# Dynamic Agro-economic Modeling for Sustainable Water Resources Management in Arid and Semi-arid Areas

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## Contents

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**Abstract**

The water resource has become increasingly scarce. This situation will become acute in the future years in Morocco and in other countries of the world. Furthermore, nonratial use of irrigation water resources constitutes a major constraint on agricultural development in Morocco's watersheds, including the Tadla subbasin. A better valuation and adoption of more water-efficient practices are becoming increasingly necessary, especially in arid and semi-arid regions. Thus, it is essential in these areas to have effective instruments to manage and organize the control and allocation of water resources and ensure their protection and conservation. In this context, the aim of this work is to analyze water resources sustainability in the current context of agricultural policies with estimating the likely changes in water management parameters and in the sensitivity of the agricultural sector to possible external shocks. Given the multidimensional nature of water management, this research presents an integrated agronomic, economic, and hydrological modeling for the Tadla subbasin in Morocco, which classifies agricultural areas according to different sources of irrigation water. To promote the database of this modeling framework and to give a clear idea about the agro-economic system functioning underlying the current water management in the study area, we have characterized Technico-economic efficiency and water valuation through the study of the main agricultural crops in the Tadla region. The characterization of the agro-economic system was followed by a modeling of this system and then by an analysis of water management in the study area. The proposed model is disaggregated by territorial unit, municipalities, water irrigation sources, and crops. This tool allows decision-makers to predict the interannual variations of selected socio-economic indicators of water management according to different scenarios. To test the sensitivity of water valuation to external shocks, we first simulated the impact of an increase in the selling price of irrigation water applied to surface water in the irrigated perimeter of Tadla. Another type of exogenous shocks related to climate change was tested, and we examined their potential impacts on the long-term agricultural water management in the region. Given the results, this research provides a viable modeling framework for sustainable water resources management in order to help decision-makers to improve irrigation water management and mitigate the exogenous shocks effects on the system sustainability in arid and semi-arid areas.

## Introduction

The world is facing major and growing challenges to maintain the sustainability of water resources and meet the growing demand for water (Bastiaanssen et al. 2007). Sustainable water resources management has become a central topic for the implementation of sectoral policies related to water resources and one of the most studied issues in research laboratories working on natural resource management. Given this importance, water management conflict was among the pressing issues to take care during the UN Conference on climate change (COP 22) held in Marrakech, November 2016, especially since half the food produced worldwide come from irrigated areas and drained land (Bastiaanssen et al. 2000; Lobell et al. 2003).

In Morocco, the effects of climate change can be dramatic on agriculture which production is related to the amount and distribution of annual rainfall in rainfed areas and to the water amount stored in Dams and groundwater for irrigated perimeters (Benabdelouahab et al. 2016). The challenge is more serious for the arid and semi-arid regions, like Tadla region, where water resources is facing a number of constraints, including spatial and temporal climate irregularities, population pressure, accelerated urbanization, and food security requirements. These constraints require not only the development of the water supply management strategy, but also the application of the demand management approach.

In addition, competition for access to water resources is increasing between sectors. In this context, agriculture, which considered to be the most water consuming sector with more than 78% of mobilized water (according to the Ministry of Energy, Mines, Water and Environment), faces several problems related to water management. Consequently, this sector is asked to increase its productivity by practicing crops that optimize water use efficiency. However, since water is available to users with a highly subsidized price (Lionboui et al. 2014), users have no incentive to conserve this resource, which is sometimes overexploited or wasted without paying attention to its rarity. Even more, the cost of water mobilization, which has become so high in the last years, reflects a growing imbalance between water supply and water demand for the majority of the country's river basins. Alarming depletion of groundwater, drying-up of water sources, deterioration of water quality, and the risk of declining availability of water resources due to climate change are all signs that indicate the worsening situation (MDCE 2015). This has led to a strong mobilization to consolidate institutional reforms and agricultural policies for a rational sharing of water resources between different users.

Since the application of the water laws, 10-95 law and later 36-15 law, the policies of the country were redirected towards a decentralized management of water resources according to the rules of good governance. Public action has focused on a territorial approach with a basic unit: the river basin, involving a very wide range of stakeholders, in order to take an interest in all sectors concerned by water resources: agriculture, industry, tourism, and municipal water.

Often hydrologists and agronomists are more interested in the functioning of hydrological systems (reservoirs or aquifers) and agronomic systems (plants), respectively, without taking into account the economic principles that are essential

for sustainable development. Economists of natural resources, on their part, have made a significant contribution to sustainable development modeling, but their work usually simplifies the physical complexity that affects decisions on all the natural resources system. Hence, the need to bring the work of hydrologists, agronomists, and economists is closer together to develop an analytical framework for sustainable water resources management.

Water resources management is an interdisciplinary topic; therefore, integrated modeling, obtained by hydro-economic models that represent the hydrological, environmental, and economic water resources systems into a coherent framework, appears currently important (Blanco-Gutiérrez et al. 2013; Brouwer and Hofkes 2008; Heinz et al. 2007). These models have allowed water managers to evolve from a static vision of a simple water supply management problem with a single purpose to a long-term demand management approach that include the economic concept (Harou et al. 2009). In this context, different types of interdisciplinary modeling frameworks have been developed to address the different scales, particularly in the agro-economic field (Esteve et al. 2015; Peña-Haro et al. 2009).

In order to enhance the involvement of stakeholders at the basin level and to highlight the conflicts around water allocation, the adoption of a water management tool is crucial to facilitate political decision-making and to improve the sharing of water resources between all users. Thus, this modeling framework consists of an intra-annual static integrated agronomic, economic, and hydrological optimization model in addition to an interannual recursive dynamic model, which combines simulation and optimization.

This chapter has been conducted in three main stages. After a first step introducing the area concerned by this chapter, the second step was devoted to characterizing technical efficiency, economic efficiency, and water valuation through the main crops in the Tadla region. Once the system is characterized, the next step was to model this water management system and then to analyze its sensitivity to external shocks in the long-term.

## Water Resources Management in the Tadla Region

We are all aware today about the role of water resource in the main economy sectors development in the Tadla region, including the agricultural sector. The necessary trade-off between sectors in the water distribution will be one of the major problems in water management for future decades, and the agricultural sector will be constrained by other uses. Therefore, improving the management and efficiency of water resources use in agriculture is crucial for the country and especially for the Tadla region. In this context, considerable scientific research efforts must be undertaken to support the development strategies of the Morocco Green Plan in order to ensure a rational and optimal management of water resources in the irrigated Tadla area. Before modeling this agricultural production system, it is important to have a better understanding of the current state of water resource management at the regional level. This section presents the water allocation and management for agricultural use in the irrigated Tadla area.

## Choice of the Study Area

As part of this research, we will focus on the Tadla subbasin. The choice of this basin is due to both strategic and practical considerations. Indeed, the Tadla basin plays a strategic and economic role in terms of water availability for the central part of the country and in terms of the pressure due to the increasing water demand within the basin and by the neighboring regions, which are experiencing an unceasing water deficit, particularly in the Doukkala and Haouz regions. From a practical point of view, the choice of this watershed is justified by a considerable saving of material resources, particularly for surveys, since this work will benefit from a considerable knowledge and data of the biophysical environment of this basin. The presence of one of the oldest and largest irrigated areas of this basin, as well as its economic and environmental importance, has resulted over time in the accumulation of a large number of studies and researches for which the results will be an important knowledge for the achievement of this work.

The Tadla subbasin covers a total area of 320,000 ha. The useful agricultural area is about 300,000 ha, of which 124,600 ha are irrigated and 207,700 ha of land divided into the cultivated area, which represents 135,205 ha, forests with an area of 10,325 ha, and an area of 16,220 ha which is not cultivated.

The subbasin of Tadla is located 270 km south-east of Rabat and covers an area of about 3600 km$^2$ and extends north of the High Atlas (ABHOER 2012). It is bounded to the north by the Phosphates plain, which gradually rises without a definite transition. Towards the east, the plain narrows along the Oum ERRabia and the reliefs of the *Zaïan* region. In the West, no geographical limit separates the Tadla from the BAHIRA that follows. The regional course of Wadi El-Abid will be taken as the regional and hydrogeological limit of the study area.

## Water Management and Development Plans

The large hydraulic areas of Beni Moussa and Beni Amir, located in the Tadla Basin, were originally developed according to the two canal systems A and B. The hydraulic system was designed in such a way that, in the same block (20–30 ha) and for a water flow of 25 l/s, the farmers use all the canal system in common. A district is cut into rectangular strips whose width is between 80 and 100 m and perpendicular to the tertiary channel. A quaternary channel of 400 m serves each of them along its length. In the canal system B, each band corresponds to a sole, and the area is divided into five soil types. A farm crosses all the soils and presents itself in the form of a rectangle whose direction of the length is perpendicular to the sprinklers. For the canal system A, farms are generally delimited by two sprinklers.

Since 1962, the canal system B has been chosen to achieve the four main objectives:

– Establishment of prescribed rotations to meet production objectives
– Collective mechanization of small farms

– Irrigation according to an identical water turn for all the farmers according to the soils crop occupation
– The introduction of the wheel line irrigation as an efficient technique of irrigation at the farm level

In fact, collective mechanization has never been adopted by farmers. The infiltration losses in the sprinklers penalize of course the plots furthest from the tertiary channel. Now, in the canal system B, farms located at a given distance from the tertiary waterway belong to the same farmer. The farm located downstream of the sprinklers is systematically disadvantaged, whereas the one that is upstream still benefits from the maximum flow. As a result of these constraints, the canal system B was neglected and crop rotation was liberalized. The crop production system at the farm level depends on water requirements and the volume of water available.

The water distribution within the irrigated area is achieved according to the water turn system. Meaning that the amount of water (8 h/ha) and a flow of about 25 l/s that flows inside one or more irrigation bloc according to a pre-established program of the cultivated crops. At present, since crop rotation is liberalized, water turn is set up on the basis of the individual farmers demands depending on irrigated areas, transformed into hourly allocations based on crop water requirements and according to this, farmers can irrigate each week.

At the level of the water network distribution, the malfunctioning of some control structures and the absence of a reliable measurement network do not allow an equitable distribution of water volumes across all sectors of the irrigated area.

In terms of irrigation techniques, the most commonly used method is surface irrigation, called "Robta" also known as flood irrigation, which consists in irrigating flat strips in small areas (50 m$^2$). We have to notice that in the Tadla area, the choice of irrigation model is based on surface irrigation at the beginning of its development. The choice of this system could be justified according to socio-economic considerations, in particular, the use of more labor and few imported equipment.

The main reason why farmers continued to use the surface irrigation system was the poor maintenance of the initial land leveling, which gradually deteriorated because of the crop cultivation practices and tillage (Benabdelouahab et al. 2015).

## Crops Water Allocation in the Agricultural Production System

In Tadla region, the cultivated crops require more or less quantities of water depending on the production system, which depends also on the physiological needs of each plant. Table 1 shows the total average volumes consumed by major crops during 10 cropping years between 2005 and 2014.

During these cropping years, forage crops consumed more than 34% of the total amount of water distributed, followed by cereals, about 18%. These crops account for the most dominating crops in the area.

**Table 1** Average water volumes consumed per crop

| Crops | Average area (ha) | Average volume (Mm³) | % |
|---|---|---|---|
| Cereals | 45 352 | 136 | 18 |
| Sugar beet | 14 247 | 114 | 15 |
| Vegetable | 10 746 | 54 | 7 |
| Citrus | 7 784 | 93 | 13 |
| Olive | 15 235 | 91 | 12 |
| Forages | 21 310 | 256 | 34 |
| **Total** | **115 210** | **744** | **100** |

Source: ORMVAT (2016)

**Table 2** Share of irrigation water cost in relation to total production costs

| Crops | Total inputs cost (Dh/ha) | irrigation water cost (Dh/ha) | The total cost share (%) |
|---|---|---|---|
| Cereals | 5 909,0 | 540 | 9,1 |
| Sugar beet | 9 111,4 | 1 440 | 15,8 |
| Vegetable | 13 620,0 | 900 | 6,6 |
| **Citrus** | 10 629,0 | 2 160 | 20,3 |
| **Olive** | 4 680,0 | 1 080 | 23,1 |
| **Forage** | 5 582,5 | 2 484 | **44,5** |

Source: ORMVAT (2014)

**Irrigation Water Cost in the Production System**

By comparing the cost of irrigation water with other production input costs, we notice large differences depending on crop production (Table 2).

While the irrigation water cost accounts for 44.5% of the total inputs cost for forage crops, this ratio represents only 9% for cereals (ORMVAT 2014). This ratio is explained by the fact that forage crops, such as alfalfa, consume to much irrigation water compared to cereals.

## Irrigation Water Pricing

Since the 1960s, Morocco has faced an important challenge that is the pricing of irrigation water in order to promote the water use efficiency. In the tariff system, the structure of the fee paid for water is based on the volume of water consumed, which provides the user with a transparent and simple tariff signal and encourages him to have a conservative behave towards water. Since its introduction by the 1969 Code of Agricultural Investment (CIA) by Dahir 1-69-25 July 1969 and Decree 2-69-37, on the conditions of distribution and use of irrigation water in the perimeters, water pricing has been the subject of several discussions in order to equilibrate between funding up water service charges and ensure the water valuation and potential productivity enhancement. So that farmers have the capacity to pay water irrigation fee at a rate that ensure the sustainability of their system (Belghiti 2005).

The beneficiaries' financial participation takes two forms: the first one consists of paying part of the costs of creating irrigation schemes by a direct participation in land valuation and the second form is linked to fees of the use of irrigation water that permit to cover all operating costs for maintenance and depreciation of external irrigation equipment.

Since the first irrigation water charges fixed in 1969, there have been significant increases. Indeed, the tariff for irrigation water in 2005 is 10 times the initial price of 1969 (Fig. 1). The evolution of the water price is considered as slow when it is compared to important increase of inputs and equipment materials prices.

The evolution of irrigation water charges reveals three major periods:

- The first period from 1969 to 1979 was characterized by maintaining the same water charges fixed in 1969.
- The second period from 1980 to 2008 was characterized by successive increases in water charges. This period was marked by the following tariff measures: first, the doubling of the water charge rate in 1980 (fixed at MAD $0.048/m^3$) and the revising of the water charges formula according to the evolution of prices and salaries in 1983.
- The third period from 2009 to 2016 was marked by a stabilization of the water charges.

Over the years, the tariff system foresees a gradual application of the water charges, called the equilibrium rate, in accordance with the gradual effects of irrigation and the learning production in irrigated system. The irrigated perimeter of Tadla was concerned by a decision to increase the irrigation water charges. Since its publication in the official bulletin No. 5781 on October 26, 2009, this joint decision between the Ministry of Agriculture and Maritime Fisheries, the Ministry of the Economy and Finance and the Ministry of Energy, Mines, Water and Environment (No. 2451.09/17 September 2009) has not been applied until now.
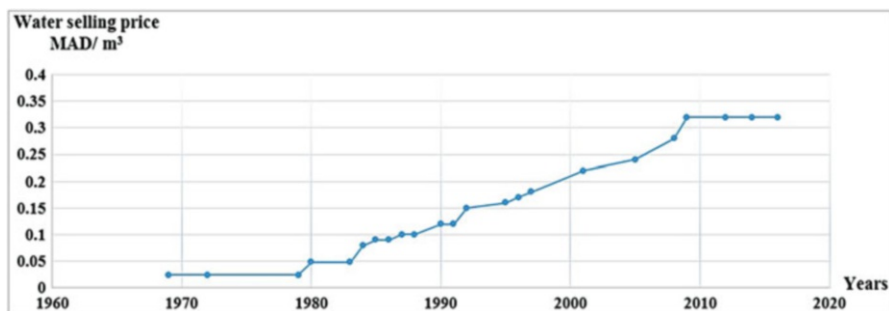


**Fig. 1** Evolution of irrigation water selling price in Tadla

## Hydro-Agricultural Subsidies

In order to improve farms financial resources in Morocco, agricultural policy offers grants and credits under favorable conditions for beneficiaries. The Agricultural Investment Code (CIA) introduced in 1969 provided new forms and formulas of aid to farmers. These grants, subsidies, or loans are intended, in particular for the acquisition of agricultural equipment, the intensification of crop production, and the development of agricultural properties.

In the irrigation water component, governmental subsidies are for drip irrigation projects and additional equipment and materiel.

These subsidies include (MAPM 2016):

– Drilling and wells casing
– Supply and installation of water pumping equipment
– Development of water storage ponds
– Supply and installation of equipment supply and installation of irrigation water supply and distribution pipes
– Provision and fitting of irrigation water pipes
– Development of basins for water storage
– Adaptation of the existing drip irrigation system in the context of densification of tree plantations

It should be noted, however, that the subsidy can only be granted at the first installation and that any renewal of equipment is excluded from such subsidies.

The following table presents the subsidy rates for localized irrigation projects and supplementary development projects reserved for farmers (Table 3).

In addition to public investments and subsidy incentives, to promote private investment in agriculture, the State has introduced a tax exemption for the agricultural sector, which benefits from the minimum import duties and taxes imposed on imports of some products and agricultural equipment (irrigation equipment, drilling and groundwater exploitation equipment, etc.).

**Table 3**  Subsidies rate for drip irrigation projects and complementary development projects

| | Subsidy rate | |
|---|---|---|
| Investment type | Individual projects | Collective or smallholder projects |
| **Drip irrigation project** | 80% | 100% |
| **Complementary development projects** | 80% | 100% |
| **Grant limit (Dh/ha)** | 36,000 | 45,000 |

Source: MAPM (2016)

## Modeling Contribution to Evaluate Farms Performances in Terms of Technical and Economic Efficiency and Water Valuation

Improving production efficiency is a key objective of government action to mitigate inefficiencies and increase the incomes of agricultural producers. Thus, the analysis of the technical, allocative, and economic efficiency levels of the agricultural producers of the irrigated perimeter of Tadla in Morocco is one of the main objectives of this chapter. In order to estimate efficiency indices, the methodology of the data envelopment analysis was adopted. This method is based on microeconomic theory that compares all similar units in a given population and simultaneously takes into account several dimensions (Avkiran 1999; Evanoff and Israilevich 1991; Isik and Hassan 2003; Sathye 2001; Wheelock and Wilson 1999). It determines the frontier of efficiency from the point of view of best practice. The empirical application of this method consists in generating a production boundary by means of mathematical programming.

In the Data Envelopment Analysis (DEA) method, the efficient boundary is defined by the best performing practices of the sample used (Hoang 2013). In order to define the technological envelope used as a reference for measures of technical, allocative, and economic efficiency, it is necessary to define the outputs and the inputs used in the production technology (Coelli et al. 1998). To calculate the technico-economic efficiency scores, an aggregate of outputs and five aggregates of inputs were considered. The sample used consists of 60 farms chosen according to the method of access to irrigation water. Therefore, a typology based on the mode of access to irrigation water was adopted in this chapter, in order to analyze the diversity observed in the farmers' behavior, especially towards water management. This typology considers four types of farms: (a) farms with an easy access to groundwater and surface water (A_SGW); (b) farms with an easy access to surface water and with limited access to groundwater (A_SW); (c) farms with easy access to groundwater and not having access to surface water (A_GW); and (d) farms who do not have access to surface water and groundwater (R_A) (Lionboui et al. 2016b).

The results showed significant variability in technical, allocative, and economic efficiency between farms and irrigation sources. Farms that use groundwater ensure better irrigation water valuation in comparison with those that combine surface and underground water and those that used only water providing from dam.

## Technical and Economic Efficiency of Tadla Farms

The results obtained show a heterogeneity of farms efficiency scores in the sample. In terms of technical efficiency, the average score is 90% with an amplitude ranging from 51% to 100% (Fig. 2).

The results suggest that overall, farmers could improve their production by almost 10% without increasing the levels of production factors used. This indicates that these farms do not exploit all available technology. Concerning allocative efficiency, about 8.33% of farms have an allocative efficiency score below 0.5. This shows that
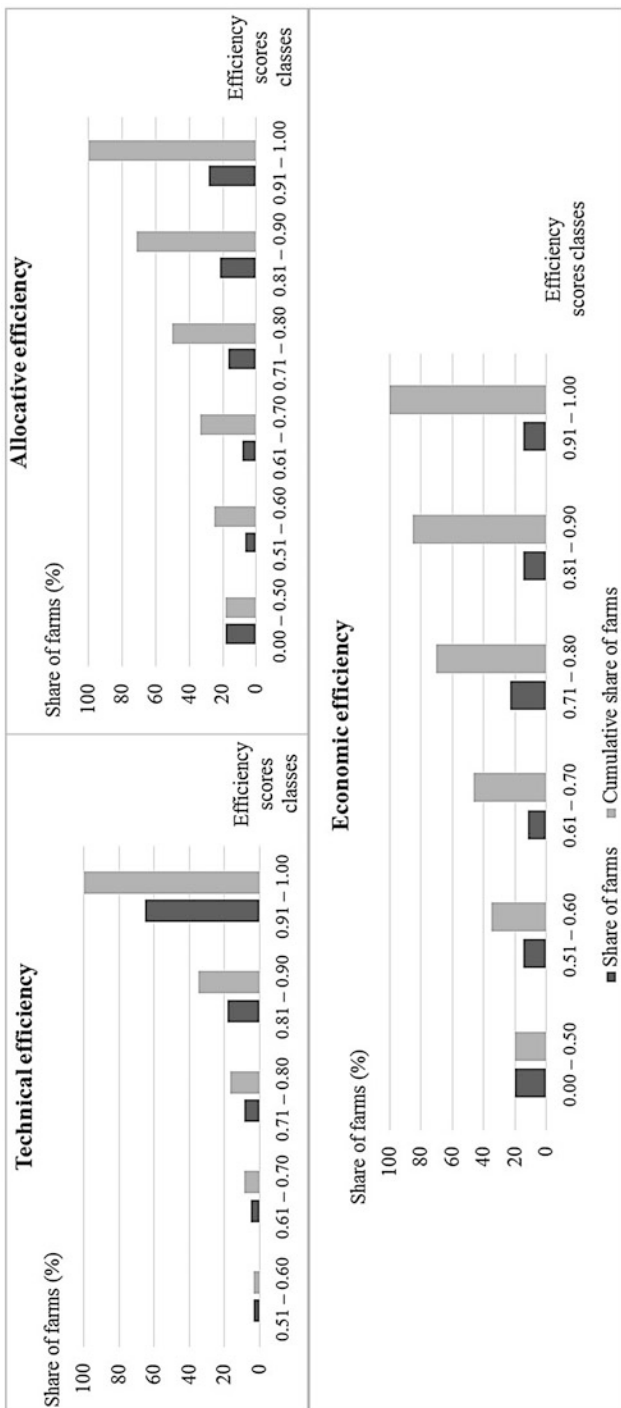
**Fig. 2** Frequency distribution of technical, allocative, and economic efficiency scores

these farms are not able to allocate optimally their production factors in order to produce a given level of production. For these farms, significant improvements are possible in terms of allocative efficiency.

Economic efficiency combines technical and allocative efficiency at the same time. The average economic efficiency score is about 69%, for the observed farms. However, it is noteworthy that 20% of farms have an economic efficiency score less than 50%, which gives an idea of the possible improvement in order to improve farmers' production and income.

## Farms Efficiency According to the Mode of Access to Irrigation Water

Considering different modes of access to irrigation water in the Tadla region, the average scores of technical, allocative, and economic efficiency are presented in Fig. 3.

The results show that farms conducted in "A_GW" mode are technically the most efficient followed by those conducted in "A_SGW" with an average efficiency score of 0.95 and 0.94, respectively. Then come those conducted in "A_SW" mode, which have an average technical efficiency score equal to 0.84 and those conducted in "R_A" mode, with an average technical efficiency score of 0.82. However, we observe that there is no significant difference between the average technical efficiency scores for the four farm types. That said, there is no significant heterogeneity between the four farms types in terms of using the available technology.

Except for farms conducted in "R_A" mode, results show that there is no significant difference between the averages allocative efficiency scores for the other three farms types. Thus, farms conducted in "A_GW" mode are the most efficient in terms of production factors allocation, with an average score of 0.88 followed by those conducted in "A_SGW" mode, with an average allocative efficiency score of 0.86. Then, come the farms conducted in "A_SW" mode, which has an average allocative efficiency score equal to 0.79. Finally, the farms conducted in "R_A" mode with an average allocative efficiency score of 0.46. Also in the case of allocative efficiency, we note that there is not a great difference between the averages scores for the first three
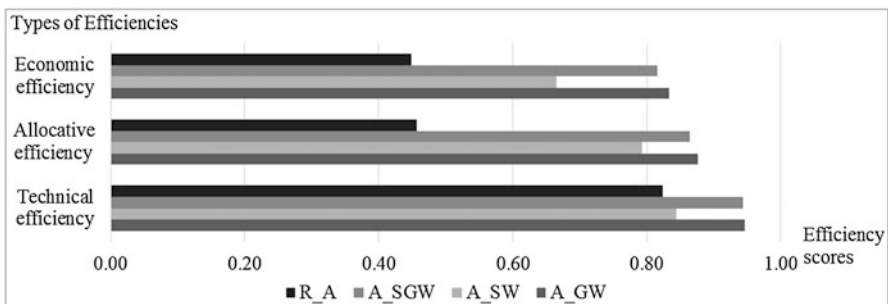


Fig. 3 Technical, allocative, and economic efficiency according to the mode of access to irrigation water

types of farms. This shows that it is possible to be efficient, in terms of the allocation of production factors, irrespective of the source of irrigation water.

In terms of the economic efficiency, farms conducted in "A_GW" mode are economically the most efficient with an average score equal to 0.83. Farms conducted in "A_SGW" mode, come second with an average score of 0.82. These two types of farms are characterized by the possibility of choosing the moment considered appropriate to irrigate their crops and to adopt the irrigation technique most adapted to the context of their farms. Then come those conducted in "A_SW" mode, with an average economic efficiency score of 0.67. According to the farmers' judgment, this type of farms receive irrigation water at inappropriate times and the majority of these farms adopt flood irrigation. Finally, farms conducted in "R_A" mode are the last, with an average economic efficiency score of 0.45. These farms depend directly on rainfall, which quantity varies depending on the climatic years.

## Farm Efficiency and Irrigation Water Valuation

In Morocco, the issue of water valuation is at the center of policymakers' concerns. Most studies that analyze this concept consider the water valuation indicator as the net margin per cubic meter of irrigation water used (e.g., Sali and Monaco 2014; Stanley 2005; Waughray and Rodríguez 1998). However, farmer's interest is not necessarily similar to that of the community, which is more interested to the overall income and has several long-term development goals such as water conservation. In this chapter, the water valuation indicator was approached according to the interest of the community, in terms of value added per cubic meter of irrigation water used by each observed farm.

In order to determine a relationship between water valuation and farms economic efficiency in the Tadla region, the average scores of economic efficiency as well as the average indicators of water valuation have been posted for each farm type (Table 4).

The results show that farms conducted in "A_GW" mode have the better value of water valuation indicator, with an average of 2.19 MAD/m$^3$. In addition, this type of farms is the most efficient with an average economic efficiency score of 0.83. In second position, farms conducted in "A_SGW" mode, come with an average water valuation indicator and economic efficiency score of 1.98 MAD/m$^3$ and 0.82, respectively. Finally, the farms conducted in "A_SW" mode, get the lowest value of water valuation indicator (1.83 MAD/m$^3$) and of economic efficiency score (0.67). This type of farms achieves on average lower yields than the other types because of the difficulties water management between these farms which depend only on the water coming from the dam.

**Table 4** Economic efficiency and irrigation water valuation

| Farm type | Average economic efficiency | Gross margin (MAD/ha) | Irrigation water use (m$^3$/ha) | Water valuation (MAD/m$^3$) |
|---|---|---|---|---|
| A_GW | 0.83 | 17931.80 | 8771.34 | 2.19 |
| A_SW | 0.67 | 11637.33 | 7305.08 | 1.83 |
| A_SGW | 0.82 | 18002.24 | 9859.97 | 1.98 |

# Agro-Economic Modeling Framework: Evolution of Water Management Indicators

The irrational allocation of irrigation water is a major obstacle to the development of agriculture in the country's watersheds, particularly the Tadla basin. In this regard, it is essential for the study area to have effective instruments to manage, organize allocation, control the use of water resources, and ensure their protection and conservation. This third part of the chapter constitutes a contribution to study this type of issues that arise in this basin, through the development of an integrated agronomic, economic, and hydrological modeling framework disaggregated by territorial unit, communes, irrigation sources, and crops.

## Vision and Approach

For a sustainable development of water resources, several orientations and principles have been defined throughout the world, which is essential for regional development, particularly, in the arid and semi-arid regions of the world. In order to apply these orientations and principles to the sustainable management and to the maintenance of water resources systems, it is essential to translate them into operational concepts specific to each region. This research presents a modeling framework that focuses on the quantitative analysis of the sustainable management of irrigation water resources at the watershed scale. We conceptualize a decision-making approach for long-term sustainable management of water resources in a semi-arid climate, where irrigation is the main water user. Sustainable water management has been taken with regard to ensure a stable irrigation water supply according to crop water requirements and to maintain a sustainable relationship between irrigation practices and environment. In order to reflect the interdisciplinary nature of water resources issues, an integrated agronomic, economic, and hydrological approach has been developed to model and analyze sustainability of water resource management across the Tadla subbasin.

Hydrological, agronomic, and economic relationships are integrated into an endogenous modeling framework applied at the basin scale. The results of the modeling framework are examined in terms of risks related to hydrological and political uncertainties and to the impact of climate change on agricultural activity in the region. This shows that the modeling framework can provide policy instruments that can guide the future choices of decision makers for more rational use of water resources.

The modeling framework presented in this chapter is a combined model with a short-term annual model and an interannual control model. The integrated agronomic, economic, and hydrological model in the Tadla basin, which is applied to a 1-year time horizon with 12 periods (months), is defined as a short-term (annual) model. The objective function of the short-term model is to maximize the total value added at the watershed level in 1 year. The introduction of the dynamic aspect in the model will be done by creating a set representing the years and a loop. This loop will

make iterations taking into account parameters and variables that will be introduced over the years (Lionboui et al. 2016a). Long-term decision-making aims to achieve long-term optimality that will meet the immediate crops water requirements without compromising those of the future years.

In the static model, essential hydrological, agronomic, and economic relationships are integrated into a coherent analytical framework at the basin level to reflect the interdisciplinary nature of water resource management issues. The interannual model includes long-term changes and uncertainties in water supply and demand, in agricultural policies, and incorporates the sustainability principles for monitoring the performance of the basin system. The relationships between short-term irrigation practices and their long-term economic and environmental consequences are also taken into account in interannual modeling.

The methodology adopted is applied to the case study of the Tadla basin. The research was based on field data collected and surveys carried out in the region. The problems in the study area are specifically analyzed, and suggestions are presented based on the modeling framework results throughout this part.

## Variation in the Shadow Price of Water

### Water Shadow Price in a Normal Year

The shadow price of water is defined as the marginal increase in the value of the objective function (agricultural profit) if the water supply is increased by an additional cubic meter. The shadow price reflects the scarcity of the water resource. Thus, it represents one of the most important results presented in this chapter that will make it possible to assess the economic value of water in different agricultural areas (Fig. 4).

The results obtained show a heterogeneity of the water shadow price values within the same Agricultural Territorial Unit. Farmers do not have a similar chance of accessing irrigation water. The average shadow price of irrigation water is around 1.33 MAD for 1 $m^3$ of water. It varies between 1.19 MAD/$m^3$ in the agricultural areas of the third agricultural territorial unit "UTA3" to 1.40 MAD/$m^3$ on average for agricultural areas belonging to the first agricultural territorial unit "UTA1."

While the selling price of irrigation water at the first agricultural territorial unit is 0.32 MAD/$m^3$, its shadow price is 1.40 MAD/$m^3$. This difference can be explained by the irregularity of water supplies through irrigation canals fed by the "Ahmed El Hansali" and "Bine Elouidane" dams. At the level of the second agricultural territorial unit, the average cost for the extraction of groundwater is estimated at 0.60 MAD/$m^3$ at the regional level according to the Regional Directorate for Agriculture. However, the shadow price calculated for this zone is 1.25 MAD/$m^3$ on average. In the medium term, farms in this region do not have a problem of water availability since it is a private pumping area. However, this value is mainly due to the fact that farmers invest in high value-added crops.

Finally, for the third agricultural territorial unit, the right of irrigation water is a private property and the rights holders have the possibility to put it on sale or rent.
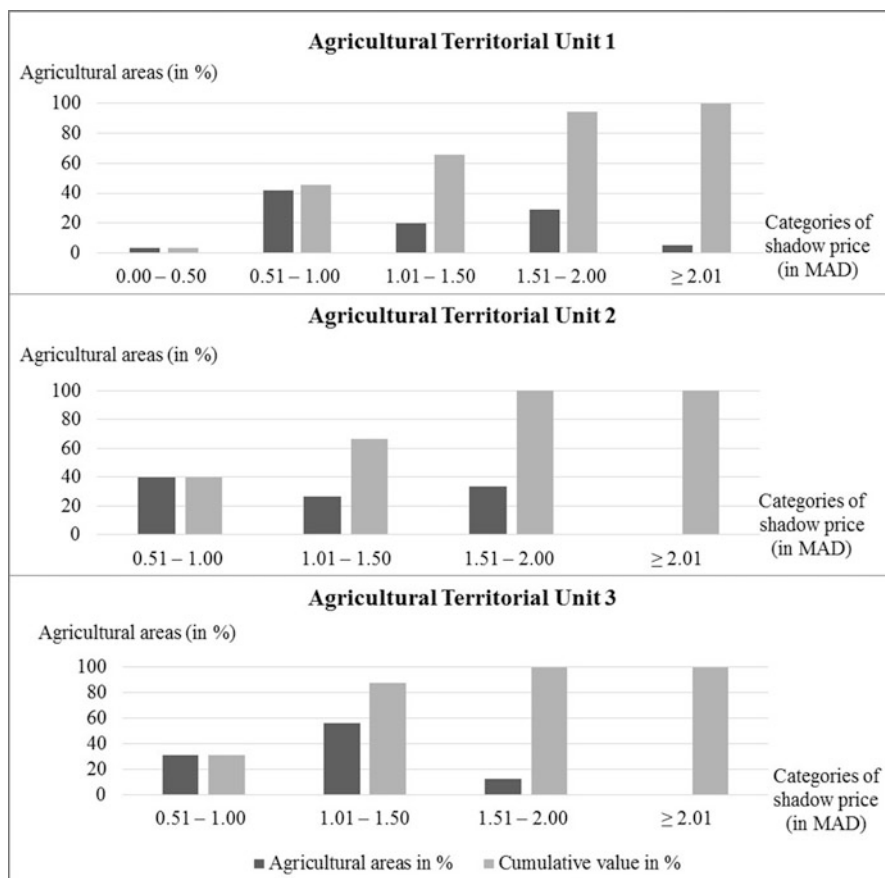
**Fig. 4** Frequency distribution of the shadow price values in different agricultural areas

The sale price of the water estimated by the Provincial Directorate of Agriculture is 0.22 MAD/m$^3$. This value, which is significantly higher than its shadow price of 1.25 MAD/m$^3$ on average, does not reflect its true value.

### The Shadow Price of Irrigation Water in the Situation of an Increase in its Selling Price

The water value analysis is a relevant indicator of water pricing (Griffin 2001). This scenario simulates the impact of an increase of 25% in the selling price of irrigation water applied in Tadla irrigated perimeter in the case of a normal year. The level of increase selected for this simulation is 0.4 MAD/m$^3$, estimated according to the Tadla Adjustment Plan.

In the case of a selling price of 0.40 MAD/m$^3$, the marginal value of irrigation water increased to 1.34 MAD/m$^3$ on average in comparison with the current situation (Table 5).

**Table 5** Water shadow price variation according to the farms type in the Tadla subbasin

| Farm type | Water shadow price | |
|---|---|---|
| | Absolute value (MAD/m$^3$) | Variation/current situation (%) |
| A_SW | 1.45 | +3.57 |
| A_GW | 1.91 | 0 |
| A_SGW | 1.15 | +10.5 |



**Fig. 5** Evolution of the shadow price of irrigation water according to the climatic scenarios

With the exception of farms conducted in A_GW mode, which will not be affected by the increase in the water selling price, the shadow price of irrigation water will increase significantly at the farms conducted in A_SW and A_SGW modes. This variation in the water shadow price raises fundamental questions about the choice of crops, and the measures taken by farmers to reach a good agricultural profit while ensuring the sustainability of water resources in the region. The increase in the selling price of irrigation water risks weakening farms conducted in A_SW and A_SGW modes. However, the average water shadow price remains well above its selling price. Therefore, the increase in the selling price of water is not a limiting factor in this case.

### Evolution of the Shadow Price of Irrigation Water Under Climate Change

In this part, the shadow price of irrigation water will allow to assess the variation of its value over the years according to the two climatic scenarios RCPs 4.5 and 8.5 (Fig. 5).

The shadow price of irrigation water calculated after calibration is 1.13 MAD/m$^3$ for the climatic scenario RCP 4.5 and 1.08 MAD/m$^3$ for RCP 8.5 in the Tadla subbasin. These values are high, compared to the selling price of irrigation water in this region, which is 0.32 MAD/m$^3$.

In the years following the reference year, the shadow price of irrigation water will have an estimated increase of 0.0022 MAD/m$^3$ each year under RCP 4.5 scenario and 0.003 MAD/m$^3$ according to RCP 8.5 scenario. Thus, it will reach a maximum value of 1.26 MAD/m$^3$ in 2039. This result is due, on the one hand, to the irregularity of surface water supplies through irrigation canals fed by the "Ahmed El Hansali" and "Bine Elouidane" reservoirs in the Tadla sub-basin, which makes irrigation water a limiting factor in production. On the other hand, this can be explained by the

progress of planned agricultural intensification projects and the orientation of farmers towards high value-added crops.

## Evolution of Agricultural Profit

### Current Situation

The agricultural profit calculated at the Tadla subbasin level is 2094 million MAD per year, with an average per hectare of 9513.40 MAD. By maximizing the agricultural profit, its value realized by each agricultural territorial unit appears different from one unit to another (Fig. 6).

The first agricultural territorial unit "UTA1" contributes by 1193.58 million MAD and achieves the highest agricultural profit per hectare, 14231.48 (MAD/Ha). In this territorial unit, 92.74% of the cultivated land has access to irrigation water. As a result, farmers are achieving high yields because they have the opportunity to irrigate their crops. As for others agricultural territorial units ("UTA1" and "UTA2"), they are composed mainly of "Bour" rainfed agricultural land. The latter are entirely dependent on rainfall, which the amount varies according to the climatic years and directly affects crop yields.

### The Case of an Increase in the Selling Price of Irrigation Water

In the case of an increase in the selling price of irrigation water, the most important risk to be analyzed is the reduction of farmers' income. In general, a pricing policy, although beneficial for the community because of the positive effects on production, and on the water economy, it has no chance of being adopted if farmers do not generate sufficient income.

Concerning the variation in agricultural profit of farmers, the result of this simulation shows a decrease of around −6.33% in subbasin of Tadla. Thus, its value decreased from 2094 million MAD realized in reference year to 1961.42 million MAD.

**Fig. 6** The contribution of each agricultural territorial unit to the total agricultural profit of Tadla subbasin
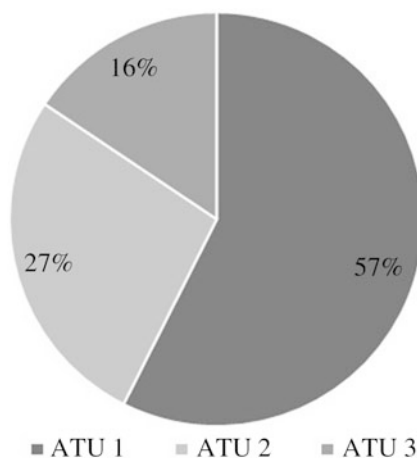
The impact of the increase in the selling prices of water on the agricultural profit per hectare is noticeably significant in A_SW and A_SGW modes, which use surface water for irrigation (Fig. 7). However, farms conducted in A_SW mode are most vulnerable to the effects of this change in the selling price of irrigation. Their agricultural profit per hectare decreased significantly, by 14.49% on average, because they depend directly on surface water.

Then, the farms conducted in A_SGW mode comes in the second place by a decrease of 7.29% in their agricultural profit per hectare. These farms are relatively less affected by this simulation, since they combine the use of surface and ground water. Finally, farms conducted in A_WGW and A_R modes will not be affected because they are not concerned by the use of surface water.

## Change in Agricultural Profit Under Climate Change

Over the years, the agricultural profit will experience changes that vary according to climatic scenarios RCP 4.5 and RCP 8.5. The results of this research show that the agricultural profit per hectare will decline slightly in the years following the reference year. Its value will decrease by an annual average of −13.23 MAD each year for the climatic scenario RCP 4.5 and −15.97 MAD for RCP 8.5 (Fig. 8).

The total agricultural profit created in the Tadla subbasin on its part will have a downward trend. This decrease is quantified at −7.2 million MAD per year under scenario RCP 4.5 and −9.28 million MAD according to RCP 8.5. This is mainly due to the reduction in irrigation water supplies expected during the period under study. As well, we have noticed the existence of differences between agricultural territorial units in terms of the evolution of their agricultural profit. The decline in the value of agricultural profit is more pronounced at the level of the first territorial unit fed mainly by water supplies through the irrigation system channels coming from reservoirs. Unlike the other two units, the decline is less important in the short to medium term, because of the use of groundwater and water springs.
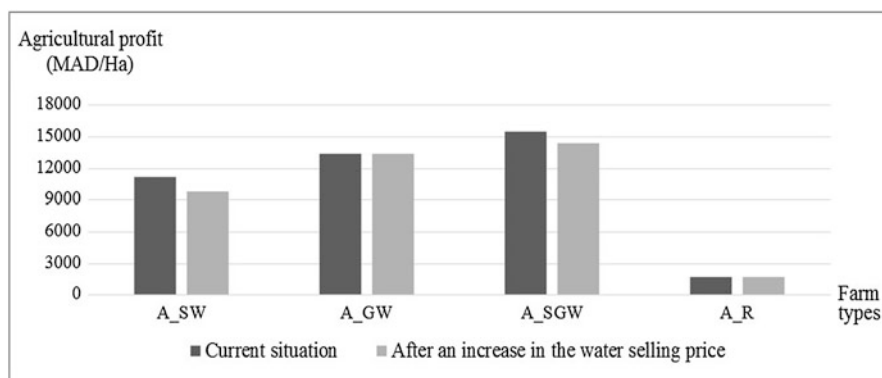


**Fig. 7**  Change in agricultural profit per hectare according to the mode of access to irrigation water
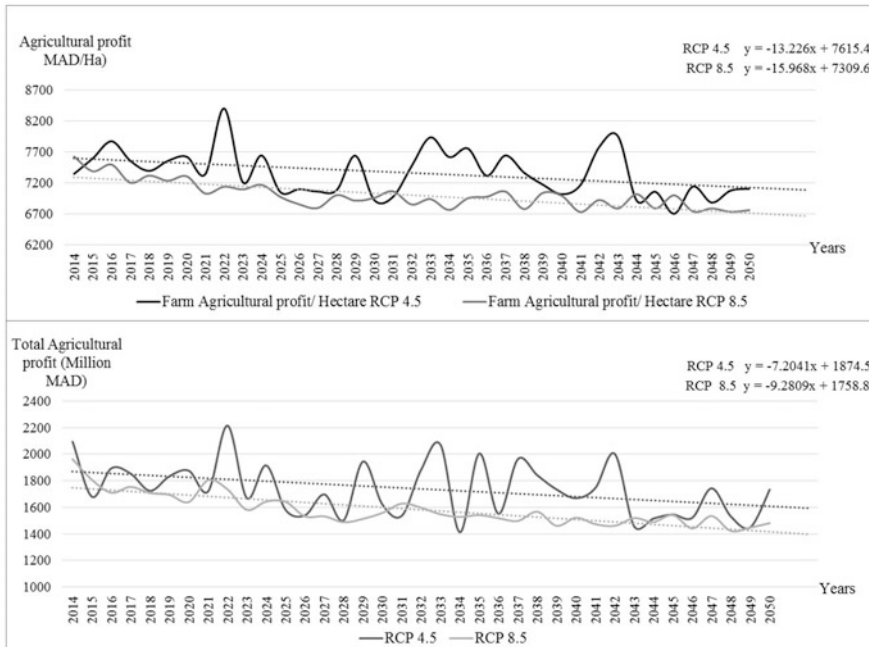
**Fig. 8** Evolution of total agricultural profit according to the climatic scenarios

## Change in Agricultural Land Use

### The Case of an Increase in the Selling Price of Irrigation Water

In the case of an increase in the selling price of irrigation water, the results show that this situation will lead to a slight decrease in the area allocated to irrigated crops (Table 6).

Indeed, this decrease is more visible in the first group of farms (A_SW/A_SGW), about −0.15%. The majority of these farms are directly dependent on surface water supplies. For the second group (A_GW/A_SGW), the cultivated area will decrease slightly by 0.02%. As a result, the rainfed area will have a small increase of 0.1%.

The main results obtained in the case of an increase in water selling price in terms of agricultural land use are summarized in Table 7.

With the exception of the increase in cultivated areas of cereal crops and the decrease of lands allocated to forage crops, the increase in the selling price of irrigation water did not have a major impact on the share of crops. Therefore, forage crops that will experience this decline are considered the crops most vulnerable to higher water tariff.

### Evolution of Agricultural Land Use Under Climate Change

Climate change is a problem of global concern considering its adverse effects on the economies of countries. In the case of Morocco, the expected climate change will

**Table 6** Effect of the increase in selling price of irrigation water on the agricultural land use

|  | Areas in the current situation (ha) | Areas in the case of an increase in the water selling price (ha) | Change/ current situation (%) |
|---|---|---|---|
| Farms conducted in A_SW/A_SGW modes[a] | 77657.27 | 77539.52 | −0.15 |
| Farms conducted in A_GW/A_SGW modes[a] | 29099.75 | 29093.58 | −0.02 |
| Total areas of irrigated crops (A_SW/A_SGW/ A_GW) | 92127.46 | 92014.47 | −0.12 |
| Total cultivated rainfed areas | 98139.6 | 98250.59 | 0.1 |

[a]Agricultural areas conducted in A_SGW mode are included in both groups: A_SW/A_SGW and A_GW/A_SGW

**Table 7** Variation in agricultural land use induced by an increase in the selling price of irrigation water

| Culture | Share of crops in the current situation (%) | Share of crops in the case of an increase in the water-selling price (%) | Change/ current situation (%) |
|---|---|---|---|
| Cereals | 67.645 | 67.856 | 0.211 |
| Forage crops | 15.73 | 15.549 | −0.181 |
| Vegetables | 1.272 | 1.265 | −0.006 |
| Sugar beet | 4.142 | 4.153 | 0.011 |
| Sesame | 0.122 | 0.125 | 0.004 |
| Legumes | 0.612 | 0.612 | 0 |
| Citrus | 2.012 | 2.001 | −0.012 |
| Olive | 7.915 | 7.887 | −0.027 |
| Almond | 0.138 | 0.138 | 0 |
| Pomegranate | 0.199 | 0.199 | 0 |
| Others | 0.213 | 0.213 | 0 |

have significant consequences on the water resources potential. In this situation marked by the declining availability of water resources, Tadla region, in Morocco, is facing a slight decrease of 1.90% in cultivated area. For the three agricultural territorial units of the subbasin, the use of agricultural land will vary over the simulated years. These variations are presented in the following figure through the shares of major crops at the regional level, according to climate scenarios RCPs 4.5 and 8.5 (Fig. 9).

In order to maximize their profit, farmers are obliged to adapt to the new situation due to the declining trend of water resources supplies in the Tadla subbasin. Thus, they optimize their choice by opting for crops that require less water and create a reasonable margin. Consequently, there will be an increase in the areas allocated to tree crops, sugar beet, and vegetables, to the detriment of cereal and forage crops.
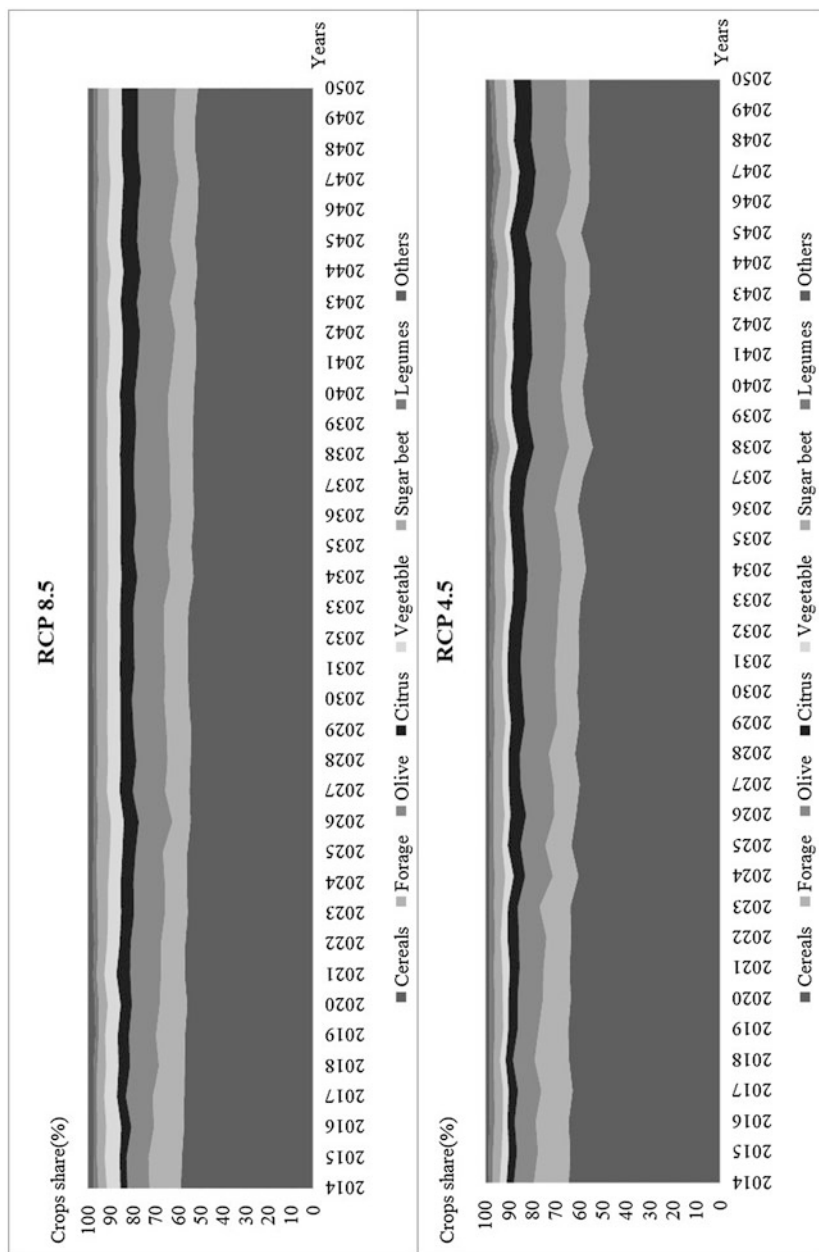
**Fig. 9** Evolution of agricultural land use according to the climatic scenarios

## Conclusions

Drought, water shortages, and in addition to the poor rules of sharing irrigation water, are factors that threaten the sustainable water supply, a major key element of agricultural production. The objective of a sustainable approach to water resource management is to achieve improvements in the efficiency of water use while preserving the associated environment. This objective requires detailed information on current water supply conditions, data on climate change risks, way of current water use, and the individual water needs for different users. Thus, the problem of this research revolves around this management approach in order to achieve the sustainability of water resources supply reserved to the agricultural sector at the watershed level. As a result, the use of modeling for decision-making, simulation, and prediction is increasingly felt to be a necessity to accompany the different stages of development of the agricultural sector in Morocco.

From the conceptual specification to the development of the model on the one hand, and from the preparation of data and the test of model to the processing of results on the other hand, the modeling framework developed in this research integrates the sustainability approach in water resource management. Thus, the model developed is strongly recommended as a decision support tool for the analysis of sustainability in the management of water resources at the watershed level.

This research can be added as another successful example of applying the systemic approach to water resource management. However, by formulating, solving, and analyzing the model developed during this research, some limitations appear. First, the proposed model integrates several components and assumptions are made for each of these components. Yet no rigorous study has been conducted to show how these assumptions within the different components affect others and how they affect modeling results when combined in a single model.

Although data from several surveys that we have conducted with farmers and decision-making institutions of the region are used in this research, a lot of data required for dynamic modeling, particularly forecasting data on agricultural policies, are still not available and cannot be estimated or guessed. For example, in economic relations, it is assumed that prices and costs are constant for all years of study in the long-term model, which can be subject to wide variation in the future. Therefore, for the practical use of the long-term model, it is better to provide estimates of these parameters or include more economic relationships in the model, so that some of these elements can be calculated by the model.

The modeling framework developed depends strongly on some empirical relationships between the hydrological, agronomic, and economic components and how sustainability criteria are expressed mathematically. The mathematical expressions of sustainability criteria in this research are closely related to our understanding of the specific problems at the study area level. Furthermore, if this modeling framework is applied to another watershed, the definitions and mathematical expressions will be modified according to the conditions specific to this area.

In order to go beyond these limitations and to create more new practical applications, the following efforts are needed in the future: (1) conduct additional research

to verify the interrelationships between the hydrological, agronomic, economic components, incorporated into the model; (2) carry out more scenarios to find the most appropriate agricultural policies adapted to the context of the region; and (3) conduct studies to asses model outputs.

Generally, the methodological approach used involved several sciences in order to understand a system that was, a priori, hard to pin down. This work seems ambitious for a single study; however, it reaches a viable modeling framework for sustainable water resources management in the Tadla region. Thus, thanks to the methodological approach adopted, we were able to integrate all the key aspects of different disciplinary fields (agronomic, hydrological, and economic) that were used to characterize the study area as well as possible. This is the originality of this research, which shows the feasibility and effectiveness of advanced modeling in sustainability analysis, a concept of the utmost importance that will strongly influence the future of water resources management studies.

# References

ABHOER (2012) Etude du Plan Directeur d'Aménagement Intégré des Ressources en Eau du Bassin de l'Oum Er Rbia et des bassins côtiers atlantiques. Ministère délégué auprès du Ministre de l'Energie, des Mines, de l'Eau et de l'Environnement- chargé de l'Eau, Rabat

Avkiran N (1999) An application reference for data envelopment analysis in branch banking: helping the novice. Int J Bank Mark 17:206

Bastiaanssen WGM, Molden DJ, Makin IW (2000) Remote sensing for irrigated agriculture: examples from research and possible applications. Agric Water Manag 46:137–155. https://doi.org/10.1016/s0378-3774(00)00080-9

Bastiaanssen WGM, Allen RG, Droogers P, D'Urso G, Steduto P (2007) Twenty-five years modeling irrigated and drained soils: state of the art. Agric Water Manag 92:111–125. https://doi.org/10.1016/j.agwat.2007.05.013

Belghiti M (2005) Valorisation de l'eau et tarification dans les périmètres de grande hydraulique au Maroc, Rabat

Benabdelouahab T, Balaghi R, Hadria R, Lionboui H, Minet J, Tychon B (2015) Monitoring surface water content using visible and short-wave infrared SPOT-5 data of wheat plots in irrigated semi-arid regions. Int J Remote Sens 36:4018–4036. https://doi.org/10.1080/01431161.2015.1072650

Benabdelouahab T, Balaghi R, Hadria R, Lionboui H, Djaby B, Tychon B (2016) Testing Aquacrop to simulate durum wheat yield and schedule irrigation in a semi-arid irrigated perimeter in Morocco. Irrig Drain 65:631–641. https://doi.org/10.1002/ird.1977

Blanco-Gutiérrez I, Varela-Ortega C, Purkey D (2013) Integrated assessment of policy interventions for promoting sustainable irrigation in semi-arid environments: a hydro-economic modeling approach article. J Environ Manag 128:144–160

Brouwer R, Hofkes M (2008) Integrated hydro-economic modelling: approaches, key issues and future research directions. Ecol Econ 66:16–22

Coelli T, Prasada Rao DS, Battese GE (1998) An introduction to efficiency and productivity analysis. Boston. Springer US

Esteve P, Varela-Ortega C, Blanco-Gutiérrez I, Downing TE (2015) A hydro-economic model for the assessment of climate change impacts and adaptation in irrigated agriculture. Ecol Econ 120:49–58. https://doi.org/10.1016/j.ecolecon.2015.09.017

Evanoff D, Israilevich P (1991) Productive efficiency in banking. Econ Perspect 15:11–32

Griffin RC (2001) Effective water pricing. J Am Water Resour Assoc 37:1335–1347

Harou J, Pulido-Velazquez M, Rosenberg DE, Medellνn-Azuara J, Lund JR, Howitt RE (2009) Hydro-economic models: concepts, design, applications and future prospects. J Hydrol 375:627–643

Heinz I, Pulido-Velazquez M, Lund JR, Andreu J (2007) Hydro-economic modeling in river basin management: implications and applications for the European Water Framework Directive. Water Resour Manag 21:1103–1125

Hoang V (2013) Analysis of productive performance of crop production systems: an integrated analytical framework. Agric Syst 116:16–24. https://doi.org/10.1016/j.agsy.2012.12.005

Isik I, Hassan M (2003) Financial deregulation and total factor productivity change: an empirical study of Turkish commercial banks. J Bank Financ 27:1455–1485

Lionboui H, Fadlaoui A, Elame F, Benabdelouahab T (2014) Water pricing impact on the economic valuation of water resources. Int J Educ Res 2(6):147–166

Lionboui H, Benabdelouahab T, Elame F, Hasib A, Boulli A (2016a) Multi-year agro-economic modelling for predicting changes in irrigation water management indicators in the Tadla sub-basin. Int J Agric Manag Dev 5:96–105

Lionboui H, Benabdelouahab T, Hasib A, Boulli A (2016b) Analysis of farms performance using different sources of irrigation water: a case study in a semi-arid area. Int J Agric Manag Dev 6:145–154

Lobell DB, Asner GP, Ortiz-Monasterio JI, Benning TL (2003) Remote sensing of regional crop production in the Yaqui Valley, Mexico: estimates and uncertainties. Agric Ecosyst Environ 94:205–220

MAPM (2016) Irrigation et aménagements fonciers. Ministère de l'Agriculture et de la Pêche Maritime, Rabat, Morocco.

MDCE (2015) Projet de performance vol Année budgétaire 2016. Ministère Délégué aurès du Ministre de l'Energie, des Mines, de l'Eau et de l'Environnement, Chargé de l'Eau, Rabat

ORMVAT (2014) Monographie de Tadla. Office de mise en valeur Agricole, Tadla

ORMVAT (2016). "Etat d'avancement des projets Plan Maroc Vert." Office de mise en valeur Agricole, Tadla.

Peña-Haro S, Pulido-Velazquez M, Sahuquillo A (2009) A hydro-economic modeling framework for optimal management of groundwater nitrate pollution from agriculture. J Hydrol. https://doi.org/10.1016/J.Jhydrol.2009.04.024

Sali G, Monaco F (2014) Irrigation water resource in a rice-growing area: economic evaluation under different pricing conditions. In: Zopounidis C, Kalogeras N, Mattas K, van Dijk G, Baourakis G (eds) Agricultural cooperative management and policy. Cooperative management. Switzerland: Springer, pp 23–40. https://doi.org/10.1007/978-3-319-06635-6_2

Sathye M (2001) X-efficiency in Australian banking: an empirical investigation. J Bank Financ 25:613–630

Stanley CB (2005) Investigation of the economics of water as used by smallholder irrigation farmers in South Africa vol Master's dissertation, University of Pretoria, Department of Agricultural Economics, Extension and Rural Development

Waughray DK, Rodríguez A (1998) Valuing water as an economic good in dryland areas – balancing the need for food, environmental and financial security. Paper presented at the world congress of natural resource economists, 24–27 June

Wheelock D, Wilson P (1999) Technical progress, inefficiency, and productivity change in U.S. banking (1984–1993). J Money Credit Bank 31:212–234