012), with average median decrease reaching 12% (NIC, 2009) . For Tunisia, this rainfall trend will result in a decline of water availability with up to 28% in 2030 (Paeth et al., 2009 ; ITES, 2014). The World Bank (2016) also reports that water-management policies can exacerbate the adverse growth impacts of CC, while good policies can go a long way towards neutralizing them. 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 these effects based on some scenarios development and simulation.

Agriculture is an important sector in Tunisia contributing with about 8.7% to the national GDP and employing around 16.2% of the total employment in the country (World Bank, 2013). 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 semi-arid climate that covers more than ¾ of its area (Lachaal et al., 2005). The agricultural sector is also highly dependent on water resources since it consumes more than 75% of total water use in the country (Frija et al., 2015; MARH, 2013). Climate variability is high all over the main agricultural areas of Tunisia leading to highly variable yields among years. As an example of this fluctuation, total cereal production in 2002 was around 0.51 Million tons while in 1996 and 2003 it was around 2.9 Million tons (Dhehibi et al., 2014). The same figure is observed for all other cereal crops where the yields of durum wheat (between 0.5 and 2 tons/ha), Soft wheat (between 0.5 and 2.5 tons/ha), and barley (between 0.4 and 1.5 tons/ha) are highly variable from one year to another. Not only yields are variable, 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 make both yields and areas decreasing. To deal with this variability, Tunisia started since the early 70s to expand its irrigated areas in order to ensure more reliable supply of agricultural commodities over the years (Frija et al., 2015). This strategy partly succeeded in developing around 450 thousand ha of irrigated areas representing around 8% of total agricultural area in the country. This percentage is low but is reflecting the highest surface that can be irrigated by the available water resources, given the current levels of irrigation water use efficiency.

However, despite their small share in total agricultural land, irrigated areas in Tunisia are producing 35% of the agricultural value added, 20 % of total agricultural exports and 27 % of agricultural employment (Atiri, 2007). Around 48% of these irrigated areas are irrigated from groundwater sources, including both superficial and deep aquifers (Frija et al., 2015). Overall water resources in the country are estimated to be only around 4700 Mm3 ITES, 2014 including 650 million m^3 of non-renewable 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 (MARH, 2013). 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 10ha indicating a main structural problem facing the modernization of the agricultural sector and the irrigated areas. As described above, 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. In this paper, we rather 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 (Kirchweger and Kantelhardt, 2015). This complex and dynamic process constitutes a reallocation of land use and farms specialization, as well as a re-positioning of the agricultural sector as compared to other sectors of the economy (Blandford, 2006; Happe et al., 2011; Kirchweger and Kantelhardt, 2015). In the rest of this paper, we particularly refers to structural change as being the reallocation of land use and crops specialization among different regions in Tunisia, as well as among rain fed and irrigated conditions. A regionally disaggregated Agricultural Supply Model for Tunisia (ASMOT) will be 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 added value as well as employment in both irrigated and rain fed sectors will be assessed under different water-related scenarios. To our knowledge, ASMOT is the first attempt of disaggregated sector modelling in Tunisia which we aim to further develop and validate in the coming years.

2. *Methodology and Analysis*

The ASMOT model is an agricultural supply model (ASM) build based on primary and secondary data of farming inputs and outputs for different crops, regions, and systems (rain fed & irrigated). ASMOT is the first regionally disaggregated ASM developed for Tunisia. The model includes 21 of the most strategic crops of Tunisia (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 thousand ha). The ASMOT model is build based on regional disaggregated data, including 24 governorates of Tunisia.

These governorates have been aggregated into 5 regions (North West, North Est, Center West, Center Est, and South) based on bioclimatic homogeneity. The model was calibrated through Positive Mathematical Programming (PMP) (Howitt, 1995), and using official 2011 data about observed crops areas by region and system (irrigated/rain fed) as recorded by the Ministry of Agriculture, Hydraulic Resources and Fisheries of Tunisia (ONAGRI, 2016). 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 crops evapotranspiration and their respective effect on yields. The different crops and regions included in the ASMOT model are shown in table 1 below.

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

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 (Bizerte, Beja, Seliana, Le Kef, Jendouba); North Est (Nabeul, Ariana, Manouba, Ben Arous, Zaghouan) Center West (Sidi Bouzid, Kasserine, Kairouan, Gafsa) Center Est (Sfax, Mahdia, Monastir, Sousse) South (Tozeur, Kebili, Tataouine, Médenine, Gabes)

2.1. Structure of the ASMOT model.

The aggregated agricultural supply equation (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). Equation 1 can be read as follows:

$$\mathrm{AS}_{c,s} = \sum_r \mathrm{RAS}_{r,c,s} = \sum_r \left\{ [P_c * (Y_{r,c,s} - \Delta Y_{r,c,s})] - [AC_{r,c,s} + \mathrm{WP}_r] \right\} * \mathrm{X}_{r,c,s} \qquad (1)$$

Where $AS_{c,s}$ is the total Agricultural Supply of different crops (c) and systems (s). Systems can either be rain fed or irrigated. $RAS_{r,c,s}$ indicates the Regional Agricultural Supply by region, crop, and system. Pc is the producer price of crop c, Y is the yield expressed by region, crop, and system, and ΔY is the variation of yields which can be due to hydric stress (higher temperatures and evaporations). AC is the average cost of crops production excluding water costs. Ac is expressed by region and system. WP is the irrigation water price in different regions. Finally, $X_{c,r,s}$ is the variable of the agricultural supply equation and is defined as being the total crops area under rain fed and irrigated system and in different regions. Observed $X_{c,r,s}$ of the year 2011 were used for the calibration of equation 1. Once calibrated, X became variable and can be optimized under different scenarios. Yield variation ΔY is calculated as follows:

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

Where *ky* is the yield variation coefficient, Eta and ETM are respectively the real and maximal evapotranspiration.

$$\sum_{c,s} X_{r,c,s} \leq A_r \quad (3)$$
$$\sum_{c,(s=irr)} X_{r,c,s} \leq IA_r \quad (4)$$
$$\sum_{(c=trees),s} X_{r,c,s} \leq TA_r + (1 + \gamma_{c=trees}) \quad (5)$$
$$\sum_{c,s} w_{r,c,s} * X_{r,c,s} \leq WA_r \quad (6)$$
$$X_{r,c,s} \leq X^o_{r,c,s} * (1 + \varepsilon) \quad (7)$$

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. Constraint 4 indicates that the sum of crops irrigated areas in each region should not exceed the total irrigable areas (IA) available in that region. Constraint 5 bounds the annual trees area expansion to the observed annual growth rates of these areas in Tunisia during the last two decades. Constraint 5 is also set at regional level. Constraint 6 indicates that the sum of water requirement of all crops cultivated under different systems in a given region should not exceed the water availability (WA) in that region. Finally, constraint 7 is a calibration constraints which will be used in the first PMP step in order to estimate the cost function calibration coefficients (α and β). The average cost AC function is a nonlinear expression (Eq.8) estimated using two main calibration coefficients (α and β) which were calculated by solving equation 1 under the set of all considered constraints (3-7), including the calibration constraint (Heckelei and Britz, 2005; Howitt, 1995). Coefficients α and β were calculated using the dual values of the constraints 7, and following the approach of (Heckelei and Britz, 2005; Kanellopoulos et al., 2010), 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 sector and other farm type modelling and calibrations (Gómez-Limón et al., 2016; Graveline, 2016; Howitt et al., 2012; Medellín-Azuara et al., 2012; Solazzo and Pierangeli, 2016; Torres et al., 2016).

$$AC_{r,c,s} = \alpha_{r,c,s} + \beta_{r,c,s} X_{r,c,s} \quad (8)$$

Equation (8), will be replaced in equation (1) which will generate a calibrated nonlinear objective function. To validate the calibrated model, we optimize equation 1 under all constraints while excluding the initial calibration equation 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 scenarios simulations. AMOST validation and calibration performances will be presented in the result section.

2.2. Source of data

The data used to feed the ASMOT model was of different types and thus collected from various sources. Specific crops inputs and outputs levels for different regions and systems were collected through farmers questionnaires which were conducted for the season 2012-2013, in all regions of Tunisia in the framework of the EVSAT (Eau Virtuelle et Sécurité Alimentaire en Tunisie, funded by the IDRC) research project. Many focus groups with regional experts in crop production were conducted afterward in order to revise the average inputs and outputs 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 (FAOstat). Other secondary data regarding water availability, initial crop areas distribution, irrigated areas, etc. were collected from official national datasets, especially available at the level of ONAGRI (Observatoir National de l'Agriculture). 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.

2.3. Water scenarios

In relation to the overall objective of the paper, our scenarios 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 (Paeth et al., 2009). Based on this, our first scenario suggest a cut of water availability by 25%, while second and third scenarios will consider improvements of irrigation water use efficiency (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 (Blinda, 2012). This shows a wide scope to improve IWUE through appropriate investments in farmer's skills and modernization of the irrigation networks. On the other side, it is well known that better integration of farmers along commodities value chains may offer enhanced producer prices (Trebbin, 2014), which can be considered as market incentives allowing farmers to enhance their technical investments and adaptation capacities (Bahinipati and Venkatachalam, 2015; Mwinjaka et al., 2010). Based on these arguments, scenarios which will be 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 linear across all regions of the country.
- Scenario 2. Cutting total fresh water availability by 25%, and improving irrigation water use efficiency 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 following: +5% for cereal prices, and +10% for fruits and vegetable prices.

3. 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 1) meaning that the model is well performing (Howitt et al., 2012).

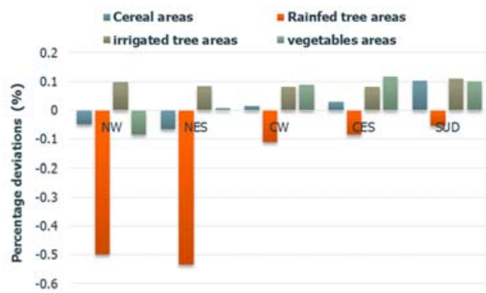

Figure 1. Percentage deviation of simulated vs observed crops areas in different regions included in the ASMOT model.

This validation test show that ASMOT is performing well and can thus be used for scenarios simulation. The next step will be 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 will be presented in the following sections.

3.1. 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 crops yields, costs, and incomes in the different regions and systems of Tunisia (Table 2). Results in Table 2 shows the overall trend of land use under different scenarios (SC1, 2, and 3).

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. 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.

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

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

Figure 2 provides another summary of table 2 showing that total irrigated area in Tunisia will decrease by 10.6% under SC 1, but this same decrease will significantly be lower (3.7%) if IWUE will improve as suggested by SC2. The same figure shows that north east and central western parts of Tunisia will be the most affected by water scarcity. Irrigated areas in the latter regions will decrease with about 18%, 6.4%, and 6.6% respectively under SC1, SC2, and SC3.

Figure 2. Percentage reduction of total irrigated (both figures) and rainfed (right side figure) areas in different regions under different scenarios.

3.2. Irrigation water demand under different scenarios

Total water use for irrigation under different scenarios in Tunisia were 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 decrease to 1876.5, 1818.1, and 1833 Million m^3. By considering the new irrigated areas under each scenarios, these decreases led to average water consumptions of 5949 m^3/ha, 5349.7 m^3/ha 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.

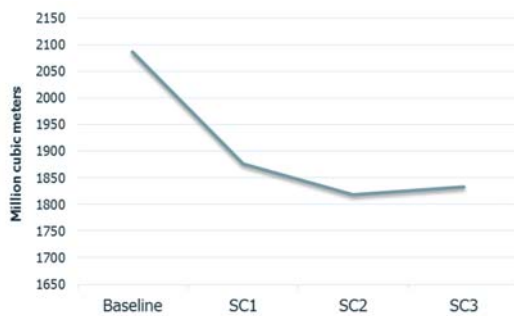

Figure 3. Total water use for irrigation under different scenarios

3.3. 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 SC 1 and SC 2. However, these slight changes, despite the sharp cut of water availability can only be possible if structural adaptations of the Tunisian agricultural sector, based on specific land use reallocations (as shown in Table 2) will be adopted.

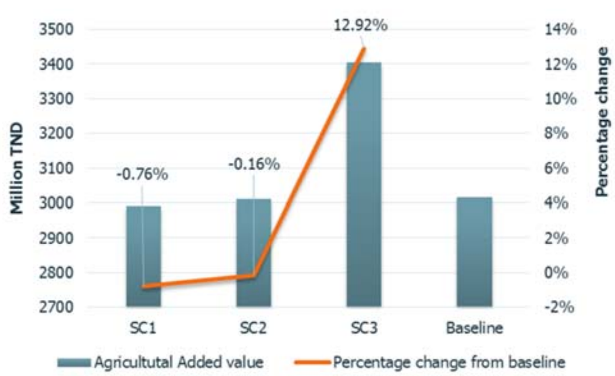

Figure 4. Effect of water scarcity scenarios on the national agricultural value added.

Scenario 2 shows that with 10% increase of irrigation water use efficiency, the cut of water availability can be effectively mitigated, with an agricultural added value 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 added value 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 prices inflation, but also to the restructuring of land use and the 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 compared to 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 non-proportional increase of the value added (+13%), showing a relevant and positive multiplier and environmental effect of this price instrument.

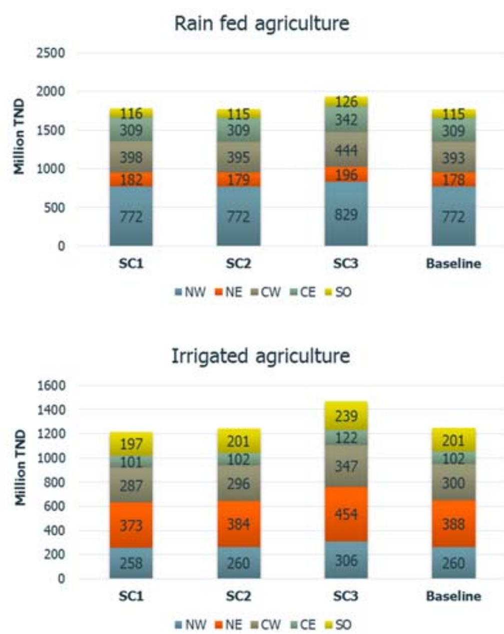

Figure 5. Changes of regional agricultural value added under different scenarios in Tunisia (Million TND).

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 Centre west, and North east Tunisia will be the most 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.

3.4. 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 demand will still be negatively affected under both SC

1 and SC 2, 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 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 for the irrigation sector will increase under SC3 despite the decrease of the irrigated areas under this scenario (-3.6%).

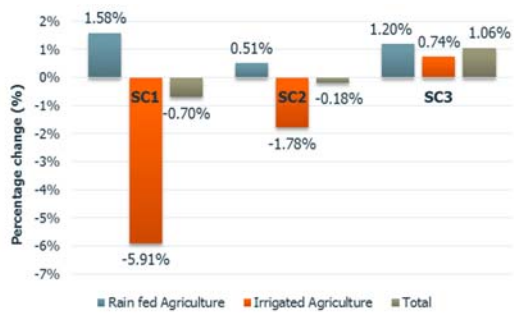

Figure 6. Effect of different scenarios on regional agricultural labor demand (percentage changes compared to baseline)

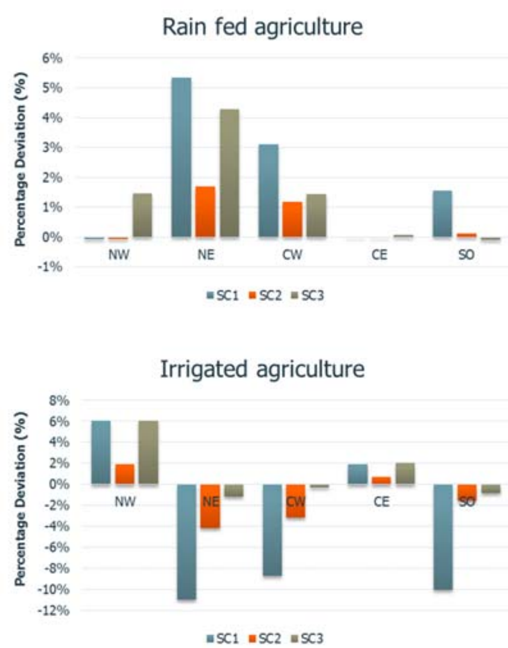

Figure 7. Effect of different scenarios of regional agricultural employment under different scenarios (percentage change compared to baseline)

Similarly to the agricultural value added, labor demand in agriculture will disproportionally be affected among the different regions of Tunisia. Figure 7 capture 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 in the same time maximizing 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.

4. Discussions

The scope of enhanced water use efficiency was proven through our analysis to be highly effective in mitigating the effects of water scarcity in the different regions of Tunisia. Better WUEs (SC2), allowed for lower decrease of irrigated areas compared to the no WUE 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 WUE to improve irrigation performances and sustain irrigation. However, WUE can be defined at different scales including user/scheme and basin levels. Through our modeling framework, we only captured benefits of WUE in terms of water saving. However, In addition to the benefits captured by our model in terms of water saving, physical efficiency at user/scheme level will also be translated into increased water productivity (or economic efficiency) (Turral et al., 2011). 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 water use efficiency through better technology and management can generate real water savings (Turral et al., 2011).

Without substantial improvement in the productivity of rainfed agriculture, and despite a considerable expansion of cropped area, irrigated area would have to increase to close to 500 million ha globally to meet expected food demand, entailing a doubling of water use (IFPRI, 2016). 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 will be 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, added value 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 with improved if producer prices can be increased. Increased producer prices does 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 (Trebbin, 2014), which can in turn be considered as a type of market incentive for farmers and can be used to promote specific agricultural productions (Bahinipati and Venkatachalam, 2015; Mwinjaka et al., 2010).

5. Conclusions

In this paper, 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 an 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 multiplier effect on agricultural added value of 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 can be revised using further socioeconomic data, and applied for an optimal restructuring of agricultural production in Tunisia. 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 for better producer prices which will thus be translated into higher adaptation capacities of farmers to climate change and water scarcity.

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