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Estimating the Economic Impact of Climate Change on Agricultural Water Management Indicators

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ABSTRACT

Climate change has been strongly dealt with in the literature on the economy in recent decades. In many semi-arid regions of the world, issues related to climate change including the scarcity of water resources are crucial for consideration in overcoming obstacles to development. The value of water increases and presents itself as a quantitative and qualitative constraint to its domestic, industrial and, particularly, agricultural use. Given the multi-dimensional and multi-scalar nature of climate change, this research proposes an integrated agronomic, economic and hydrologic modelling for the Tadla sub-basin in Morocco to assess the potential economic impacts of climate change on agricultural water management in this region. This tool permits to predict inter-annual variations of selected socio-economic water management indicators from 2014 to 2050. The simulated climate scenarios include the RCP (Representative Concentration Pathway) 4.5 and RCP 8.5 scenario, taking into account the main crops, water resources and the socio-economic context of the study area. The results show that climate change can have an impact in reducing the total agricultural profit calculated across the Tadla sub-basin (by about -0.34% and -0.44% each year according to RCP 4.5 and RCP 8.5 climate scenarios, respectively) and in increasing irrigation water shadow price progressively. Overall, this research helps to improve understanding of the potential economic impact of climate change and to guide stakeholders in their choices in terms of future adaptation policies.

Keywords: Agricultural profit, climate change, economic impact, RCPs 4.5 & 8.5, water management

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INTRODUCTION

Climate change is a socio-economic and environmental phenomenon that challenges and concerns the international political and scientific communities, given its growing impact on global food security. In

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Mediterranean countries, water resources are severely affected by climate change and so, the effects become more noticeable and more expensive (Iglesias et al., 2011).

Located in Africa, with a significant Mediterranean coast, Morocco is a country highly vulnerable to extreme weather and climate change (Niang et al., 2014). The country's hydrological context is mainly influenced by a spatial and temporal heterogeneity of renewable water volumes and by their scarcity, about 22 billion (m^3/year) (CESE, 2014), the equivalent of 660 (m^3/pers.an). Considering the water scarcity indicator, defined by Falkenmark (1989) as the volume of renewable water per capita, Morocco is facing a chronic water shortage, which can be aggravated by climate change. For this, the country was early committed to the international regime of climate change. It adopted the Framework Convention of the United Nations about Climate Change (UNFCCC) in 1992, which marks the basis for defining the means for worldwide sustainable development. With this convention and the Kyoto Protocol, various initiatives and actions have been implemented. However, climate change remains a major challenge facing the country because it is difficult to identify all the negative consequences of this phenomenon on ecosystems and humans.

In fact, one of the most affected activities, in this regard, is agriculture. Agriculture is considered a strategic sector for the socio-economic development of Morocco in terms of its contribution to the Gross Domestic Product (GDP), its role in employment (about 80% of rural employment) and its contribution to external trade (Toumi, 2008). However, the sector remains highly dependent on rainfall and, therefore, on climatic conditions. In Morocco, water availability is one of the main limiting factors in achieving good yields. A set of irrigated areas in the country was equipped with the means to improve and secure better crop production. Irrigated agriculture occupies only 15% of the cultivated area (about 1.5 million ha) in the country, but accounts for about 45% of the agricultural Gross Domestic Product and 75% of agricultural exports, depending on the season. According to Ministry of Agriculture reports, these statistics are more interesting when production in rain-fed areas is severely affected during dry years.

In spite of the large amounts of consumed irrigation water, crop yields in irrigated areas remain unstable from one season to another due to fluctuating water availability (Benabdelouahab et al., 2016). Therefore, climate insecurity may cause costly food insecurity for the country, leading to the need for massive imports in dry years, and drastically affects the living conditions of the rural population, with fallouts on other economic activities. Furthermore, productivity per irrigated hectare has not yet reached the potential for certain farms, now 69% in terms of economic efficiency on average, and the volume of water (m^3) is not sufficiently valued by high-value crops (Lionboui et al., 2016).

In this situation, a considerable effort in scientific research must be undertaken to support current agricultural policies in order to assess and control the economic impact of climate change on agricultural water management. Several models have been adopted to identify and assess the damage caused by climate change and to support and assist adaptation policies. However, most of this research has been based on biophysical modelling that focusses on one specific dimension of climate change, such as the hydrological dimension (Immerzeel et al., 2010; Nepal, 2016) or the agronomic dimension (Moriondo et al., 2010; Ventrella et al., 2012). For the economic dimension, the models used for assessing the economic impact can be

classified into two main types, namely, the general equilibrium and partial equilibrium models. The first model considers the economy as a complete system of interdependent elements. The second is based on the analysis of part of the whole economy as a single market or a subset of markets. Owing to the sophistication involved in their use, the general equilibrium models are generally unsuitable for developing countries (Baby et al., 2014) such as Morocco. Therefore, the partial equilibrium models are the most appropriate in this case for assessing the economic impact of climate change on agriculture (Mishra & Sahu, 2014). The literature mentions, on the one hand, models based on the Ricardian approach (Mendelsohn et al., 1994) or hedonic pricing method; however, in the economic theory, this method is considered more appropriate for consumer goods than for production factors (Martin & Vaitkeviciute, 2016). On the other hand, we find models based on agronomic-economic and/or hydrologic approach (D'Agostino et al., 2014; Esteve et al., 2015; Hurd & Coonrod, 2012) that are based on controlled experiments in the field or laboratory settings that we have adopted for this research.

The proposed model was developed to predict inter-annual variations of selected socio-economic water management indicators at the Tadla sub-basin level from 2014 to 2050. In this perspective, this dynamic agronomic-economic-hydrologic model allows analysis of potential economic impact of climate change on agricultural water management while taking into account the development projects scheduled in the context of current policies. Therefore, this research was intended to provide applied tools for decision-makers to implement new approaches to adopt the most appropriate agricultural policies that may be able to reduce the negative impact of climate change.

MATERIALS AND METHODS

Agricultural Water Resources and Irrigation Schemes of the Study Area

The Tadla sub-basin is characterised by semi-arid to arid climate, with a dry season from April to October and a wet season from November to March. It covers three agricultural territorial units (ATUs): the Tadla plain (ATU 1), a rain-fed agricultural area that uses private groundwater pumping (ATU 2) and the Dir unit (ATU 3). Created in the 1940s, the irrigated perimeter of this sub-basin was among the first large irrigation schemes in the country. The landscape is a plain located in central Morocco (32°23´ N latitude; 6°31´W longitude; 445 m above sea level). This plain covers about 100,000 ha and is characterised by flat topography. It is characterised by semi-arid climate, with about 300 mm average annual precipitation over the period of 1970-2010, with a high inter-annual variation ranging from 130 to 600 mm in the same period (ABHOER, 2012). The average temperature is 18°C, with a maximum of 38°C in August and a minimum of 3.5°C in January (ORMVAT, 2014).

The irrigated perimeter of Tadla is divided into two sub-schemes by the Oum-Er-Rbia river, flowing from the Middle-Atlas Mountains (east) to the Atlantic Ocean (west) (Figure 1). Irrigation water used in the Tadla perimeter comes mainly from surface water (87.1% of the total amount of irrigation water consumed in 2009/2010). Two dams, Ahmed-Al-Hansali (750 mm³) and Bin-El-Ouidane (1.5 billion m³), supply irrigation water to the Tadla perimeter, besides groundwater pumping.

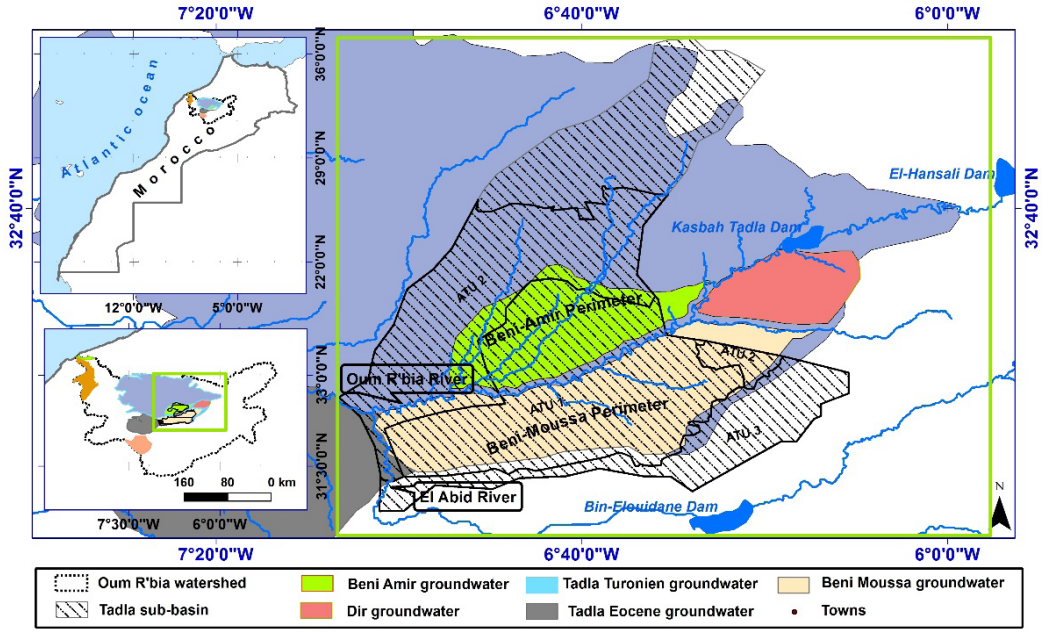

Figure 1. Location of the Tadla sub-basin

The overexploitation of groundwater has led to a lowering of piezometric levels. However, the amount of groundwater use has increased in these last few years due to the frequent recorded droughts. Groundwater used for agricultural purposes in Tadla comes from Beni-Moussa and Beni Amir groundwater and the Turonian deep water table.

Model and Data

In a context of climate change, the main objective of this study is to develop an agronomic, economic and hydrologic model in order to help decision-makers to choose the most appropriate adaptation measures for the country's context. This model is based on the simulation of water flows, equilibrium equations of water supply and use, water flows at different river nodes and the allocation of water resources (Lionboui et al., 2014). It is programmed in GAMS (Brooke et al., 1998) and was resolved using the non-linear solver CONOPT.

In addition to reflecting the dynamics of interactions between the different components i.e. hydrologic, agronomic and economic components, this tool allows the assessment of the potential economic impacts of climate change on agricultural water management under various climate scenarios (RCPs 4.5 and 8.5), taking into account the major crops, water resources and the socio-economic context of the region (Figure 2).

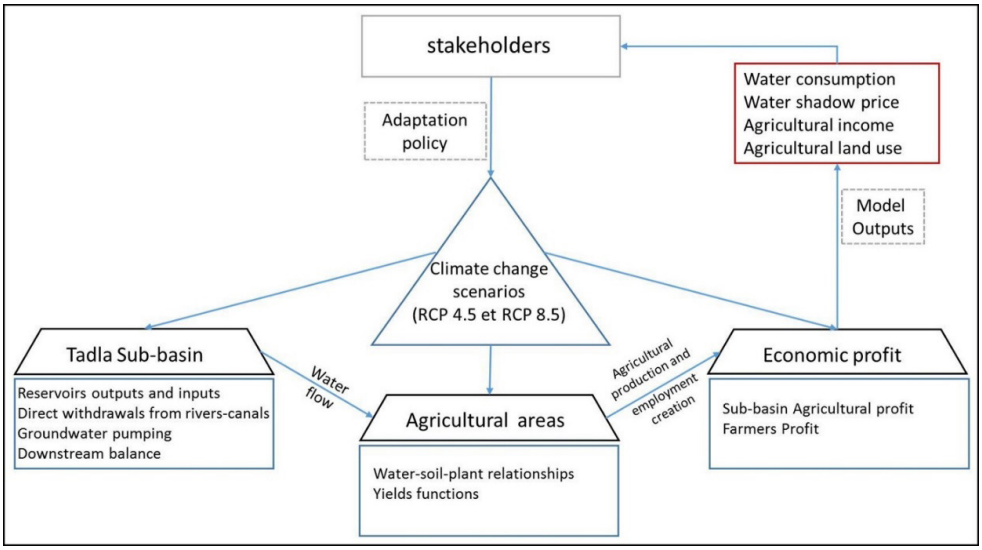

Figure 2. Tadla sub-basin model linkage

The proposed model is a non-linear optimisation model, which, given various constraints, maximises an objective function that can be value-added, or any other function reflecting the preferences and choices of decisions-makers at the sub-basin level. Once the objective function (Eq.1) and the functions of specified constraints was identified, the calibration of the model was obtained by using positive mathematical programming (Howitt, 1995) as follows:

$$Max\ VA = \sum_A \left(\sum_{IM} VA_CAL_{A,IM} \right) \quad (1)$$

'VA' is the agricultural net value-added factor at the sub-basin level and 'VA_CAL' is the net value-added per agricultural area and per irrigation mode after calibration. 'A' is the agricultural area, referring to the sub-unit of the commune in order to differentiate between the existing irrigation modes. The net value-added per agricultural area was calculated from the output generated by the agricultural production and the labour cost, minus the producing and amortisation costs.

The model optimises the objective function on the basis of the observed values. Thus, the Earth availability constraint was also taken into account in the model. 'CU_AREA' represents the sum of cultivated areas by agricultural area 'A' and did not exceed the available area of arable land 'AV_AREA' in the Tadla sub-basin (Eq. 2):

$$AV_AREA \geq \sum_{A,IM,Cr} CU_AREA_{A,IM,Cr} \quad (2)$$

The initial land-use constraint refers to the part of each crop in the cultivated land by agricultural area and by irrigation mode. The marginal value of this constraint was used in the model calibration (Eq. 3):

$$CROP_PT_{A,IM,Cr} = \frac{CU_AREA_{A,IM,Cr}}{\sum_{Cr} CU_AREA_{A,IM,Cr}} \quad (3)$$

'CROP_PT' defines the variable that determines the part of each crop in the total cultivated area and 'CU_AREA' is the parameter that indicates the area occupied by each crop in the reference year (2013-2014).

In the Tadla sub-basin, the water quantity used for irrigation ('TOT_WAT') refers to water coming from reservoirs and other surface sources ('SF_WAT') by period (months) 'Pd' and water pumped ('GD_WAT) from aquifers 'Aq' (Eq.4):

$$\sum_{Cr} TOT_WAT_{A,IM,Cr,Pd} = SF_WAT_{A,IM,Pd} + \sum_{Aq} GD_WAT_{A,IM,Aq,Pd} \quad (4)$$

In this model, crop-yield functions are designed as non-linear approximations of the ratio between the maximum and actual evapotranspiration according to the definition proposed by FAO, derived from the Penman Monteith method (Allen et al., 1998; Samuelsson et al., 2015; Xin-e et al., 2015), which makes the yield depend on the water demand per hectare.

The observed data used in this study included, firstly, agronomic parameters, such as yield per crop, production factor requirements, crop areas, effective rainfall, maximum evapotranspiration, and the crop-yield response coefficient. Data relating to technical and hydrological parameters like loss rate of agricultural water, water demand in relation to agricultural area and farm type, regulated volume, evaporation and maximum volume of reservoirs, gradient, depth, permeability and storage coefficient of each aquifer were also considered by the model. Finally, socio-economic parameters were included for each agricultural area such as selling price of agricultural products, agricultural production input prices, selling price of irrigation water and farm economic efficiency rates.

In order to reflect the complexity of operating and valuation conditions of irrigation water, the proposed model was designed to be a recursive dynamic type that runs over 37 years (from 2014 to 2050). The period was limited because of the absence of agricultural policy and economic data forecasts beyond the year 2050 (Elbadraoui & Berdai, 2011; Lahlimi Alami, 2015; Sinan et al., 2009). The dynamic aspect of the model was done by defining a period of years (37 years) and a loop. This loop would make iterations, taking into account the parameters and variables that may be influenced by climate change and that are introduced in the set representing the year. We used two parameters (rainfall and temperature) for climate data from the recent results of experiments based on regional and international climate models that were available from the National Meteorology Directorate in Morocco (DMN), namely, the MIROC-ESM (Model for Interdisciplinary Research on Climate-Earth System Model) and CanESM2 (Canadian Earth System Model, 2nd generation). The results of these models show a decrease in rainfall for the two climate scenarios (RCPs 4.5 and 8.5) during the period covered by this study (Figure 3).

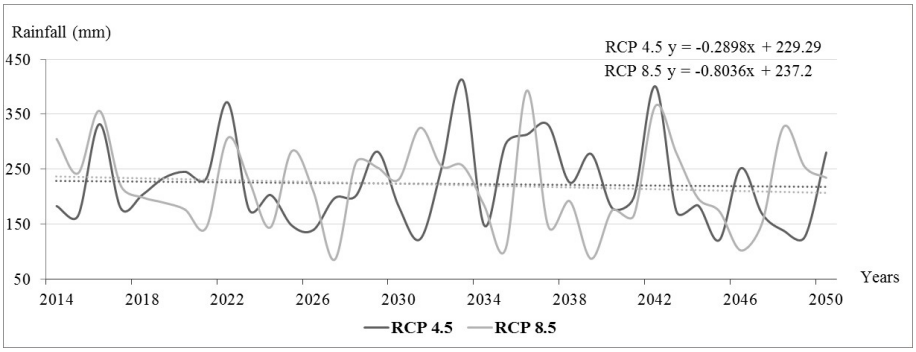

Figure 3. Annual rainfall trends in the Tadla sub-basin

These models leave little ambiguity about climate risks associated with increasing greenhouse gasses (Le Treut & Jancovici, 2004). Simulations conducted in this research involve the main crops in the study area under two climate scenarios, RCP 4.5 and 8.5.

As for reservoirs, water remaining in the first year (end of August) was used as the initial water quantity in the second year (beginning of September). Some other data were taken from agricultural development project reports, including the rate of conversion to water-saving systems established through the National Programme of Irrigation Water Economy (NPIWE) projects and projects focussing on crop expansion. The reference year chosen for this research was 2013-2014 from September to August (crop year) when the rainfall was about 410 (mm) according to data collected by the National Meteorology Directorate.

RESULTS AND DISCUSSION

Agricultural Profit

The average agricultural profit calculated for the Tadla sub-basin was 7486.57 MAD[1] per hectare. During the simulated years, this value showed a different evolution according to the climate scenarios, RCPs 4.5 and 8.5. The results of predicting this evolution are shown in Figure 4.

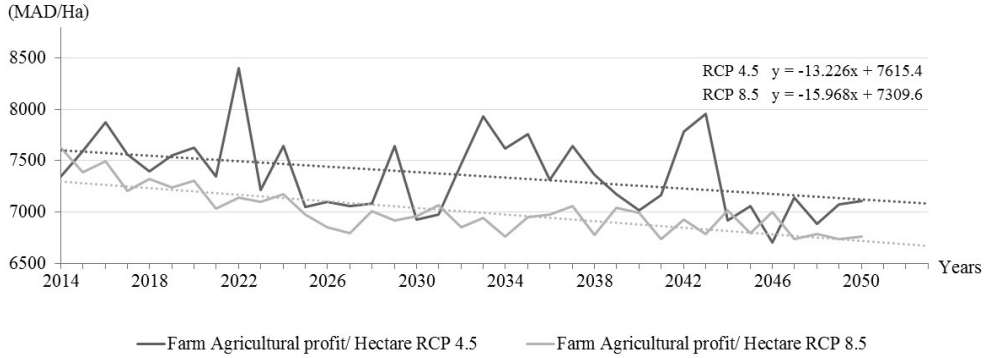

Figure 4. Predicted changes in agricultural profit according to the climate change scenarios, RCP 4.5 and RCP 8.5

[1] At the time of writing (mid-February 2017), MAD1.00 was approximately equivalent to £0.07, $US0.11 and €0.09.

The results showed that the agricultural profit per hectare in the study area was likely to experience a slight decline over the years decrease by an average of -13.23 MAD/Ha and -15.97 MAD/ha each year according to the RCP 4.5 and RCP 8.5 climate scenarios, respectively. The total agricultural profit calculated across the Tadla sub-basin was 2094 mil MAD. It also showed a declining trend (Figure 5).

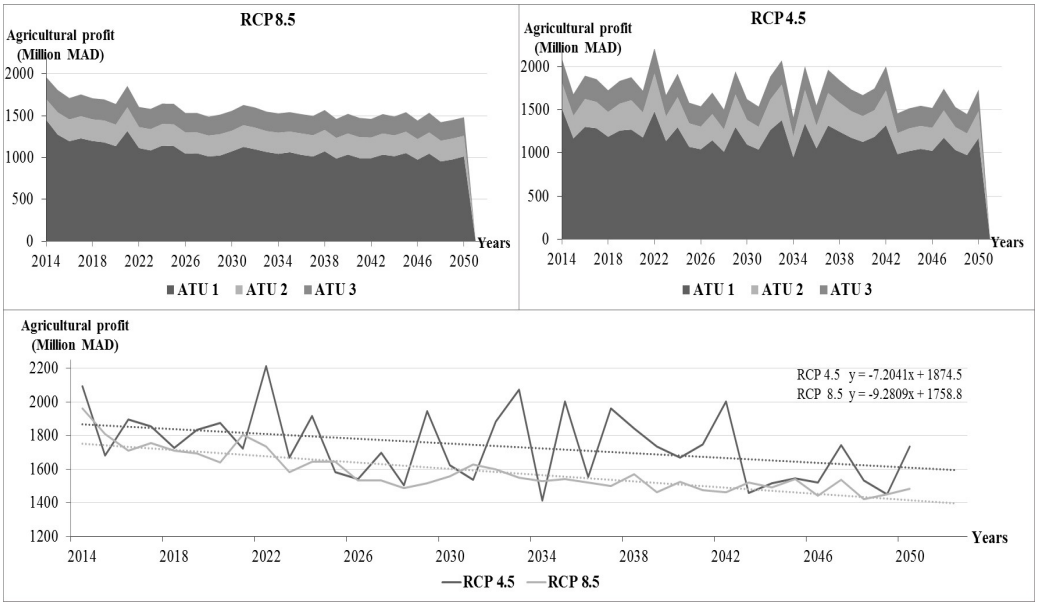

Figure 5. Predicted changes in total farm profit according to climate change scenarios, RCP 4.5 and RCP 8.5

This decline was quantified at about -7.2 million MAD (-0.34 %) per year according to RCP 4.5 and -9.28 million MAD (-0.44 %) according to RCP 8.5. This is mainly caused by the decrease in the cultivated areas that may have been affected by reducing irrigation water supplies predicted during the study period. In addition, we noticed existing differences between the agricultural territorial units and the evolution of their agricultural profit. The decline of its value was more pronounced at the first agricultural territorial unit (ATU1) because of the irregularity of surface water supplies through the irrigation system channels coming from the Ahmed El Hansali and Bine Elouidane dams. For the two other agricultural territorial units, (ATU2) and (ATU3), the decline was less important. In these agricultural territorial units, encouraged by the availability of groundwater throughout the year, farmers are diversifying and intensifying their agriculture.

Irrigation Water Shadow Price

Irrigation water shadow price is defined as the marginal increase in the value of the objective function (agricultural profit) if water availability is increased by an additional cubic metre.

This shadow price reflects the scarcity of water resources in contrast with the financial price. Thus, it represents one of the most significant results calculated in this study, which intended to assess the change in its value through the years under two climate scenarios (RCP 4.5 and RCP 8.5) (Figure 6).

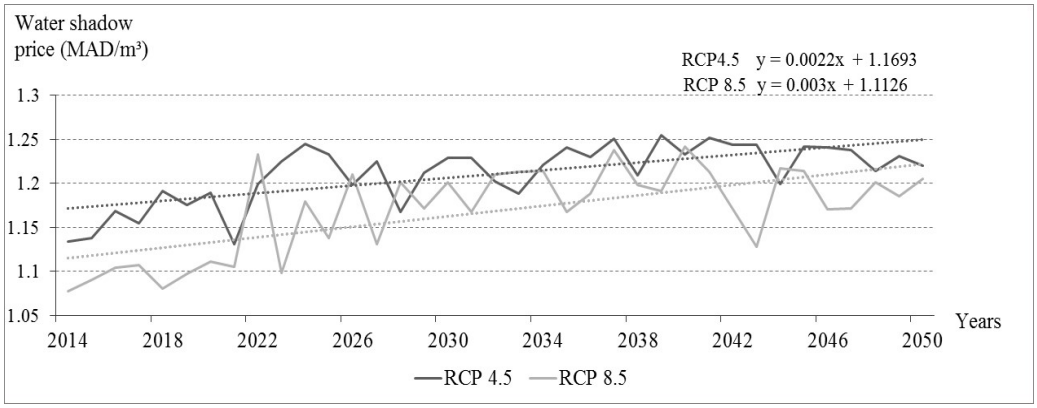

Figure 6. Predicted changes in the irrigation water shadow price according to the climate change scenarios, RCP 4.5 and RCP 8.5

The average shadow price of irrigation water calculated after calibration for the Tadla sub-basin was 1.13 MAD/m³ for the climate scenario RCP 4.5 and 1.08 MAD/m³ for RCP 8.5. These values were much higher than the selling price of irrigation water in the study area, which is 0.32 MAD/m³.

During the simulated years, the irrigation water shadow price was predicted to increase by 0.0022 MAD/m³ (+0.20 %) and 0.003 MAD/m³ (+0.28 %) per year according to the climate change scenarios RCP 4.5 and RCP 8.5, respectively. It could, therefore, reach a maximum value of 1.26 MAD/ m³ in 2039. This increase confirmed the results obtained by Heidecke and Heckelei (2010) in a relatively similar context of water availability. This result was linked to the irregularity of surface water supplies through the irrigation channels system coming from the Ahmed El Hansali and Bine Elouidane dams in the Tadla sub-basin, making irrigation water a production-limiting factor. In addition, it can be explained by the expected programmed intensification projects and by the orientation of farmers towards high-value crops.

Water Consumption

The total consumption of surface water calculated across the Tadla sub-basin was about 784 Mm³ on average in the reference year (2013/2014). The other part of irrigation water consumption is provided by groundwater, with a volume of 295 Mm³. The change in irrigation water consumption during the simulated years according to the climate change scenarios, RCP 4.5 and RCP 8.5, are shown in Figure 7.

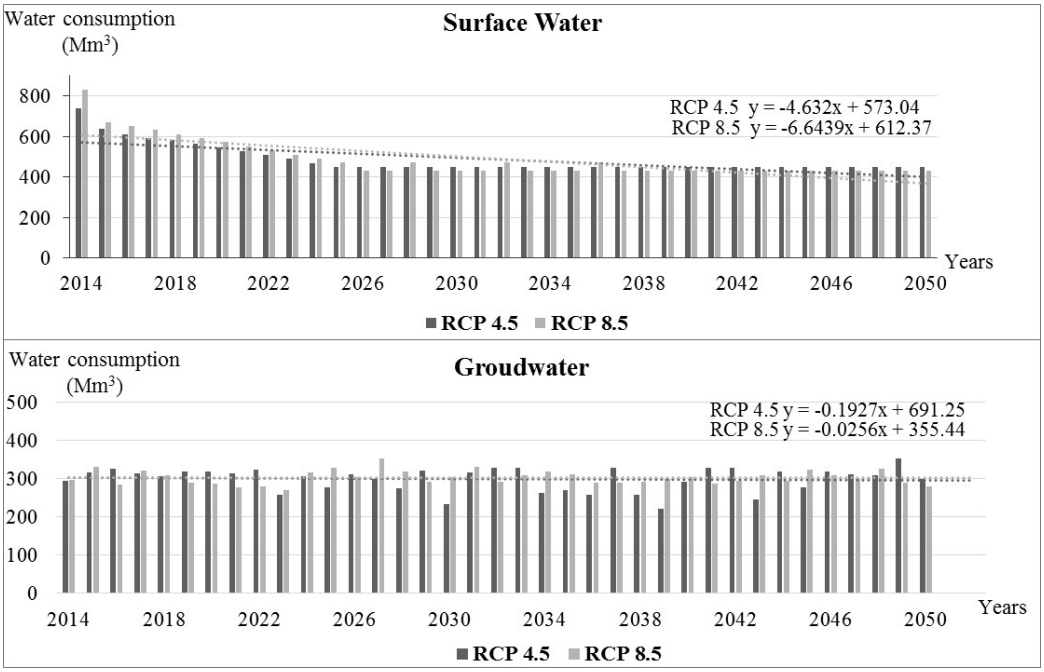

Figure 7. Predicted changes in total water consumption according to the climate change scenarios RCP 4.5 and RCP 8.5

From 2014 until 2050, the total consumption of irrigation water is likely to experience a significant decrease, particularly in the case of surface water. The decline is estimated at -4.63 mm³ per year according to the climate scenario RCP 4.5 and -6.64 mm³ for RCP 8.5. This is essentially linked to the reduction of cultivated areas caused by the expected decrease in surface water resources expected during the simulated period. Moreover, in order to cope with the expected reduction of surface water inflows in the Tadla sub-basin, current agricultural policies have proposed a set of measures, such as providing grants and launching extension programmes to encourage the adoption of water-saving systems.

Groundwater consumption will tend to stabilise over the years. Thus, the results show a slight decrease of -0.19 mm³ and of -0.03 mm³ per year according to the climate change scenarios RCP 4.5 and RCP 8.5, respectively. Indeed, encouraged by the availability of groundwater throughout the year, farmers tend to diversify and intensify their agriculture. Consequently, they reserve more areas to crops that offer good profit margins, whatever their water consumption.

Agricultural Land Use

The availability of climate change information will bring different agricultural stakeholders in the region to seek the best way to limit the negative consequences of this global phenomenon. In the Tadla sub-basin, cropping plans will vary during the simulated years. These changes are presented in Figure 8 through shares of major crops in the region according to the climate change scenarios, RCP 4.5 and RCP 8.5.

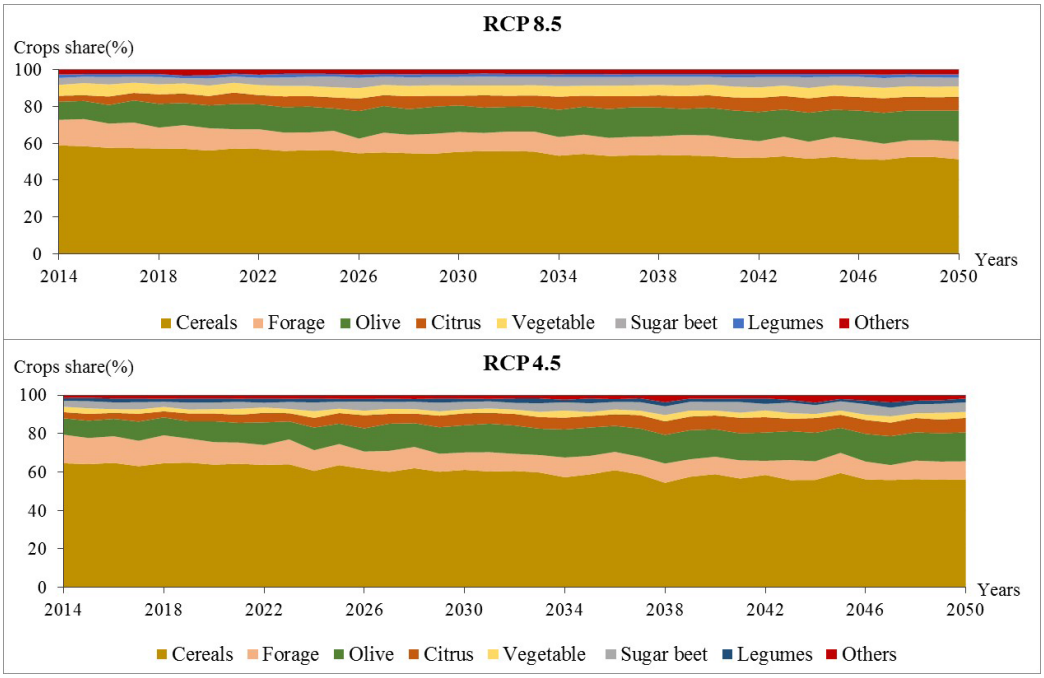

Figure 8. Predicted changes in the crops according to the climate change scenarios, RCP 4.5 and RCP 8.5

In the Tadla sub-basin, the reduction in water inflows will lead farmers to adapt to this new situation and thus, to optimise their choices by opting for crops that require less water, but offer good margins, in order to maximise their profits. Thus, an increase in areas allocated to tree crops, sugar beet and vegetables will be recognised at the expense of cereal and forage crops.

CONCLUSION

According to the two climate scenarios simulated in this study, RCP 4.5 and RCP 8.5, it was found that climate change may severely affect the agriculture sector in Tadla region. The total agricultural profit will have a declining trend (-0.34% per year, in the case of the climate scenarios, RCP 4.5 and -0.44%, for the RCP 8.5). This will be mainly due to the reduction in cultivated areas caused by the declining availability of water inflows during the simulated years. On its part, the irrigation water shadow price is predicted to increase by 0.20% and by 0.28% each year according to the RCP 4.5 and RCP 8.5 climate scenarios, respectively. This result will occur mainly because of the irregularity of surface water inflows, making irrigation water a limiting factor of production. The risk for farmers differs according to the technology used, the mode of access to irrigation water and the spatial location of agricultural land in the sub-basin. The climate change will also affect the irrigation water consumption that will undergo a significant decrease over the years. This can be explained by the reduction in land since many areas are left uncultivated during unfavourable years. The reduction of cultivated areas will lead farmers to optimise their choice by opting for crops that require less water and make significant margins to maximise their profit.

Finally, this study offers a scientific approach and a useful decision tool for improving the understanding of potential climate change impact in order to help policy makers to select the most appropriate adaptation policies for the Tadla sub-basin.

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