Simulating the Impact of Climate Change and Adaptation Strategies on Farm Productivity and Income: A Bio-economic Modeling Analysis

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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°C, 2°C, and 3°C) with two levels of decreasing precipitation (10% and 20%) 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 bio-economic model, i.e. coupling 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 about 15 to 20% and its income about 5 to 20% 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 about 35 to 55%, and 45 to 70%, respectively. When simple adaptation strategies based on new management techniques are tested for hard wheat – more irrigation and fertilization, and delay in sowing dates - 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 farm level.

Key words: Climate change, global warming, agriculture, farm income, biophysical model, economic model, climate scenarios, adaptation strategies, Tunisia.

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^{o}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. Global sea level has grown at a faster rate over the period of 1993-2003 compared to the period of 1961-2003. Change in the state of the climate is perturbing the planet and the life of creatures that is strongly related to a fragile ecosystems' balance between soil and climate.

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 in 2007, climate change can cause a reduction in rain-fed agricultural yields by up to 50%. The global GDP losses range from 1 to 5% 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 more on agriculture and uses low capital and inputs. Moreover, semi-arid 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 under-covered. Therefore, attempts to anticipate the environmental modifications and their impacts on agriculture are of interest for Africa.

Therefore, this study aims to understand the impact of climate change on agriculture in Africa. A bio-economic model that combines biophysical or cropping system 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 at farm level or a small scale, is a crucial step before moving into a large and general analysis, because the large models are just not a simple addition of the small models.

The rest of the paper is organized as follows. Section 2 discusses the IPCC's possible future climate scenarios. To better understand what changes in the climate system mean for agriculture productivity and food production, the effects of climate variables on plant growth and crop yields are summarized in section 3. The farming system of production and its modeling are highlighted in section 4. Climate change scenarios and simulation results are discussed in section 5 and some adaptation scenarios are explored in section 6. Finally, the conclusion section presents key results and recommendations of the study.

1. IPCC's Climate Change 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 (CO2) is the only greenhouse gas accounted for in the study as its effect on plants has been widely studied and agreed upon.[1] Hereon, climate change refers to changes in temperature, precipitation, and concentration of CO2 in the atmosphere.

This section presents the set of possible changes in temperature, precipitation, and atmospheric carbon dioxide concentration as described in the IPCC's Fourth Assessment Report (AR4) of 2007. The report identifies various individual scenarios offuture climate grouped into six families. The report makes different assumptions about future technological development, consequently, the level of GHG emissions and future economic development.

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

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 is 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 patterns in recent trends continue, 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, the decrease in precipitation is expected to be by as much as 20% by 2100 in IPCC's driest climate change scenario.

According to IPCC's report (AR4, 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. CO2 is identified as the most important anthropogenic GHG. According to the report, about 38 gigatonnes of CO2 were ejected into the atmosphere in 2004, representing 80% more emissions than in 1970 and 77% of total anthropogenic GHG emissions. If current climate change mitigation policies continue, the GHG emissions will grow by rates between 25% and 90% from 2000 to 2030 according to the same report. The

[1] Ainsworth (2008); and Long, Ainsworth, Leakey, Nosberger, and Ort (2006).

IPCC predicted an annual increase in CO_2 concentration at a rate of 2.5 parts per million and a doubling of CO_2 by 2040 or 2050 depending on various degrees of regulation.

2. 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, its 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.

2.1. Temperature

Heat is the most important element of climate. It regulates plant development and limits its area of production. Its most convenient measure is temperature; 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 in a specific range of temperatures which vary according to plants. Beyond 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. Only temperatures above the zero of vegetation shall be considered in calculating the duration of a plant growth cycle. 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.

2.2. Water

Through the 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%) remains in the plant to integrate new cells and take part in photosynthesis. The plant is often considered as 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: hence, the concept of evapotranspiration.

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

2.3. Carbon dioxide

Atmospheric CO_2 is decomposed by light (solar radiation) to assimilate carbon and realize photosynthesis. A greater availability of CO2 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 CO2 varies widely according to species and varieties. C3 crops (e.g. wheat and rice) are less efficient in CO2 fixation than C4 crops (e.g. maize and soybean). Therefore, the effects of an increase in CO2 are expected to be higher on C3 than C4 plants.

3. Modeling farm production system

The study assesses the impact of climate change and adaptation scenarios on crop productivity and farm income using a bio-economic model. The latter combines a biophysical or cropping system model and a farm optimization model to replicate the production system of a large commercial farm in Tunisia: "El Khir".

3.1. Description of the production system

"El Khir" is located in Ben Arous Gouvernorat, 30 kilometers from the capital, Tunis. The region faces a semi-arid climate with a ten-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.

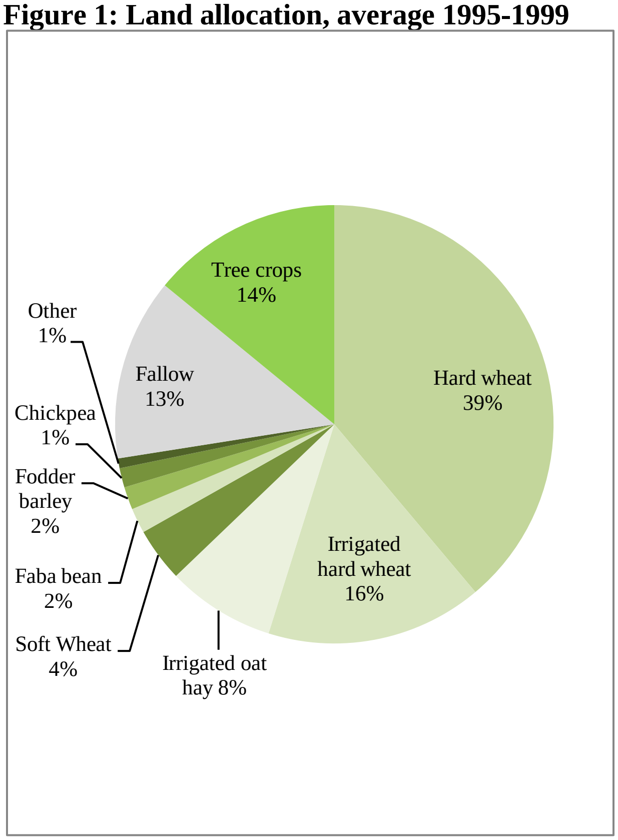
The structure of the farm's soil is 95% silty-clay. The soil is poor in organic matter and phosphorous; it is more acidic than alkaline and has a normal potassium level. The total farm surface area is 2300 ha distributed into 200 ha of pastureland and 2100 ha of arable land. One-fourth of the latter (24%) is irrigated using water from the "Bir M'Chirga" dam and "Medjerda" river through canal transfer.

As shown in *Figure 1*, 13% of the surface has not been cultivated (fallow land) over the last 5 years and 14% has been used for tree crops (arboriculture). Rainfed hard wheat is the most important crop in terms of surface allocation (39%). It is followed by irrigated hard wheat (16%), irrigated oat hay (8%), soft wheat in dry (4%), Faba bean in dry (2%), fodder barley in dry (2%), and chickpea in dry (1%). The rest of the surface (1%) is occupied by sulla, small peas, triticum grain, and fodder sorghum. Animal feed crops (oat hay, fodder barley, fodder sorghum, and sulla) occupy 10% of the surface. Because of the small size of their activities, sulla, small peas, triticum grain, and fodder sorghum are omitted from this analysis.

"El Khir" has diversified its activities over past years with 57% of its gross margin generated by annual crops, 28% from arboriculture and 15% from livestock (*Figure 2*). A close look at annual crop income (*Figure 3*) shows that 52% of annual crop income comes from rainfed land crops.

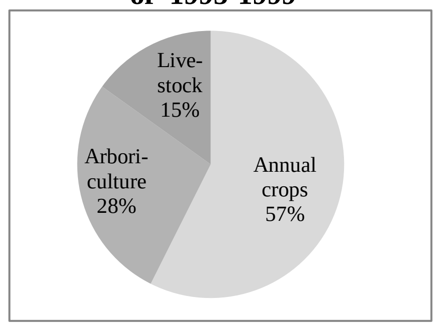
Although the modifications in climate variables affect farm income throughout all crop activities, their effect are expected to be pronounced on more climate-sensitive activities, i.e. rainfed crop activities.

Figure 1: Land allocation, average 1995-1999



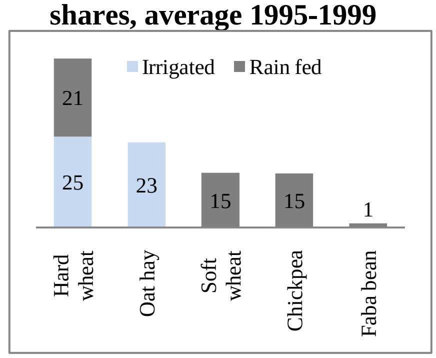
Source: "EL Khir"farm (2000).

Figure 2: Income shares, average of 1995-1999



Source: "EL Khir"farm (2000).

Figure 3: Annual crops income shares, average 1995-1999



Source: "EL Khir" farm (2000).

3.2. Farm Modeling

The effects of climate change on "El Khir's" production and income are analyzed using bio-economic 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, for example, climate change and food security (Deybe, 1998; Nelson et al., 2010).

3.2.1. The biophysical model

CropSyst, the abbreviation of Cropping Systems, is a biophysical simulation model that serves as an analytical tool to study the effect of cropping systems management on productivity and the environment. It is a user-friendly, multi-year, multi-crop, and daily time step simulation model that contains various complex production functions designed to simulate soil water budget, soil-plant nitrogen budget, crop canopy and root growth, dry matter production, yield, residue production and decomposition, and erosion.[2]

The model requires primary input data separately organized in four modules: location, soil, crop, and management techniques. For each module, many files can be created as needed. There are as many crop files as simulated crops. In turn, every crop file is combined to a specific management file. The soil file can be more than one 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 1 (hard wheat, soft wheat, oat hay, fodder barley, faba bean, and chickpea). Each file includes agronomic, morphological and physiological parameters of the crop and is combined with its management techniques file. The conclusion to have one soil file is made as no major difference in feature or structure appeared from 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 over the period 1994 to 1999.[3]

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.

3.2.2. 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 criterions are integrated into the constraints.

The objective function is an expected farm profit function measured in term of gross margin:

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

[3] 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).

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

c is the index for crops, m is the type of management, i.e. 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). That is:

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

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

Soil occupation: The sum of allocated surface to crops cannot exceed total available surface ($\overline{T^S}$) for each type m of land management (rainfed or irrigated).

$$\sum_{c} T_{c,m} \leq \overline{T_m^S}$$

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.

$$S_{cc,mi} \leq S_{cf,mi}$$
$$\overline{S}_c^{\min 5 years} \leq S_c \leq \overline{S}_c^{\max 5 years}$$

Water: Water (W) supplies to irrigated crops cannot exceed the availability ($\overline{W^S}$) for each month (t).

$$\sum_{c} W_{c,t} \leq \overline{W_t^s}$$

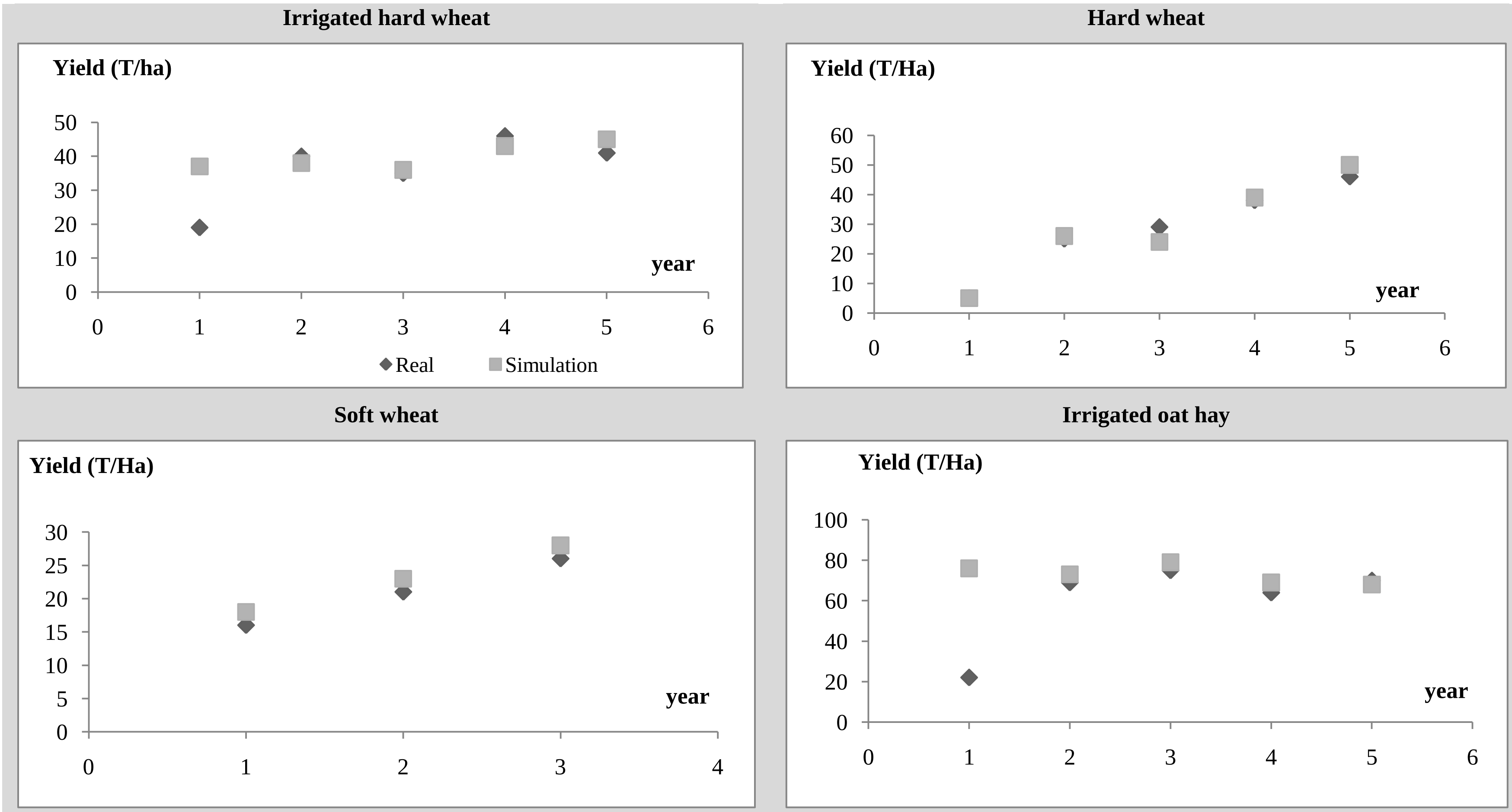
Animal food: The impact of climate change on livestock is not analyzed and modeled in this study. Therefore, food requirements for animal feeding are maintained fixed and adjusted through the supply side. Stubbles, pasture grass, silage, concentrated diet of grain, soy, corn, and other supplements, and 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 stubbles 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 decision across crops. Products and factor prices remain constant as the farm is a price taker. Finally, there is no constraint on the farm's access to other factors – e.g. labor and capital.

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 of ingestion 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.

Figure 4: Calibration of the biophysical model, results for main crops



Sources: Author from simulation results and "El Khir" technical documents.

3.3. Model Calibration

The farm system of production is analyzed and modeled using technical, economic, and environmental data gathered during five successive agriculture years (1995-1999). 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 both data 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, crops parameters, and crops 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 to the farm's annual observed yields over the last five years. The fitness of the model to the real data is presented in *Figure 4*.

In general, the biophysical model fits well to the farm environment despite the gaps observed in the first year for irrigated crops. The gap could be explained by exceptional conditions due to drought that year that contribute to considerably reducing 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 that led to higher simulated crop yields compared to actual observed crop yields.

4. Simulation scenarios and results

Because of the uncertainties surrounding forecasts on climate change, the study runs various climate sensitivity tests based on the SRES scenarios of the IPCC. As discussed in section 2, it focuses on the two major climate factors, i.e. temperature and precipitation, and among the GHG, only carbon dioxide, since its effects on plants has been widely studied, is considered.

4.1. 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 percentage precipitation from the current level (-10% and -20%). These changes range in the IPCC's predicted intervals and result in six climate change scenarios as presented in Table 1.

Table 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. **Legend**: ppm stands for Parts per million.

Climate change scenarios are implemented into the model through the creation of six additional climate files representing the possible future climates presented in table 1. The new climate files are substituted one-by-one to the baseline climate file when simulating the climate change scenarios. The outcomes of the climate change scenario simulations are then compared to 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.

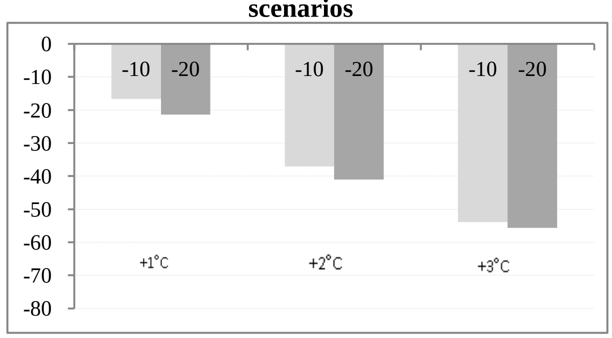
4.2. Simulation results

The simulations are performed for five succeeding years. Average values for technical coefficients, i.e. crop yields and inputs quantities, are computed and fed into the economic model. The latter consists of maximizing farm income through an optimal reallocation of 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 its gross income net of operational costs. Farm productivity is expressed in term of average yield of annual crops, i.e. production per unit of surface.

Simulation results are depicted in Figures 5 and 6. *They show an important drop of 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% (Figure 5). Consequently, farm income also falls by about 5 to 69% compared to the baseline level (Figure 6).

The severity of the productivity and income losses depends on the magnitude of changes in temperature and precipitation. In the perspective of the IPCC scenarios, i.e. an average increase of 0.2^{o}C over decades and ranging from 0.15^{o}C to 0.3^{o}C, the analysis demonstrates that average farm productivity is most likely to fall by 17 to 21% by the year 2050 depending on the magnitude of change in precipitation. As a consequence, farm income is also expected to decline by about 5 to 21% by year 2050 as compared to the baseline level. In the long-run, the losses are expected to be higher, as much as 37 to 56% for productivity, and 44 to 69% for income.

Figure 5: Percent change in average land productivity, simulation compared to baseline scenarios

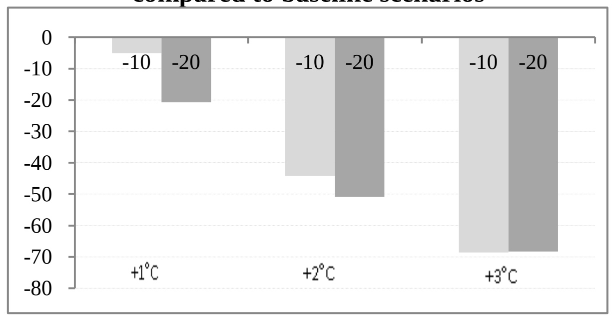


Source: Author from simulation results.

Note: The horizontal axis depicts the climate change scenarios in terms of additional increase of temperature (+1^{o}C, +2^{o}C, and +3^{o}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.

Precipitation has lesser effects on farm productivity and income as the climate warms up (Figures 5 and 6). For a marginal increase in temperature, plant growth is less affected when it is already facing water-stress. As discussed earlier in section 2, 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.

Figure 6: Percent change in gross margin, simulation compared to baseline scenarios



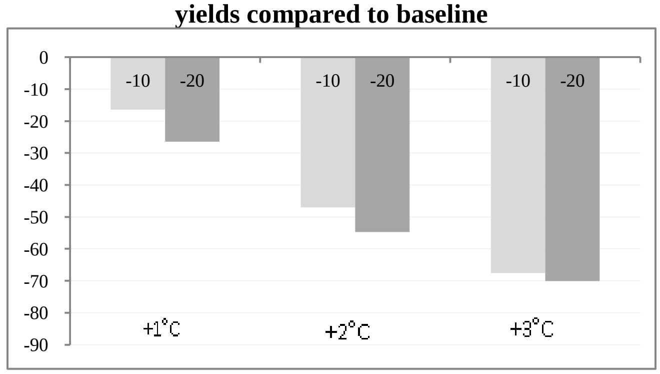
Source: Author from simulation results.

Note: The horizontal axis depicts climate change scenarios in terms of additional increase of temperature (+1^{o}C, +2^{o}C, and +3^{o}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 reduction in farm income results from the decline in crop yields from climate change and, consequently, land reallocation decisions. The following section discusses the impact of climate change scenarios on major crop yields with particular attention given to the effects on land-water management type, i.e. 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 7 and 8). *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 7: Rainfed hard wheat, percentage change in yields compared to baseline

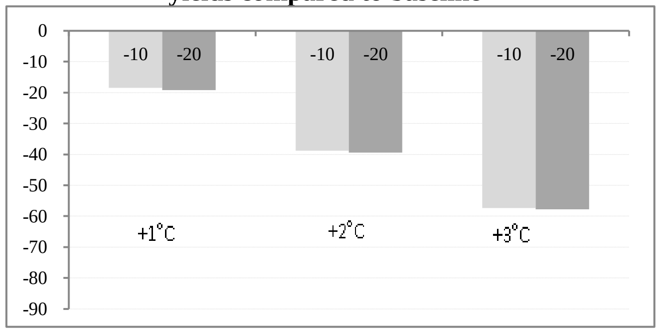


Source: Author calculation from simulation results.

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.

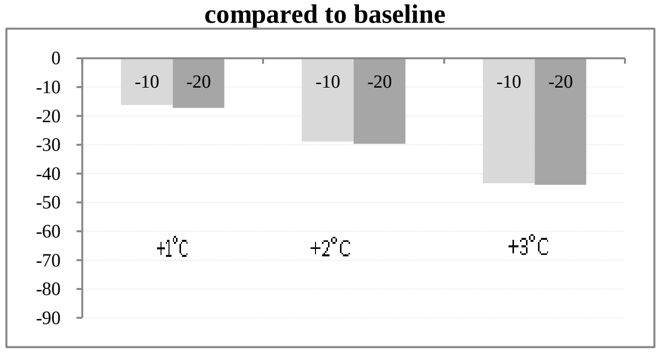
Crops are affected differently by climate change. Among irrigated crops, oat hay is less affected than heard wheat (Figures 8 and 9). A marginal increase of temperature reduces the yields of irrigated oat hay by about 10 percentage points; the effect on irrigated hard wheat is twice as high. Among rainfed crops, hard wheat, fava bean, and chickpea 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 8: Irrigated hard wheat, percentage change in yields compared to baseline



Source: Author calculation from simulation results.

Figure 9: Irrigated oat hay, percentage change in yields compared to baseline



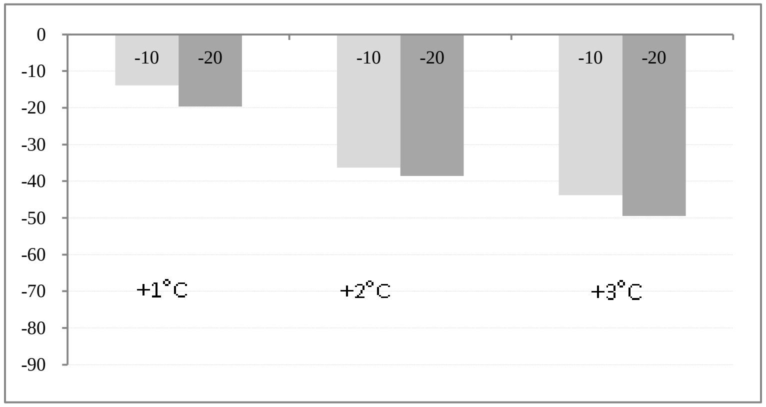
Source: Author calculation from simulation results.

5. 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 three actions: the use of irrigation in rainfed crop lands, the increase in fertilization, and the delay of sowing dates. For the latter, two sub-scenarios are experimented: delays of two and four weeks of the sowing dates.

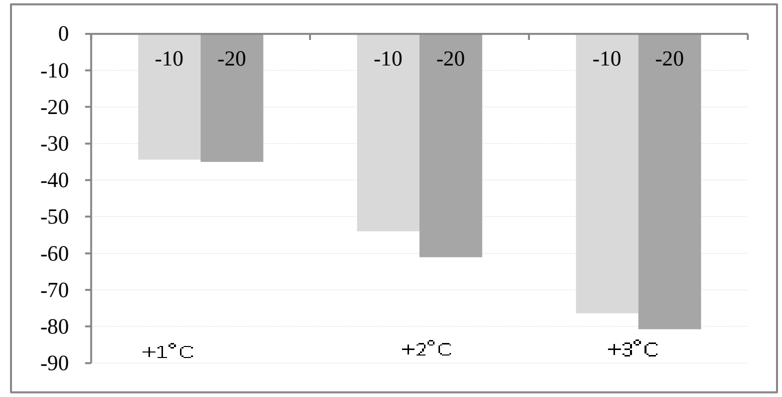
While the application of the third action (delay of sowing dates) seems straightway, the implementation of the first two requires more time for planning and resources. It means that the farm must increase its water availability and be ready to absorb the adjustment costs: materials and installation costs, technician wages, etc. Although weakly realistic, we assume that these costs are low and the farm can increase its supply of water and fertilizer and, therefore, only faces operational charges related to the additional water and fertilizer used.

Figure 10: Rainfed soft wheat, percentage change in yields compared to baseline



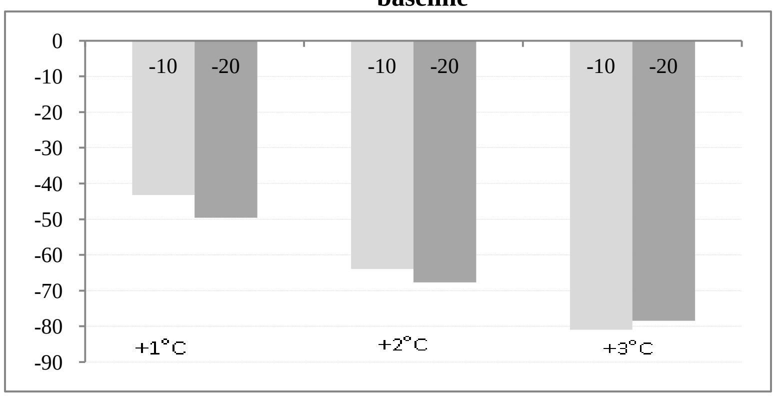
Source: Author calculation from simulation results.

Figure 11: Rainfed chickpea, percentage change in yields compared to baseline



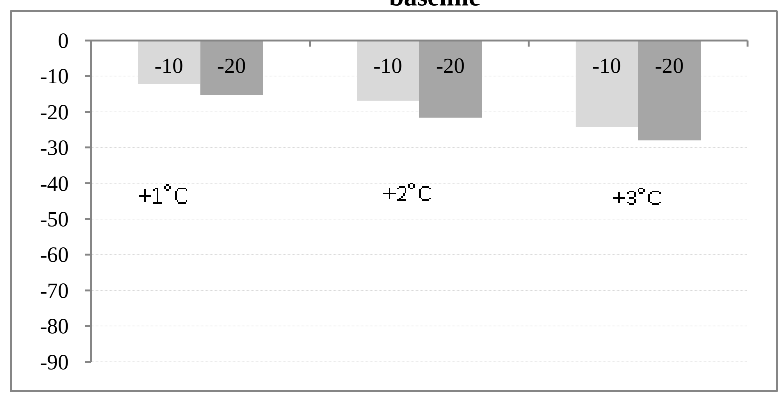
Source: Author calculation from simulation results.

Figure 12: Rainfed faba bean, percentage change in yields compared to baseline



Source: Author calculation from simulation results.

Figure 13: Rainfed fodder barley, percentage change in yields compared to baseline



Source: Author calculation from simulation results.

For simplicity, the analysis of the adaptation scenario is limited to hard wheat, the major crop activity run by the farm – consisting of 55% of surface area and 46% of income. The economic analysis is also omitted as this section focuses only on the productivity impact 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 do not matter anymore for the analysis. Therefore, the analysis is limited to a scenario with three levels of increased temperature: +1°C, +2°C, and +3°C.

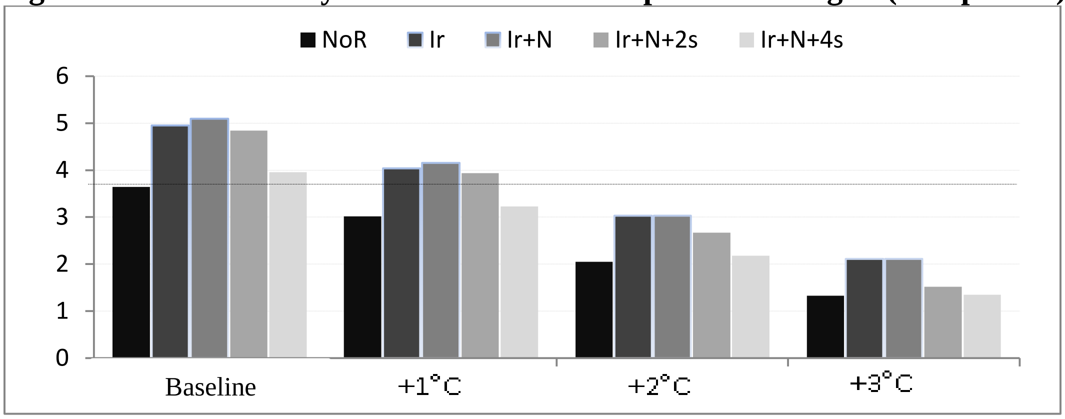
In most cases, adaptation scenarios mitigate the negative effects of global warming on (hard wheat) crop yields compared to the scenario without adaptation (Figure 14). In a case of 1°C increase in temperature, irrigation may be enough to compensate for the reduction of crop yields compared to the current productivity. 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, as compared to a baseline situation, is not significantly different among scenarios (Figure 15).

Although adaptation scenarios contribute to mitigating the adverse impact of climate change, they do not contribute to compensating for the loss in yields triggered by a higher elevation of temperature (+2°C and +3°C). The adaptation strategies are not effective when the climate warms up.

Results show that the more the climate warms up, crops use more water 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 atmosphere. Irrigation increases crop yields and appears to be slightly more efficient than other scenarios (Figures 14 and 15). However, the success of this adaptation strategy highly depends on the availability of more water and the lower additional cost to mobilizing it at farm level.

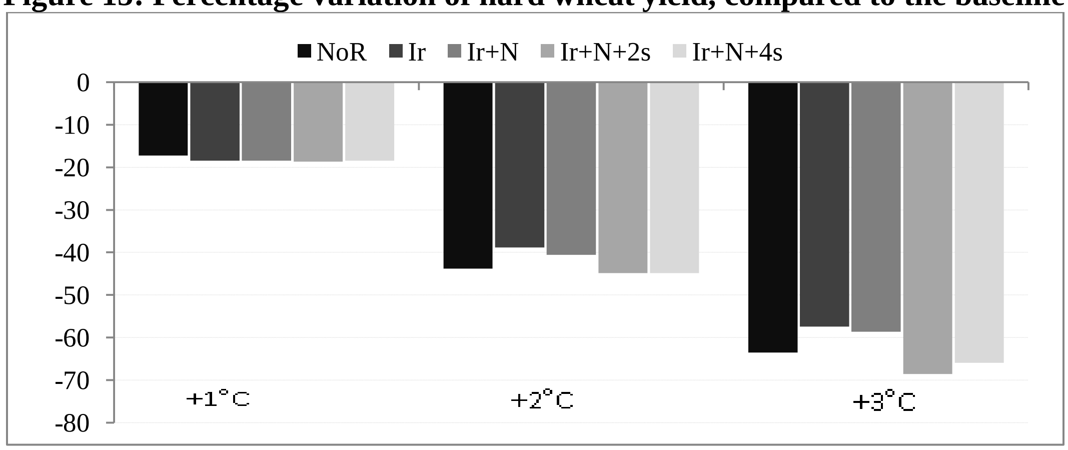
Nitrogen fertilization combined with irrigation does not provide significant additional gains on crop yields (Figures 14 and 15). Therefore, nitrogen fertilization has a small marginal contribution according to the current level available for crops. The delay of sowing dates shortens most crop development cycles because of high temperatures at the end of spring and beginning of summer, and a faster accumulation of heat during this period. The delay of sowing dates reduces crop yields compared to other adaptation scenarios.

Figure 14: Hard wheat yield under various adaptation strategies (Ton per Ha)



Source: Author calculation from simulation results.
Note: **NoR**: No response ; **Ir** : Irrigation ; **Ir+N** : Irrigation + Nitrogen fertilization ; **Ir+N+2s** : Irrigation + Nitrogen fertilization + delay of sowing date by 2 weeks ; **Ir+N+4s** : Irrigation + Nitrogen fertilization + delay of sowing date by 4 weeks.

Figure 15: Percentage variation of hard wheat yield, compared to the baseline



Source: Author calculation from simulation results.
Note: **NoR**: No response ; **Ir** : Irrigation ; **Ir+N** : Irrigation + Nitrogen fertilization ; **Ir+N+2s** : Irrigation + Nitrogen fertilization + delay of sowing date by 2 weeks ; **Ir+N+4s** : Irrigation + Nitrogen fertilization + delay of sowing date by 4 weeks.

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 as its economy relies more on extensive agriculture, i.e. 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 bio-economic model combining a cropping system model and an optimization model is used to replicate 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 about 10% and 20%, and a doubling of CO2 level from 350 to 700 parts per million. The predicted intervals of variation are described in the 2007 Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).

The study reveals that "El Khir" farm will experience a significant decline in productivity and income under 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) and/or significant decline in precipitation (-10% and below) will seriously affect most of the crop activities. In the perspective of the IPCC scenarios, farm productivity is most likely to fall by about 15 to 20% by the year 2050 depending on the magnitude of changes in precipitation. In the long-run, the declines are expected to be much higher, of about 35 to 55% for productivity, and 45 to 70% 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 chickpea 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°C 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.

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