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Simulating the Impact of Climate Change and Adaptation Strategies on Farm Productivity and Income

A Bioeconomic Analysis

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INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

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ABSTRACT

This study applied at the farm level in Tunisia aims at understanding the effects of climate change on agricultural productivity and income in Africa. Possible future climates are presented through different climate scenarios. The latter combines three levels of increasing temperature (1°centigrade (C), 2°C, and 3°C) with two levels of decreasing precipitation (10 and 20 percent) and a doubling of carbon dioxide concentration in the atmosphere (350 to 700 parts per million). The farming system of production is replicated through a bioeconomic model; that is, one that couples a cropping system model and an economic model run sequentially. The study reveals that land productivity and farm income decline under climate change. Depending on the changes in precipitation, farm productivity falls by 15 to 20 percent and farm income 5 to 20 percent when the temperature increases moderately (1°C). As the climate warms up (2°C and 3°C), farm productivity and income are severely affected, by 35 to 55 percent and 45 to 70 percent, respectively. When simple adaptation strategies based on new management techniques for hard wheat are tested - more irrigation and fertilization - compensations for the negative effects of climate change are found to be worthwhile only for a 1°C increase in temperature. However, the success of adaptation strategies highly depends on the availability of more water and lower additional cost to mobilize them at the farm level.

Keywords: climate change, agriculture, productivity, farm income, adaptation strategies, bioeconomic modeling

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1. INTRODUCTION

Human activities have contributed to a rapid and unprecedented increase in greenhouse gas (GHG) emissions in the atmosphere. As a consequence, the average global temperature has increased by 0.2°C per decade and is predicted to increase between 1.1°C and 6.4°C over the next century. The increase in the average global temperature has led to more precipitation, and this pattern is expected to continue over the next decades with an uneven distribution across the globe. The global sea level rose faster during the period 1993–2003 than over 1961–2003. Climate change is profoundly disturbing the planet and the life of its creatures strongly related to the balance between soil and climate in a fragile ecosystem.

Climate change is expected to cause serious difficulties for agriculture, especially in developing countries. According to the Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report of 2007 (AR4), climate change can reduce rainfed agricultural yields by as much as 50 percent. Global losses in gross domestic product (GDP) range from 1 to 5 percent for a 4°C warming, and regional losses could be substantially higher. It is predicted that Africa is highly vulnerable to climate change since its economy relies largely on agriculture and uses low capital and inputs. Moreover, semiarid and arid regions are expected to be particularly affected, according to Mendelson, Nardhaus, and Shaw (1994) and Mendelson, Dinar, and Dalfelt (2000).

Although analyses of the impacts of climate change on agriculture have been undertaken, developing countries remain understudied. Therefore, attempts to anticipate the environmental modifications and their impacts on agriculture are of interest for Africa.

This study aims to understand the impact of climate change on agriculture in Africa. A bioeconomic model that combines biophysical or cropping systems and farm optimization modeling is used to replicate the system of production of El Khir, a large commercial farm in Tunisia. Analysis of such an important issue on a small scale, at the farm level, is a crucial step before moving into a large and general analysis, because the large models are not just a simple addition of the small models.

The rest of the paper is organized as follows. Section 1 discusses the IPCC's possible future climate scenarios. To better understand what changes in the climate system mean for agricultural productivity and food production, the effects of climate variables on plant growth and crop yields are summarized in Section 2. The farming system of production and its modeling are highlighted in Section 3. Climate change scenarios and simulation results are discussed in Section 4, and some adaptation scenarios are explored in Section 5. Finally, the concluding section presents key results and recommendations of the study.

2. IPCC'S FUTURE CLIMATE SCENARIOS

The study focuses on the most important climate variables - temperature and precipitation - as they are shown to have a significant impact on crop yields and agricultural production. In addition, carbon dioxide (CO_2) is the only greenhouse gas accounted for in the study as its effect on plants has been widely studied and agreed upon.[1] Hereafter, climate change refers to changes in temperature, precipitation, and concentration of CO_2 in the atmosphere.

This section presents the set of possible changes in temperature, precipitation, and atmospheric CO_2 concentration as described in the IPCC's AR4 of 2007. The report identifies various scenarios of future climate grouped into six families. The report makes different assumptions about future technological development and consequent levels of GHG emissions and future economic development.

According to the IPCC's AR4 (IPCC 2007), the linear warming trend over the last 50 years (1956–2005) is nearly twice that for the last 100 years (1906–2005). The AR4 report predicts a global increase in temperatures during the next century of between 1.1 and 6.4°C under various climate change scenarios. Global average temperatures have increased by 0.2°C per decade. This observation has strengthened the IPCC's confidence in its near-term projections since its first assessment report (IPCC 1990) predicted an increase of global average temperature ranging from 0.15 to 0.3°C per decade from 1990 to 2005. Therefore, the IPCC projection of warming for the next two decades (near-term) is about 0.2°C per decade.

The increase in average global temperature has also led to more precipitation due to the increase in evaporation. According to the IPCC, the trend observed in precipitation from 1900 and 2005 represents a significant increase in precipitation in the eastern parts of North and South America, northern Europe, and northern and central Asia, and a decline in precipitation in the Sahel, Mediterranean, southern Africa, and parts of southern Asia. If the observed pattern in recent trends continues, increases in precipitation are very likely in high latitudes, while decreases in precipitation are likely in subtropical land regions (IPCC 2007). In the latter regions, precipitation is expected to decrease as much as 20 percent by 2100 in IPCC's driest climate change scenario.

According to AR4 (IPCC 2007), anthropogenic GHG emissions are the drivers of increasing temperature (and variation of precipitation) beyond the natural warming that has kept the planet at an average temperature of 15°C. CO_2 is identified as the most important anthropogenic GHG. According to the report, about 38 gigatonnes of CO_2 were ejected into the atmosphere in 2004, representing 80 percent more emissions than in 1970 and 77 percent of total anthropogenic GHG emissions. If current climate change mitigation policies continue, GHG emissions will grow between 25 and 90 percent from 2000 to 2030. The IPCC predicts that CO_2 concentration will increase annually at a rate of 2.5 parts per million (ppm) and CO_2 will double by 2040 or 2050, depending on the degrees of regulation.

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[1] See, for example, Ainsworth (2008); Long et al. (2006).

3. ACTIONS OF CLIMATE VARIABLES ON CROP YIELDS

Climate is crucial in defining production area for plant species and varieties. Even for crops that are well adapted to their environment, climate's effect on yield remains important. This section highlights the general action of climate variables, in particular temperature and precipitation, on plant growth and crop yield in order to improve our understanding of results drawn from this analysis. Particular attention is also given to CO_2, the major GHG involved in the transformation of the climate system.

Temperature

Heat is the most important element of climate; it regulates plant development and limits its area of production. Temperature is the most convenient measure of heat, but what matters most is the amount of energy radiated by the sun and absorbed by the plant for organic synthesis. Temperature variations affect many functions of the plant, such as respiration, transpiration, and photosynthesis.

Increasing temperature leads to increasing respiration intensity, which requires a higher intake of carbohydrates and, consequently, a loss of biomass. The increase of temperature causes an acceleration of transpiration as a result of increased atmospheric saturation deficit. This increases plant stress and causes wilting, drying, and a serious loss of biomass. Photosynthesis is also dependent on temperature. Optimal photosynthesis is realized within a specific range of temperatures that varies according to the kind of plants. Above a certain temperature, photosynthetic activity can be seriously affected.

A crop growth cycle is strongly related to temperature. The duration of a cycle is conditioned by the daily temperatures absorbed by the plant. Therefore, an increase in temperature will speed up plant development by reducing the duration between sowing and harvesting. Biomass accumulation and crop productivity may fall with the shortening of a cycle.

Water

Through soil solution, water is the basis of plant alimentation. Water is also an integral part of living matter and is essential for its growth. Most of the water absorbed by the plant root is lost through perspiration. Only a small portion of absorbed water (an average of 1.5 percent) remains in the plant to integrate new cells and take part in photosynthesis. The plant is often considered to be an intermediary between soil and atmosphere in the water cycle. The atmosphere, through its temperature, humidity, and turbulence, determines the intensity of plant transpiration as well as direct soil evaporation: this is the concept of evapotranspiration.

An imbalance between the supply of plant and soil and the demand of the atmosphere creates a defensive reaction from the plant. This results in a partial or complete closure of the plant's stomata and therefore, a reduction of its photosynthetic activity. This can lead to temporary and possibly permanent wilting of the plant.

Carbon Dioxide

Atmospheric CO_2 is decomposed by light (solar radiation) to assimilate carbon and realize photosynthesis. A greater availability of CO_2 in the atmosphere increases photosynthetic activity. Lupton et al. (1974) and Planchon (1974) have demonstrated the existence of a positive correlation between photosynthetic activity and crop yields. However, the ability of different plants to use atmospheric CO_2 varies widely according to species and varieties. C3 crops (such as wheat and rice) are less efficient in CO_2 fixation than C4 crops (maize and soybean). Therefore, the effects of an increase in CO_2 are expected to be higher on C3 than C4 plants.

4. MODELING THE FARM PRODUCTION SYSTEM

The study assesses the impact of climate change and adaptation scenarios on crop productivity and farm income, using a bioeconomic model. The latter combine a biophysical or cropping system model and a farm optimization model to replicate the production system of El Khir, a large commercial farm in Tunisia.

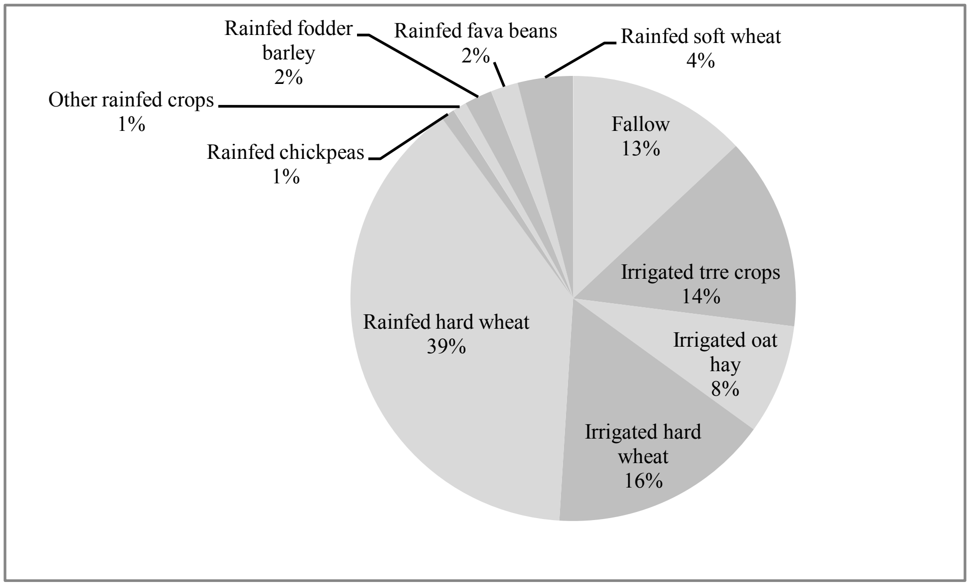
Description of the Production System

El Khir is located in Ben Arous Gouvernorat, 30 kilometers from the capital, Tunis. The region faces a semiarid climate with a 10-year average precipitation of 386 millimeters and an annual average temperature of 17.7°C (average range of 9.6°C in January and 26.9°C in August). The maximum crop-atmosphere water deficit is attained in July.

The total farm surface area is 2,300 hectares (ha), with a distribution of 200 ha of pastureland and 2,100 ha of arable land. One-fourth of the latter (24 percent) is irrigated using water from the Bir M'Chirga Dam and Medjerda River through canal transfer.

As shown in Figure 4.1, 13 percent of the surface has not been cultivated (has remained fallow land) over the last five years, and 14 percent has been used for tree crops (arboriculture). Rainfed hard wheat is the most important crop in terms of surface allocation (39 percent). It is followed by irrigated hard wheat (16 percent) and oat hay (8 percent), and unirrigated soft wheat (4 percent), fava beans (2 percent), fodder barley (2 percent), and chickpea (1 percent). The rest of the surface (1percent) is occupied by Sulla[2], small peas, triticum grain, and fodder sorghum. Animal feed crops (oat hay, fodder barley, fodder sorghum, and Sulla) occupy 10 percent of the surface. Because of their small amounts, Sulla, small peas, triticum grain, and fodder sorghum are omitted from this analysis.

Figure 4.1—Land allocation, average 1995–99



Source: Data collected at EL Khir farm, Tunisia, 2000.

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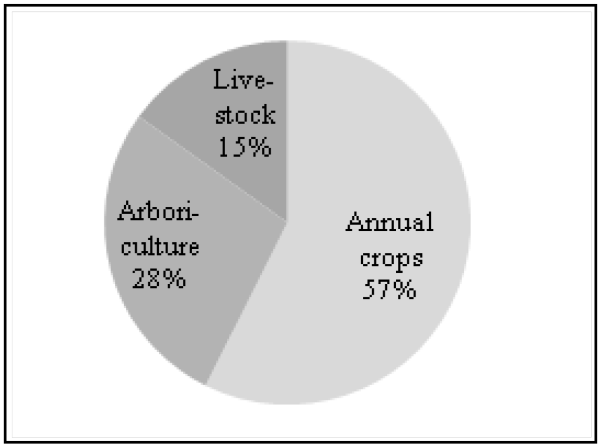
[2] Sulla (*Hedysarum coronarium L.*) is a biennual forage legume (see Sulas et. al, 1998, for additional information).

El Khir has diversified its activities over the years, with 57 percent of its gross margin generated by annual crops, 28 percent from arboriculture and 15 percent from livestock (Figure 4.2). A close look at annual crop income (Figure 4.3) shows that 52 percent of annual crop income comes from rainfed land crops.

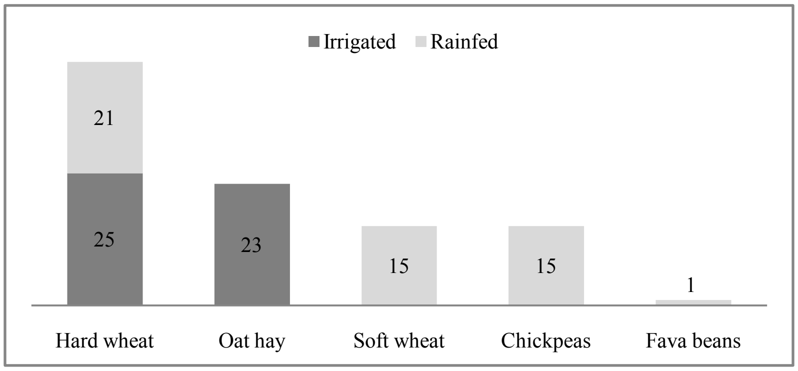
Although the modifications in climate variables affect farm income from all crop activities, their effects are expected to be more pronounced on such climate-sensitive activities as rainfed crop activities.

Figure 4.2—Income shares, average of 1995–99 (%)



Source: Data from EL Khir Farm, Tunisia, 2000.

Figure 4.3—Annual crop income shares, average 1995–99 (%)



Source: Data from EL Khir Farm, Tunisia, 2000.

Farm Modeling

The effects of climate change on El Khir's production and income are analyzed using bioeconomic modeling. The latter combines a biophysical or cropping system model and an optimization farm model. Recently, interest is growing regarding the use of these models in agricultural policy analysis of climate change and food security (Deybe 1998; Nelson et al. 2010).

The Biophysical Model

CropSyst, an abbreviation of Cropping Systems, is a biophysical simulation model that serves as an analytical tool to study the effects of cropping system management on productivity and the environment. It is developed by Claudio Stockle and Roger Nelson at the Biological Systems Engineering Department of Washington State University. CropSyst is a user-friendly, multiyear, multicrop, and daily time step simulation model that contains various complex production functions designed to simulate the soil-water budget , soil-plant nitrogen budget (supply and demand), crop canopy and root growth, dry matter production, yield, residue production and decomposition, and erosion.[3]

The model requires primary input data separately organized in four modules: location, soil, crop, and management techniques. For each module, as many input files (location, soil, crop, and management techniques) can be created as needed. [There are as many crop files as simulated crops. In turn, every crop file is combined with a specific management file. There can be more than one soil file depending on the types of soil available on the farm. In general, the location file is unique but can be increased if the farm is spread over many locations.

Concretely, the model used in this study integrates six crop files, one for every major crop presented in Figure 4.1 (hard wheat, soft wheat, oat hay, fodder barley, fava beans, and chickpeas). Each file includes agronomic, morphological, and physiological parameters of the crop, combined with its management techniques file. The decision to have one soil file was made because no major difference in feature or structure was noted in the analysis of soil samples collected from all the farm's plots. The model also features one location file that integrates data on daily temperature, precipitation, and humidity during the period 1994–99.[4]

A simulation scenario file is used to combine the parameter files and the simulation model run options. Finally, simulation scenarios are run and outputs are made available in different reports and graphics.

The Economic Model

The economic model is an optimization farm model, linear both in its objective function and its set of constraints. Simulation outcomes are classified according to a single criterion of maximum generated profit. Other important technical, economic, and environmental criteria are integrated into the constraints. The objective function is an expected farm profit function measured in terms of gross margin:

$$\max_{L} \Omega = \sum_{c,m} \left(\pi_{c,m} \times T_{c,m} \right)$$

where c is the index for crops, m is the type of management— rainfed or irrigated, Ω is the expected gross margin, T is the surface allocated to crops, and π is per hectare activity-specific gross margin.

The problem is to find the efficient allocation between crops (c) for farm limited surface ($\overline{T^S}$) under m (rainfed or irrigation) types of management such that farm gross margin (Ω) is maximized, considering crop gross margins per unit of surface (π). The latter is the difference between the sale and the operational costs (production costs excluding payroll, interest payments, taxation, and overhead).

$$\pi_{c,m} = \left(\sum_{j} y_{c,m,j} \times \overline{p_{c,j}} \right) - \left(\sum_{i} q_{c,m,i} \times \overline{p_{c,i}} \right)$$

where $\overline{p}$ is exogenous prices; y is yields for j (main and secondary) products, and q is the quantity of input i used. The values for y and q are given by the biophysical simulations. Other variables are integrated into the following constraints:

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[3] Further details are available at http://www.bsyse.wsu.edu/cropsyst.

[4] Data are collected from many places: fields and laboratory analysis (soil parameters), farm office (location and management), public administrations (location), and research institutions (crop), and, finally, reading references (crop).

Soil occupation: The sum of crop allocated surface under each type *m* of land–water management (rainfed or irrigated) cannot exceed total available surface ($\overline{T^S}$).

$$\sum_c \sum_m T_{c,m} \le \overline{T^S}$$

Rotation: The biannual cereal–fodder rotation constraint is followed on irrigated lands, $mi \in \{m\}$, the indexes $cc \in \{c\}$ and $cf \in \{c\}$ are used for cereal and fodder crops. Farm diversification policy is also considered, as surfaces allocated to crops range between the minimum and maximum crop surfaces observed over the past five years.

$$S_{cc,mi} \le S_{cf,mi}$$

$$\overline{S}_c^{\min 5\, years} \le S_c \le \overline{S}_c^{\max 5\, years}$$

Water: Water (*W*) supplies to irrigated crops cannot exceed the availability ($\overline{W^S}$) during each month (*t*). There are no operational costs associated with irrigation; only investment costs are supported by the farm. The latter do not enter into the gross profit margin maximization problem.

$$\sum_c W_{c,t} \le \overline{W_t^s}$$

Animal food: The impact of climate change on livestock is not analyzed and modeled in this study. Therefore, food requirements for animal feeding are fixed and adjusted through the supply side. Stubble; pasture grass; silage; concentrated diet of grain, soy, corn, and other supplements; and barley fodder are used for animal feeding.

The study assumes that the availabilities of pasture grass are fixed, as are supplies of silage and concentrated diet. In contrast, the supplies of stubble and barley fodder are expected to be affected by climate change. Barley fodder is the only crop production entirely used for animal feeding; that is, it does not provide direct income to the farm. Therefore, changes in animal food availability are compensated through changes in the surface allocated to barley fodder in order to meet fixed animal food requirements.

The study assumes that the farm's decisions are rational, according to its implicit objectives, available resources, and environment. Gross margins are the only variable influencing surface allocation decisions across crops. Products and factor prices remain constant as the farm is a pricetaker. Finally, there is no constraint on the farm's access to other factors– labor and capital, for example.

Climate change does not induce significant changes in the soil's physical and chemical characteristics, nor the plant's basic physiological, morphological, and agronomic characteristics by assumption. Moreover, tree crops are not seriously affected by the changes in temperature, precipitation, and concentration of carbon dioxide, as the biophysical model used in the study did not integrate this category of crop at the time the study was conducted. The contribution of pastureland used to feed animals remained unchanged. Climate change will not modify the capacity to ingest of animals and the quality of food. Water requirements for animals were not taken into account in the calculation of water availability for crops. Water supply mostly comes from surface water and water available to the farm is proportionally affected by the change in rainfall. Finally, climate change is not associated directly with the appearance of weeds, disease, and insect pests.

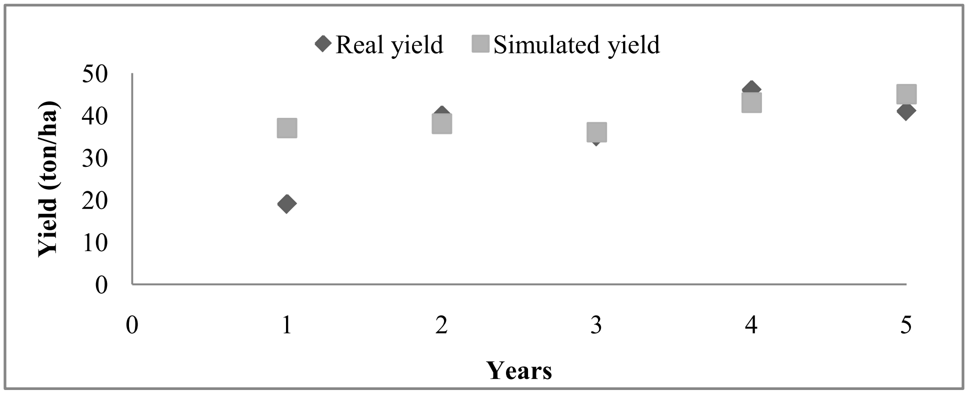
Model Calibration

The farm system of production is analyzed and modeled using technical, economic, and environmental data gathered during five successive agriculture years (1995–99). The model is then calibrated before being used for policy simulations. This important step assesses the degree of fitness of the model to the real situation. It consists of comparing the base year simulated outcomes to the real data. If they are close then the model is well fitted to the farm environment and ready to be used for simulations.

The procedure of calibration starts by integrating basic data on climate, soil, crop parameters, and crop management techniques into the biophysical model. For each crop, the model is run for five consecutive periods, and annual simulated yields are collected and compared with the farm's annual observed yields over the last five years. The fitness of the model to the real data is presented in Figures 4.4 to 4.7.

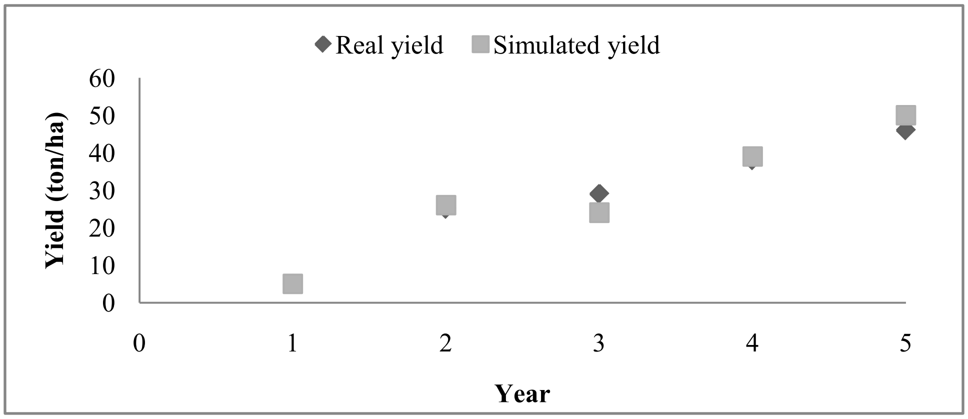
In general, the biophysical model is well suited to the farm environment, despite the gaps observed in the first year for irrigated crops. The gap may be explained by exceptional conditions due to drought that year, which could considerably reduce crop yields. The drought was also associated with the appearance of weeds, diseases, and pests that negatively affected crop yields. Initial soil conditions provided by the model do not account for this exceptional situation, which led to higher simulated crop yields than actual observed crop yields.

Figure 4.4—Calibration of the biophysical model, results for irrigated hard wheat



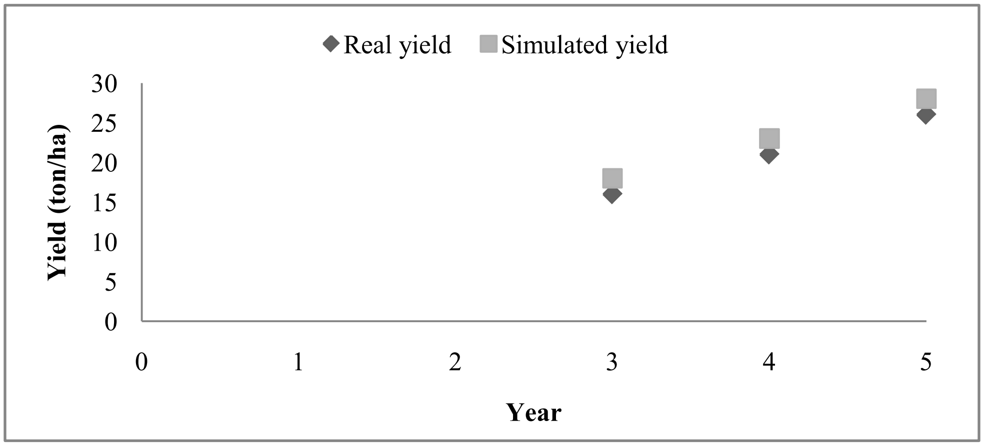
Source: Author's calculations from simulation results and El Khir technical documents.

Figure 4.5—Calibration of the biophysical model, results for rainfed hard wheat



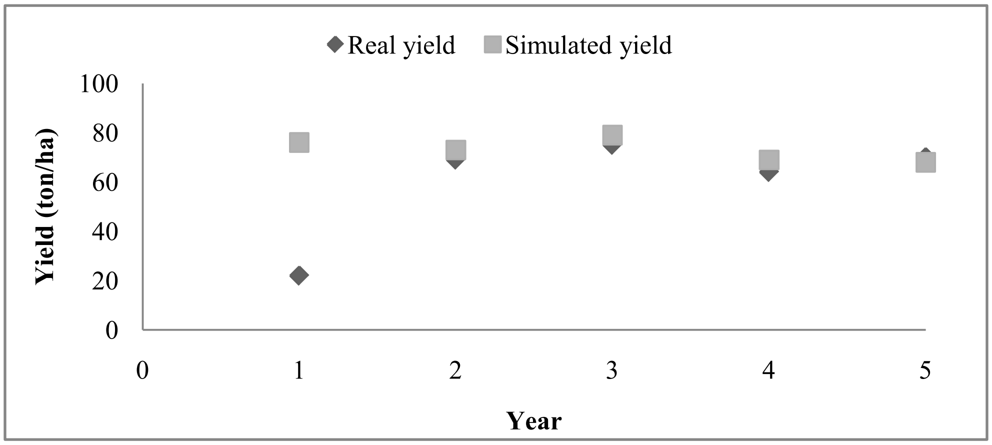
Sources: Author's calculations from simulation results and El Khir technical documents.

Figure 4.6—Calibration of the biophysical model, results for rainfed soft wheat



Source: Author’s calculations from simulation results and El Khir technical documents.

Figure 4.7—Calibration of the biophysical model, results for irrigated oat hay



5. SIMULATION SCENARIOS AND RESULTS

Because of the uncertainties surrounding forecasts on climate change, the study runs various climate sensitivity tests based on the Special Report on Emissions Scenarios (SRES) of the IPCC. As discussed in section 1, it focuses on the two major climate factors, temperature and precipitation. Among the GHG, it only considers carbon dioxide, since its effects on plants have been widely studied.

Climate Change Scenarios

The climate sensitivity tests consist of a doubling of carbon dioxide concentration in the atmosphere from 350 to 700 ppm, which is associated with three levels of increase in temperature (1°C, 2°C, and 3°C) and two levels of decrease in the percentage of precipitation from the current level (down 10 and 20 percent). These changes are within the range of the IPCC's predicted intervals and result in six climate change scenarios (Table 5.1).

Table 5.1—Climate change scenarios

CO_2 concentration	Change in daily precipitation	Change in daily temperature		
		+1°C	+2°C	+3°C
700 ppm	-10%	Scenario 1	Scenario 3	Scenario 5
	-20%	Scenario 2	Scenario 4	Scenario 6

Source: Author.
Note: ppm stands for parts per million.

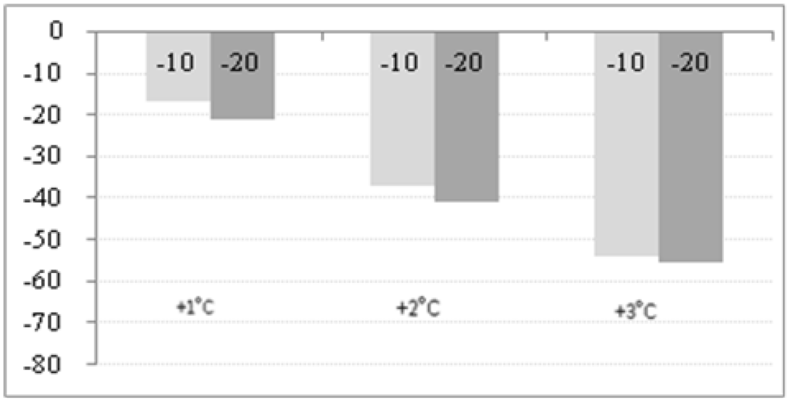
Climate change scenarios are implemented in the model through the creation of six additional climate files representing possible future climates. The new climate files are substituted one-by-one to the baseline climate file to simulate the climate change scenarios. The outcomes of the climate change scenario simulations are then compared with the baseline simulation outcomes from the calibration procedure. The baseline climate scenario reflects the current farm climate conditions in terms of the level of concentration of carbon dioxide in the atmosphere, daily temperature, and precipitation in the region.

Simulation Results

The simulations are performed for five succeeding years. Average values for technical coefficients, crop yields and input quantities, are computed and fed into the economic model. The latter consists of maximizing farm income by optimally reallocating farm land across annual crop activities, given a number of economic and technical constraints. Farm income is measured by the gross profit margin, that is, gross income net of operational costs. Farm productivity is expressed in terms of average yield of annual crops - production per unit of surface.

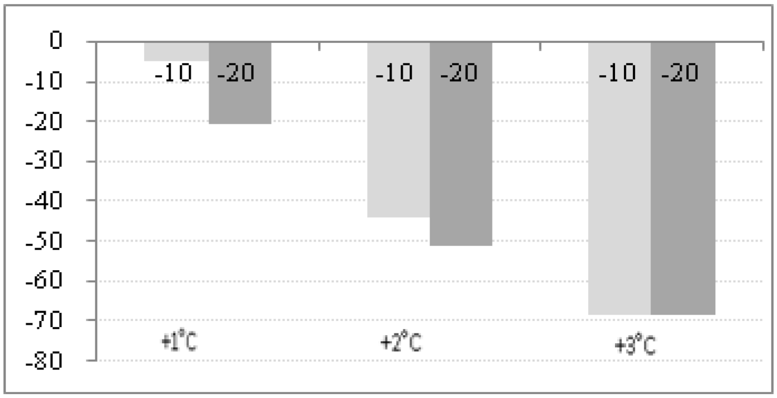
Simulation results are depicted in Figures 5.1 and 5.2. They show a significant drop in land productivity and farm income under the climate change scenarios. The decline of average land productivity compared to the baseline is about 17 to 56 percent, (Figure 5.1). Consequently, farm income also falls 4 to 69 percent, depending on the scenario (Figure 5.2).

Figure 5.1—Change in average land productivity, simulation compared with the baseline scenario (%)



Source: Author's calculations based on simulation results.
Notes: The horizontal axis depicts the climate change scenarios in terms of additional increase of temperature (+1°C, +2°C, and +3°C) and percentage decrease in precipitation (-10% and -20%) compared to the baseline levels. The vertical axis records the percentage change in productivity under the climate change scenarios. Farm productivity, or average yield, is calculated by dividing the total production of annual crops by the total surface allocated to them.

Figure 5.2—Change in gross margin, simulation compared with baseline scenario (%)



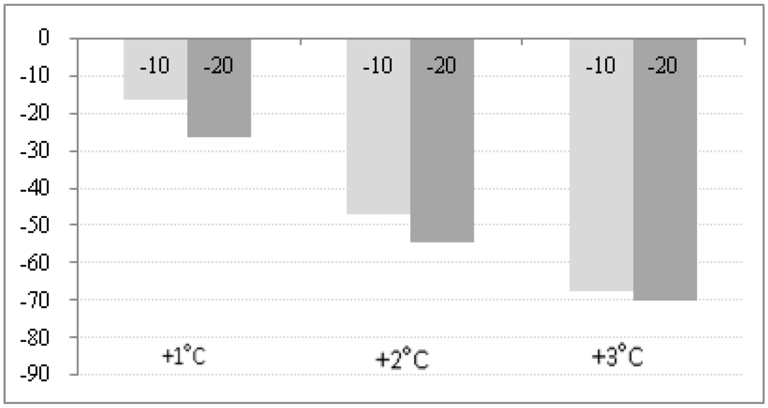
Source: Author's calculations from simulation results.
Notes: The horizontal axis depicts climate change scenarios in terms of additional increase of temperature (+1°C, +2°C, and +3°C) and percentage decrease in precipitation (-10% and -20%) as compared to the baseline levels. The vertical axis records the percentage change in farm gross margin under the climate change scenarios.

The severity of the productivity and income losses depends on the magnitude of changes in temperature and precipitation. From the perspective of the IPCC scenarios, that is, an average increase of 0.2°C over decades, ranging from 0.15°C to 0.3°C, the analysis demonstrates that average farm productivity is likely to fall by 17 to 21 percent in the near-term, depending on the magnitude of change in precipitation. As a consequence, farm income is also expected to decline 5 to 21 percent in the near-term, compared with the baseline level. In the long run, the losses are expected to be higher, as much as 37 to 56 percent for productivity and 44 to 69 percent for income.

Precipitation affects farm productivity and income less as the climate warms up (Figures 5.1 and 5.2). For a marginal increase in temperature, plant growth is less affected when it is already facing water stress. As discussed earlier, in Section 1, the atmosphere determines the intensity of plant transpiration; therefore any imbalance between atmosphere demand and the plant/soil supply creates a partial or complete closure of plant stomata, which in turn affects photosynthetic activity. The reduction in farm income results from the decline in crop yields from climate change and, consequently, land reallocation decisions. In the following section, we discuss the impact of climate change scenarios on major crop yields, with particular attention given to the effects on land–water management type - rainfed and irrigated.

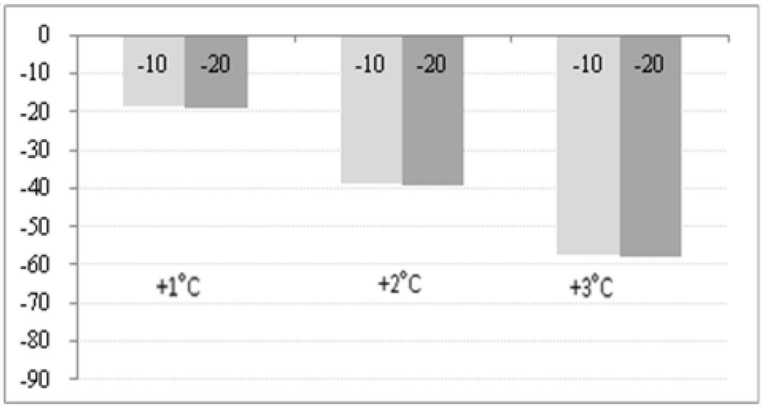
Significant reduction of yields is observed in most climate change scenarios and for most of the crops, regardless of the type of land–water management. However, a closer look at the results for hard wheat shows that irrigated crops are less affected than rainfed crops, with about 10 percentage points of productivity gap (Figures 5.3 and 5.4). The effects of climate change on irrigated crops are driven by temperature only, whereas rainfed crops face the effects of both temperature and precipitation.

Figure 5.3—Change in yields in rainfed hard wheat, compared with the baseline (%)



Source: Author's calculations from simulation results.

Figure 5.4—Change in yields of irrigated hard wheat, compared with the baseline (%)

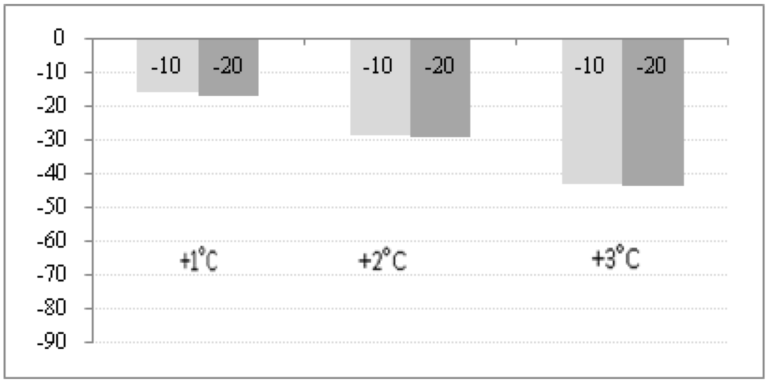


Source: Author's calculations from simulation results.

Once again, the reduction of yields of rainfed crops increases as the climate gets warmer and water becomes scarce. Moreover, crop sensitivity to changes in precipitation falls as temperature increases.

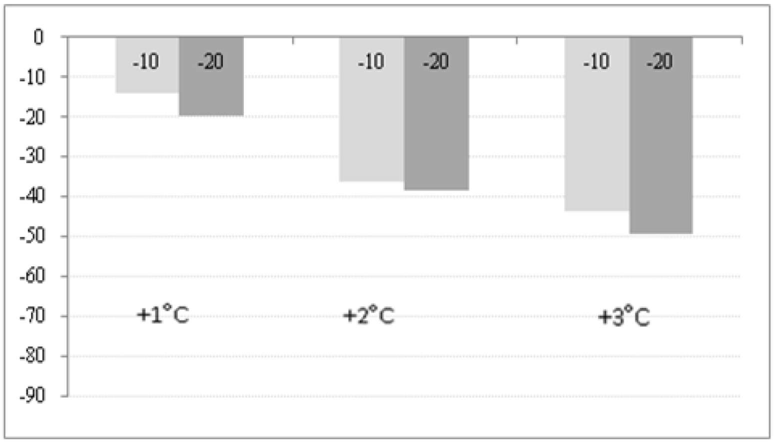
Crops are affected differently by climate change. Among irrigated crops, oat hay is less affected than hard wheat (Figures 5.4 and 5.5). A marginal increase of temperature reduces the yields of irrigated oat hay by about 10 percentage points; the effect on irrigated hard wheat is twice as high. Among rainfed crops (Figures 5.6 to 5.9), hard wheat, fava beans, and chickpeas experience a higher loss in yields. The reduction in yields is less important but still high for soft wheat, whereas barley fodder is the least affected.

Figure 5.5—Change in yields of irrigated oat hay, compared with the baseline (%)



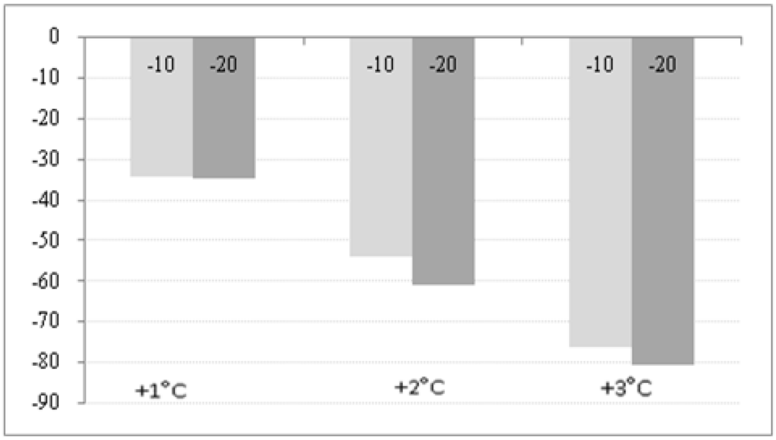
Source: Author's calculations from the simulation results.

Figure 5.6—Change in yields of rainfed soft wheat, compared with the baseline (%)



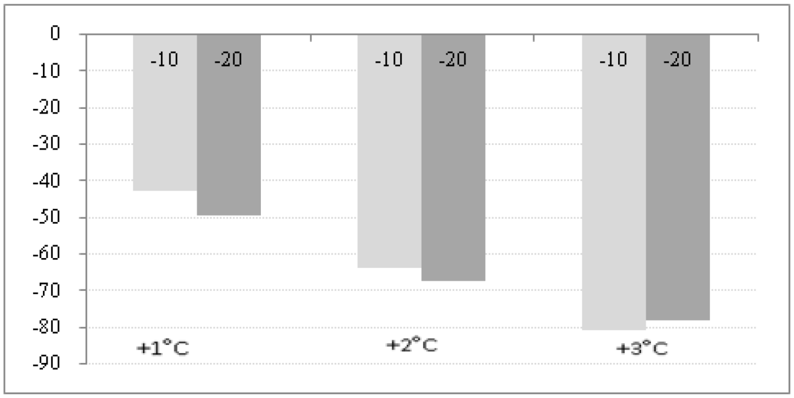
Source: Author's calculations from simulation results.

Figure 5.7—Change in yields of rainfed chickpeas, compared with the baseline (%)



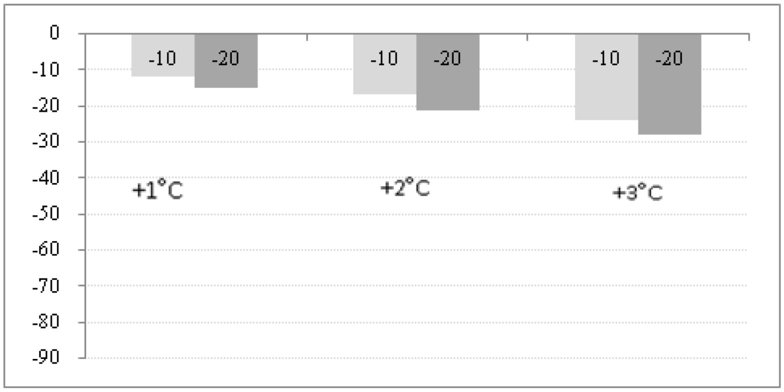
Source: Author's calculations from the simulation results.

Figure 5.8—Change in yields of rainfed fava beans, compared with the baseline (%)



Source: Author's calculations from the simulation results.

Figure 5.9—Change in yields of rainfed fodder barley, compared with the baseline (%)



Source: Author's calculations from the simulation results.

Adaptation Scenarios

The previous section highlights the impact of the climate change scenarios on agricultural productivity and income. As the climate warms up and precipitation decreases, agricultural productivity and income decline. This section discusses new management techniques to be implemented by the farm to cope with the adverse effects of climate change. The techniques fall into a range of two actions: the use of irrigation in rainfed crop lands, and the increase in fertilization.

The implementation of these simple adaptation scenarios requires more time for planning and resources. It means that the farm must increase its water availability and be ready to absorb the adjustment costs: materials and installation costs, technician's wages, and so forth. We assume that the farm does not face a financial constraint to increase its supply of water and fertilizer and, therefore, only faces operational charges related to the additional fertilizer used.

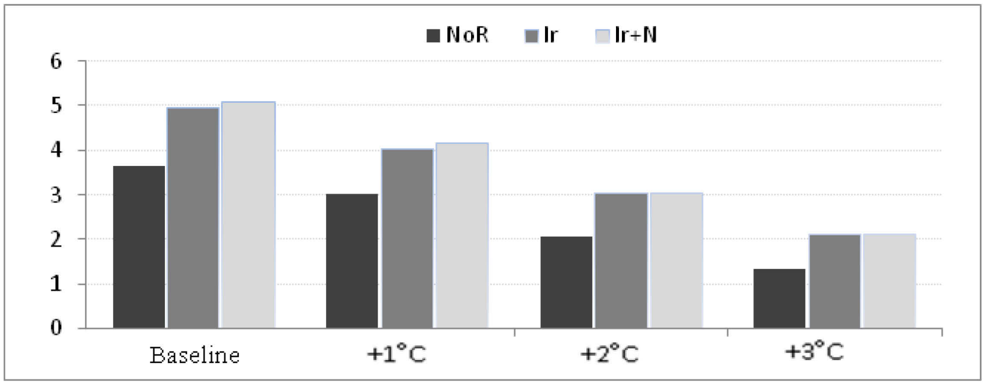
For simplicity, the analysis of the adaptation scenario is limited to hard wheat, the major crop activity on the farm. Hard wheat makes up 55 percent of surface area and 46 percent of income. I also omit the economic analysis because here the focus is on the impact on productivity of adaptation scenarios implemented through the biophysical model.

We learned from previous simulations that the yields of irrigated crops are not affected by changes in precipitation and are driven by increasing temperature only. We also expect that the implementation of irrigation provides crops with as much water as needed so that the changes in precipitation no longer matter for the analysis. Therefore, the analysis is limited to a scenario with three levels of increased temperature: +1°C, +2°C, and +3°C.

In most cases, the adaptation scenarios mitigate the negative effects of global warming on (hard wheat) crop yields, compared with the scenarios without adaptation (Figure 5.10). In the case of a 1°C increase in temperature, irrigation may be enough to compensate for the reduction of crop yields, compared with the baseline. However, none of the adaptation tests appear to be more efficient than the current situation when the analysis considers the allocation of resources. For the same quantity of resources, the loss of productivity, compared with the baseline situation, is not significantly different among scenarios (Figure 5.11). Although adaptation scenarios contribute to mitigating the adverse impact of climate change, they do not compensate for the loss in yields triggered by a higher elevation of temperature (+2°C and +3°C).

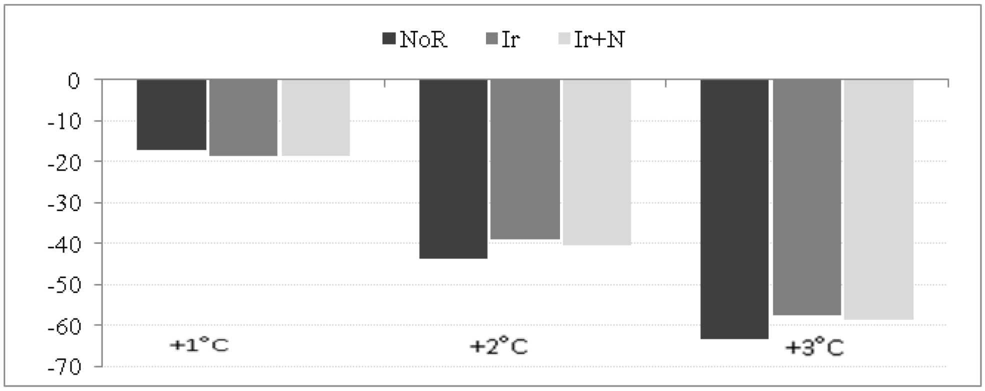
Results show that the more the climate warms up, the more water crops use per unit of biomass. This water is either directly evaporated from the soil or perspired by plants according to a greater demand for water from the atmosphere. Irrigation increases crop yields and appears to be slightly more efficient than other scenarios (Figures 5.10 and 5.11). However, the success of this adaptation strategy highly depends on the availability of more water and the lower additional cost to mobilizing it at the farm level. Nitrogen fertilization combined with irrigation does not provide significant additional gains on crop yields. Therefore, nitrogen fertilizer makes a small marginal contribution at the current level available for crops.

Figure 5.10—Hard wheat yield under various adaptation strategies (tons/ha)



Source: Author's calculations from simulation results.
Note: NoR is no response or adaptation; Ir is irrigation ; Ir+N is irrigation + nitrogen fertilization.

Figure 5.11—Percentage variation of hard wheat yield, compared with the baseline



Source: Author's calculations from simulation results.
Note: NoR is no response; Ir is irrigation; Ir+N is irrigation + nitrogen fertilization.

6. CONCLUSION

Climate change induced by the increasing concentration of greenhouse gases in the atmosphere is likely to affect crop yields, agricultural productivity, and food production around the world. Africa is particularly vulnerable to climate change because its economy relies more on extensive agriculture, using less capital and inputs. Therefore, attempts to anticipate environmental modifications and their impacts on agriculture are of interest for this region.

This study, applied at the farm level in Tunisia, aims at understanding the impacts of climate change on agricultural productivity and income. A bioeconomic model combining a cropping system model and an optimization model is used to replicate the farm system of production.

Climate change possibilities are presented through climate scenarios. Because of the uncertainties surrounding the forecasts on climate change, the study runs various climate sensibility tests based on increases in daily temperature of about 1°C, 2°C, and 3°C; decreases in daily precipitation of 10 and 20 percent; and a doubling of the CO_2 level from 350 to 700 ppm. The predicted intervals of variation are described in the IPCC's 2007 Fourth Assessment Report.

The study reveals that El Khir, farm will experience a significant decline in productivity and income with climate change. The severity of productivity and income losses depends on the magnitude of changes in temperature and precipitation. Higher temperatures (+2°C and above) or a significant decline in precipitation (-10 percent and below) or both will seriously affect most of the crop activities. In the perspective of the IPCC scenarios, farm productivity is most likely to fall by 15 to 20 percent in the near-term, depending on the magnitude of changes in precipitation. In the long run, the declines are expected to be much higher: 35 to 55 percent for productivity and 45 to 70 percent for income.

The effects of climate change on irrigated crops are driven by temperature only, whereas rainfed crops face the effects of both temperature and precipitation. Consequently, irrigated crops are less affected than rainfed crops with about 10 percentage points of productivity gap.

Crops are affected differently by climate change. Among irrigated crops, oat hay is less affected than hard wheat. Among rainfed crops, hard wheat, fava bean, and chickpeas experience a higher loss of yields. The reduction in yields is less important but still high for soft wheat, whereas barley fodder is the least affected.

Simple adaptation strategies–more irrigation and nitrogen fertilization and delay in sowing dates—contribute to coping with the adverse impact of climate change on farm productivity and income. But as the climate gets warmer, their mitigation effects are lessened. For the case of hard wheat, new management techniques implemented to cope with the adverse impact of climate change do not appear to be significantly more efficient than baseline management techniques. However, compensations for the negative effects of climate change are found to be worthwhile for the 1℃ increase in temperature scenario. However, the success of adaptation strategies highly depends on the availability of more water and the lower additional cost to mobilize it at farm level.

Although the study assumes fixed prices, climate change is likely to modify prices for many crops. Therefore, even if crop yields decline under the tested climate change scenarios, farm revenue might be less affected when output prices increase more than input prices. In a case where the price effects of climate change are important, the decline in crop yields might be compensated so that farm revenue remains unchanged or increases to some extent. Although some studies (for example, Hertel, Burke, and Lobell, 2010) have stressed out the importance of the price effect related to climate change, this issue needs further investigation.

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