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# Development of an Integrated Model to Assess the Impact of Agricultural Practices and Land Use on Agricultural Production in Morocco under Climate Stress over the Next Twenty Years

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**Abstract:** Climate change is one of the major risks facing developing countries in Africa for which agriculture is a predominant part in the economy. Alterations in rainfall patterns and increasing temperatures projected by the Intergovernmental Panel on Climate Change (IPCC) could lead to a decline in agricultural production in many areas requiring significant changes in agricultural practices and land distribution. The study provided estimates of the economic impacts of climate change, compared these with historical impacts of drought spells, and estimated the extent to which the current Moroccan agricultural development and investment strategy, the Plan Maroc Vert, helps in agricultural adaptation to climate change and uncertainty. The aim of this study was to quantify the effects of climate change on the overall economy by using an integrated framework incorporating a computable general equilibrium model. A concomitant factor to climate change will be the increase in population and its distribution and level of consumption, which will also influence agricultural production strategies, the conversion of agricultural land, the type of irrigation, and technological development. We demonstrated how changes in cereal production and area, affluence, and climate (rainfall and temperature) can be acquired for 12 regions of Morocco and used to develop and validate an earth system model in relation to the environment and socio-economic level, which projects their impact on current and potential land use over the next 20 years. We used different mathematical equations based on cereal area and production, population, consumption (kg/person), and change in climate (temperature and rainfall) in *bour* and irrigated areas for the growing season of 2014 in 12 regions to project agricultural land use over the next 20 years. Therefore, several possible scenarios were investigated to explore how variations in climate change, socio-economic level, and technological development will affect the future of agricultural land use over the next 20 years, which in turn could have important implications for human well-being. Among the 12 Moroccan regions, only 4 had a surplus of cereal production compared to their local consumption. The increase in population will generate a cereal deficit in 2024 and 2034, thus lowering the average annual quantity available per capita of cereals from 204.75 to 160.61 kg/p in 2014 and 2034, respectively. Therefore, it is necessary to reduce the amount of cereals per person by 5 kg/p and 25 kg/p so that the 2014 production could satisfy the population projected in 2024 and 2034. We found that cereal production will decrease with increasing temperature and decreasing precipitation according to the simulated scenarios, which might not satisfy the growing population in 2024 and 2034. This study provides a practical tool that can be used to provide policy makers with advice on food security assurance policy based on our current knowledge of the impending onset of climate change, including socio-economic statistics and the agricultural constraints of cereals in the 12 regions of Morocco.

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## 1. Introduction

Over the course of 10 to 50 years, global agricultural production is preparing to face multiple internal factors in interaction. The Intergovernmental Panel on Climate Change (IPCC) predicts a global warming until at least the mid-century under all emissions scenarios considered. Global warming of 1.5 °C and 2 °C will be exceeded during the 21st century unless deep reductions in CO2 and other greenhouse gas emissions occur in the coming decades [1,2]. Climate change is expected to have a significant impact on conditions that directly affect agriculture, especially temperature, precipitation, and runoff. There is a compacted interrelationship between agriculture and climate change factors, which includes both meteorological variables (temperature, rainfall, and precipitation) and greenhouse gases, primarily carbon dioxide. The other aspects related to agriculture that affect economic growth are categorized as agriculture output, prices of primary commodities, and farmers' income [3]. These conditions determine the load capacity of the biosphere to produce sufficient food for the human population and for our domesticated animals [4]. On a global scale, increasing carbon dioxide levels could also have beneficial and harmful effects on crop yields [5]. The warming is not equivocal; there is less confidence in the expected increase in the amount and distribution of precipitation. Increases in precipitation are projected to be uniform over land with the exception being the Mediterranean region, the southwestern part of the United States, South Africa, and Southwest Asia [6]. This change in climate is likely to have a significant impact on agricultural production worldwide, particularly in areas where temperature will increase and water availability decreases. Coupled with climate change, agriculture is also facing the growing challenge of feeding the world population, which is expected to reach 9.1 billion by 2050. Over the next 45 years, the cost of feeding the world population will increase to USD 6.5 billion. However, the most important population growth occurs in less developed regions where about 5.3 billion people actually live. The population is expected to grow to about 7.8 billion by 2050 in developing nations but will remain roughly unchanged at about 1.2 billion in developed countries [7].

In Morocco, since independence in 1956, the public policies have given priority to agricultural development [8]. Consequently, agriculture has become the country's leading economic sector, which generates about 14% of gross domestic product (GDP) [9]. The irrigated land occupies only 15% of the cultivated area [10]. In the case of rainfed land, unirrigated areas are the dominant cultivated areas. However, most of them are less productive and are severely affected by drought during the peak of summer [9]. As Moroccan agriculture is mostly based on rainfed agriculture, the country has developed the strategy of the Green Morocco Plan from 2008 to 2020 [11], which is designed to enhance an increase in crop production [12]. Since 2020, the Moroccan government has continued its agricultural revolution through the green generation strategy [13]. Agriculture also remains the country's largest source of employment with 40% of the working population living in this sector [9,14]. Therefore, to have a good impact on agricultural productivity, a healthy soil is required to regulate and support ecosystem functions such as nutrient cycling and uptake, water retention, gas exchange, pest and disease regulation, biodiversity, and carbon sinks [15–19]. This can only be achieved through good agricultural practices for good productivity. However, there are many options and combinations of specific soil management practices that depend on the context of the agricultural system [20].

Agriculture is mainly influenced by climatic conditions. Efficient use of water and energy are the basic requirements of sustainable agriculture. The problem of water scarcity is even more relevant in arid and semi-arid regions [21,22]. Therefore, it is very important to improve water use efficiency [23,24], and most undertaken actions of improving irrigation efficiency would enhance water management [25]. Adequate irrigation is of paramount importance to increase the size and weight of individual care and to increase the crop productivity. However, such situations have become impossible due to increased water scarcity [26,27].

Soil tillage in Morocco depends on certain factors such as the soil type, the climate, and crop requirements. It groups together all cultural practices in relation to soil surface and structure. Tillage is the main technique of land preparation for cropping. Several types of material are used to prepare the seed bed [28]. Among the factors that push the Moroccan farmers to manage the tillage of their fields is the type of land, whether rainy land or unirrigated land. The unirrigated (*bour*) lands depend on rainfall, and the irrigated lands depend on the irrigation systems. This later followed the guidelines of the National Plan of Economy of Irrigation Water in order to promote a more sustainable model of irrigation and to optimize the efficient use of water resources in order to increase the agricultural productivity [10]. The main irrigation techniques adopted in Morocco are submersion irrigation, sprinklers, and drip irrigation [29]. For submersion irrigation, it uses an open channel that brings water by gravity to smaller and smaller channels to irrigate plots. It consumes a significant amount of water, especially since a large part is lost [29]. Nonetheless, several studies pointed out that unsustainable irrigation was the major global factor of the depletion of water resources such as river flows [30] and underground aquifers [31]. As a result, surface and groundwater resources are under significant pressure worldwide [32,33]. Sprinkler irrigation is a method of applying irrigation water that is similar to natural rain. The water is distributed by a system of pipes, usually by pumping [34]. The distribution of water in this type of irrigation system depends on the design of an irrigation system and the prevailing climatic conditions [35]. Many studies have described sprinkler irrigation as a smart technology that can adapt to the negative impact of climate change and overcome the constraint of water scarcity by saving water for agricultural production [36–39]. Kato et al. [36] found that sprinkler irrigation can reduce water consumption and increase grain production. Regarding drip irrigation, it can save water and increase crop production by frequently transferring small amounts of water to the rhizosphere of plant roots [40]. It also has the potential to improve crop productivity by reducing crop costs [41–46]. Studies have provided strong evidence of the benefits of using drip irrigation in the cultivation of high-value crops [43,44].

The farmer uses other mechanical and chemical techniques in their fields. Ploughing is an operation carried out by a plough, which results in the turning over of organic matter and the destruction of weeds. It improves soil aeration by creating an artificial structure. This technique further leads to the use a harrower or a ridger to loosen the soil and facilitate the formation of particles by runoff [28]. Proper decomposition of crop residues is guaranteed by a stubble cultivator, which is also used to destroy seeds and weeds left on the ground. While at the surface of the soil, mulching is done, and this consists of placing organic and mineral matter round the stems of plants. In addition, the placement of fertilizers was consistently used and serves to fertilize the land [28]. Weeding is the practice of limiting the development of weeds by reducing their harmful effects on cultivated crops [47].

Agriculture is essential and mandatory practices for the survival of our species, especially given the climatic and socio-economic conditions expected in the middle of the century. Technological development and transfer have the potential to affect the capacity of these systems to cope with these varying environmental effects. Assessment of the effects of global climate change on agriculture is likely to help continuously anticipate and adapt agriculture to optimize and support agricultural production. If the human population then continues to increase, agricultural production must also increase to meet their demand, suggesting an increase in land devoted to agriculture, notably in developing countries. Likewise, the world population is growing with an expected increase in demands for food, forage, and fibre [48–50]. Consequently, an investment in the information of demographic change and technological advances is highly needed to improve our ability to understand, mitigate, or adapt to the multiple impacts of climate change. Increased pressure on agricultural production has likely resulted in an extension of agricultural land use in an attempt to offset the decline in production due to both adverse climate change and population growth. This could be particularly true in developing countries where technological development is still insufficient and where population growth is not yet under control, often leading to increasing demand for agricultural products. The conversion of land for agriculture is often done to the extent of forests. Several studies highlighted that most of the changes consisted of converting forests or grassland to cropland [51–53]. Studies based on Landsat satellite imagery between 1975 and 1999 show that agricultural expansion has occurred at the expense of landscapes through dramatic change [54]. Other studies have estimated deforestation rates ranging from 160 $km^2$ $an^{-1}$ in the early 1980s to nearly 1200 $km^2$ $an^{-1}$ in the late 1990s [55,56]. Many studies have been attempted to estimate the economic impact of climate change, but only fewer ones have sought to examine the impact of climate change on agricultural land use and land cover [57–61]. Therefore, this study proposed simulation projections of agricultural land use and land cover change with respect to environmental, socio-economic, and biophysical factors forcing agricultural over the next twenty years.

Understanding the links between these various factors and their implications for global agricultural demand is crucial to determine the likelihood of significant future land use and to cover trends of variation in relation to agriculture. Demand for agricultural products is better assessed relative to supply. The food supply is affected by abiotic environmental fluctuations such as those related to temperature and water. High temperatures and low soil water content are known to reduce crops' growth, development, and yields as well by inhibiting photosynthesis. The impacts of climate change on Moroccan agriculture are quite significant. On average, yields of wheat grains and sugar crops are expected to decline by 10% by 2050, accounting for 53% of total agricultural production and 50.5% of total arable land [49]. Therefore, the main question is how to support cereal agricultural production in order to ensure food security for a continuously growing population by optimizing the agricultural sector via mitigating/adapting to the multiple impacts of climate change. Therefore, the main purpose of this study was to determine the impact of climate change on land use, and this will depend on our understanding of past changes in the wheat sector of Morocco and how future climate change, technology, irrigation, population size, and distribution affect cereal production and its relationship to the extension of agricultural arable land. Certainly, the need for an increased awareness of the importance of cereals in the diet of fellow Moroccan citizens is clearly highlighted. To know how to guarantee food security, Morocco's average annual cereal consumption per capita was compared to European and Mediterranean countries by estimating how much to reduce cereal food intake by 2034.

As a result of this study, the annual average available per capita for 2014 was compared to 2024 and 2034 based on the annual cereal consumption pattern of the selected countries. In addition, it is expected that the urban population of Morocco can adjust their food wealth and include less cereals in their diet.

## 2. Materials and Methods

Morocco is one of the five countries of the Maghreb; it located in the northwest region in North Africa with an area of 710,850 $km^2$ and a population of approximately 37 million inhabitants. The country of Morocco is divided into twelve regions (Figure 1). Moroccan agriculture is of undeniable economic and social importance with 40% of total employment at the national level and 74% in rural areas. This activity also contributes nearly 13% of the GDP, but this contribution varies between regions.

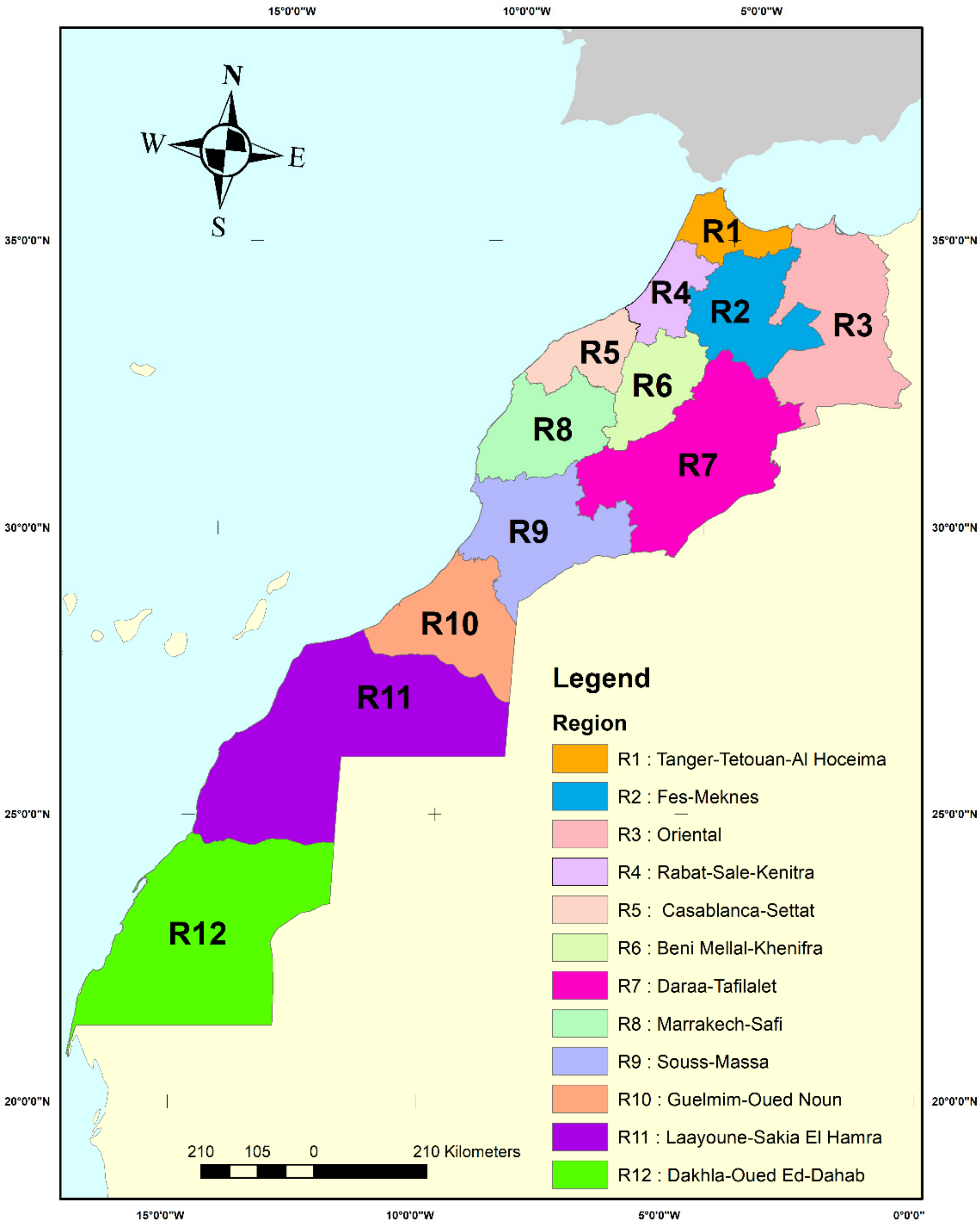


**Figure 1.** Map of the 12 administrative regions of Morocco. This map was produced by ArcGIS software.

## 2.1. Datasets on Moroccan Agriculture in 2014

*Cereal production and area*. Cereal statistics were obtained from the economic services of the Ministry of Agriculture and Maritime Fisheries of Morocco, which represents data containing cereal productions and areas seeded in both unirrigated and irrigated lands for the growing season of 2014. This data were obtained from sample surveys of the sub-provinces and organized according to the 12 regions of Morocco.

*Moroccan population and cereal consumption*. The Moroccan population census is managed by the High Commission for Planning [62]. This is an exhaustive operation carried out throughout the national territory. It concerns the entire urban and rural population and all the households that reside there. It is carried out by direct interview (door to door) to know the different socio-economic structures and economic profiles of the population, to determine the characteristics of the housing stock at all geographic levels, and to constitute the basic documentation necessary for the development of the master sample.

To monitor the levels and living conditions of this population, the High Commission for Planning (HCP) also manages the monitoring of consumption by carrying out consumption surveys through which data were collected on the quantities of cereals consumed according to the living conditions of the population. On average, based on statistics from surveys conducted in 1985, 2001, and 2014, the consumption of the main cereals in kg/year/capita was about 200 kg, knowing that the world average consumption of cereals is around 152 kg/year/inhabitant.

Bread wheat represents nearly 70% of the cereal consumption by the urban dwellers and 66% by rural dwellers. In urban areas, the consumption of durum wheat is mainly derived from industry, while, in rural areas, households consume locally produced durum wheat. Human consumption of barley and corn has become marginal, notably for urban dwellers [63].

### 2.2. Methods

*Combined and extended databases*. The methodology was to develop and validate a land-system model related to the environment and the socio-economic level, which projects their consequence on the current and potential land cover and the change of land use over the next 10 years.

*Population, consumption, and cereal production in 2014.* According to the census of the Moroccan population done by HCP in 2014, the Moroccan population in 2014 with distribution of the urban and rural population of the 12 regions of Morocco represents the statistics on which the rural, urban, and total population projection calculations were triggered and which also will be used for the calculation of real and projected consumption [64].

In this study, we were interested in the year 2014, and, according to their surveys, the following Table 1 shows their results with a difference between the urban and rural populations, which differed with respect to the annual quantity consumed per year. According to the statistics of HCP in Table 1, the consumption of the urban population was 181 kg/person and that of the rural population was 191 kg/person. These values were used to calculate Moroccan urban consumption, Moroccan rural consumption, and total Moroccan consumption (urban and rural) by using the following equations.

$$Moroccan\ urban\ consumption\ (kg) = 181 \times MoroccanUrban\ population$$

$$Moroccan\ rural\ consumption\ (kg) = 191 \times Moroccan\ rural\ population$$

$$Total\ Moroccan\ consumption\ (kg) = Moroccan\ urban\ consumption + Moroccan\ rural\ consumption$$

**Table 1.** Average annual quantity of cereals consumed per person in Morocco in 2014.

| **AAQ/P: Average Annual Quantity (kg/Person)** | | |
|---|---|---|
| Urban consumption | Rural consumption | Total |
| 181 | 191 | 372 |

The fraction of the urban, rural, and total population was calculated by Equation 1d,e (Supplementary Materials) in order to estimate the consumption of each region. Regional consumption in 2014 is calculated by the Equation 1f–h (Supplementary Materials). To be more precise, the total consumption (Urban + rural) was established for each region by using the Equation 1i (Supplementary Materials). For Morocco, the corrected consumption (kg/person), which is the average consumption/person was established by using Equation 1j (Supplementary Materials).

Cereals (wheat, corn, oats, barley, rice, sorghum, and other cereals) are cultivated in the various agro-climatic zones of the country in rotation with other annual crops, which are mainly legumes, industrial crops, and fodder crops. The main production regions are located in the rainfed areas of the plains and plateau of the regions of Casablanca-Settat, Rabat-Sale-Kenitra, Fes Meknes, and Marrakech Safi where the vast majority of cereal farms are located regardless of their size [63]. The cereal sector occupies a decisive place in the Moroccan agricultural economy, and this exists at different levels, in particular at the socio-economic level. According to statistics in 2014 from the Ministry of Agriculture and Maritime Fisheries of Morocco, cereal production represents 63.40% of the arable agricultural land (4,763,370.84 Ha) of which 92.62% of the surface area was *bour* lands and 7.38% was intended for irrigated lands [11].

*Scenarios.* Several possible scenarios were investigated to explore how variations in climate change factors, socio-economic level, and technological development will affect the future of agricultural land use over the next 10 years, which in turn could have important implications for human well-being. These scenarios are as follows:

1. Change in Population. The consequences of socio-economic changes were assessed in this scenario. For this reason, the following parameters were used:

*Population growth rate*: The growth rate of the Moroccan population was 1.22% for the urban population, 1.22% for the rural population, and 1.22% for the total population [65].

*Urban population*: The growth rate of the urban population was 1.22%. We used this rate to calculate the projections of the urban population in Morocco according to the following equation:

$$Urban\ population\ (n+1) = Urban\ population\ (n) + (1.22\% \times Urban\ population\ (n))$$

*Rural population*: The growth rate of the rural population was 1.22%. The projection of the rural population was calculated by using a similar Equation 2b (Supplementary Materials).

*Total population*: It is the sum of the urban population and rural population. In 2014, the total population of Morocco was 33,848,242, and it is projected to be 38,715,278 in 2024 and 42,118,916 in 2034 [65]. Therefore, the growth rate of the total population was estimated by Equation 2c (Supplementary Materials). Accordingly, a growth rate of the total population of 1.22% was obtained and used to calculate the total projection based on Equation 2d (Supplementary Materials).

*Calculation of New QAM/P using Corrected Consumption*. New QAM/P values were calculated by using the corrected consumption and urban and rural fractions relative to the weighted average. New QAM/P values were recorded by Equation 2e–i (Supplementary Materials). The values of these equations were served to have more precision for the calculations, which came after.

2. Change in Affluence

*Mediterranean and European affluence*. A comparison was made between Morocco and certain countries from two coasts of the Mediterranean Sea (Spain, France, Italy, Algeria, Tunisia, and Greece) in order to have an idea on the future of food security from cereal cultivation. This action was carried out thanks to datasets of some research from the web listing the average annual consumption of cereal in neighboring developed countries of the Mediterranean and Europe [66]. Several equations were developed, in particular the new consumption according to Mediterranean and European affluences. The consumption scenario under Mediterranean affluence and the consumption scenario under European affluence were used to fully understand the measures to be taken for achieving food security and to understand where the gains and deficits in cereals are located. Accordingly, the following equations were used to fulfill these gaps. Table 2 contains the values of the Mediterranean and European average consumption on which calculations were triggered.

**Table 2.** Average annual consumption of cereal (kg/person) in neighboring (because of climate and geography) developed countries of the Mediterranean and Europe.

| Year | 2012–2013 | 2012–2013 |
|---|---|---|
| Spain | 89.2 | 89.2 |
| France | 125 | 125 |
| Itlay | 156 | 156 |
| Algeria | 215 | - |
| Tunisia | 213 | - |
| Greece | 137 | 137 |
| Average | 155.87<br>Mediterranen average | 126.80<br>European average |

*Calculation of QAM/P based on Mediterranean and European averages* (Table 2). The percentage of urban and rural QAM/P was calculated with respect to the weighted average (as calculated by Equation (2h,i)). These percentages were then applied to the averages from the Mediterranean in order to calculate the fraction of urban and rural consumption per capita with the new Mediterranean and European affluence (Table 3) for Mediterranean and European averages.

**Table 3.** Urban and rural average annual consumption (kg/p) of the Mediterranean and Europe.

| | Annual Consumption Rates (kg/p) | | |
|---|---|---|---|
| | **Urban** | **Rural** | **Weighted Average** |
| Mediterranean | 152.38 | 161.18 | 155.87 |
| European | 123.96 | 131.12 | 126.80 |

The urban, rural, and total consumption per capita were calculated with the new affluence (Mediterranean and European), which represents new scenarios defined as the Moroccan consumption scenario under Mediterranean affluence and European affluence, respectively. Equation 3d–i (Supplementary Materials) was used for the calculation.

Consumption S1, which corresponds to the QAM/P for Morocco based on 2014 (186.00 kg/p) and Consumption S2 corresponding to a QAM/p (consumption scenario under Mediterranean affluence) were obtained over the Mediterranean region for 2012–2013 (155.87 kg/p). Consumption S3 (consumption scenario under European affluence) corresponds to a QAM/p obtained as an average over European and Mediterranean countries of 126.80 kg/p.

The gain (+) deficit, which represents the difference between the production of cereals in Morocco in 2014 compared to Consumption S1 in 2014, 2024, and 2034 was estimated based on Equation 3ja–jc (Supplementary Materials); it was assumed that each individual consumes 186.00 kg/p despite an increasing population in 2024 and 2034 to assess if the production of 2014 will be able to feed the populations of 2024 and 2034.

The MAS/P represents how much the consumption must be lowered per person so that the production of 2014 will be sufficient to feed the populations of 2024 and 2034. The relevant equations of these calculations are 3.k.a, 3.k.b, and 3.k.c (Supplementary Materials). In addition, the MAC/p, which represents the ratio of the total Moroccan consumption to the total Moroccan population of the same year, was used to estimate QAM (weighted average) (already calculated by Equation 2g for verification). Equation 3la–1c was used for the calculation (Supplementary Materials).

The required exchange percentage was calculated to find out how much to reduce the percentage of grain consumption in 2024 and 2034. Equation 3ma, mb was used for this purpose (Supplementary Materials). The future values were calculated to estimate the average consumption of cereals per person needed to guarantee food security in 2024 and 2034 according to Equation 3na, nb (Supplementary Materials). Afterwards, the MAC/p, the Mediterranean MAC/p, and the European MAC/p were drawn for 2014, 2024, and 2034 as explained in Equation 3oa–oc,3pa–pc,3qa–c (Supplementary Materials) in order to know if the Moroccan production in 2014 can satisfy or not the Moroccan population in 2014, 2024, and 2034 compared to Moroccan consumption based on 2014 (186.00 kg/p) (Consumption S1), the consumption scenario under Mediterranean affluence (Consumption S2), and the consumption scenario under European affluence (Consumption S3).

3. Change in climate (temperature and rainfall). A rate of change in agricultural cereal production per unit change in temperature and precipitation has been established for the years 2024 (low impact scenario) and 2034 (high impact scenario) [67].

*Temperature.* The temperature can influence the productivity on *bour* and irrigated lands, which was why the cereal production rate is intended to decline with increased temperature for these lands. These values are listed in Table 4. The following equation shows an example of the calculation of temperature-related production projections in 2024 at the *bour* land level.

**Table 4.** Rate of cereal production decline with increased temperature (%) [67].

| | 2024—Low-Impact Scenario | 2034—High-Impact Scenario |
|---|---|---|
| Rainfed | 2.3 | 5.4 |
| Irrigated | 1.6 | 3.7 |

$$Rainfed\ Production\ (2024) = Rainfed\ Production\ 2014 - (Rainfed\ Production\ 2014 \times 2.3\%)$$

The cereal yield in the total land (irrigated and *bour* lands) was affected by the decrease in temperature, which was estimated according to the following Equation 4a–f (Supplementary Materials).

*Rainfall.* In order to extract the variation of cereal production as a function of rainfall, the yield as a function of the amount of precipitation (mm) was estimated as follows:

$$\frac{Yield\ 2008 - Yield\ 1991}{Precipitation\ 2008 - Precipitation\ 1991} = \frac{7-15}{250-400} = \frac{-8}{-150} = \frac{8\ Qx/ha}{150\ mm}$$

According to this formula, with each decrease of 1 mm of precipitation, the yield will decrease by 0.05 *Qx/ha*. Therefore, 0.05 is the variation of the yield for each decrease of 1 mm of rain. The decrease in rainfall (Y) was estimated according to linear equation (y = 0.2855x (year) – 564.95) drawn from datasets listed in Table 2. According to this equation, the rainfall reduction values were 12.90% and 15.76% for 2024 and 2034, respectively. This information was used to deduce the percentage decrease in yield in *Qx/ha* (Table 5).

**Table 5.** The agro-meteorological prediction of cereal yields in Morocco [68].

| | Decrease in Precipitation in % | Average Decrease in % |
|---|---|---|
| 2030 | 14 | 14 |
| 2050 | 13 to 30 | 21.5 |
| 2080 | 21 to 36 | 28.5 |

Table 5 shows the *Qx/ha* value of 3.03, which denotes a loss of 303 kg in cereal production in one hectare. In 2014, the *bour* lands occupied 4,411,669 ha, so there was a loss of 1,336,735,707 kg of cereals representing 23.55% of the production of *bour* lands during the 2014 campaign (5,676,988,397 kg).

For 2034, there was a loss of 370 kg of cereal production in one hectare, so there was a loss of 1,632,317,530 kg representing 28.75% of the cereal production in *bour* lands in 2014. Table 5 underlines the percentage decrease in cereal production. In this study, the production from *bour* lands was the only one considered because it was based solely on rainfall. These percentages values were used to calculate the production in 2024 and 2034 following Equation 5b:

* *2024 Low Scenario*

$$Rainfed\ Production\ (2024) = Rainfed\ Production\ 2014 - (Rainfed\ Production\ 2014 \times 23.55\%)$$

* *2034 High-Impact Scenario*

$$Rainfed\ Production\ (2034) = Rainfed\ Production\ 2014 - (Rainfed\ Production\ 2014 \times 28.75\%)$$

4. Change in Technology. The change in technology was evaluated by the following parameters: yield projection, increase in cereal land, and change in land under cereal production.

* ***Yield.*** The obtained yield from 2004 to 2017 was used. The projected yield from 2018 to 2034 was based on conservative averaged values obtained from observations for the main cereal crops over the period of 1979–2006, and the values were found to be 18.35 *Qx /ha* and 19.45 *Qx/ha* in 2024 and 2034, respectively. Therefore, the increase in yield per year was about 0.11 $Qx$/ha/year. The following linear equation (yield year ($n$ + 1) = yield year $n$ + 0.11) obtained from previously published datasets (World Bank, 2015) was used to project the yield. The rainfed and irrigated yields were obtained from the total projected yield based on the percent of rainfed and irrigated yield in 2014 (above).

$$Pourcent\ production\ (2024)\% = \frac{100 \times (production\ 2024 - production\ 2014)}{production\ 2014}$$

$$Pourcent\ production\ (2034)\% = \frac{100 \times (production\ 2034 - production\ 2014)}{production\ 2014}$$

* Increase in cereal land was estimated as follows:

$$Rainfed\ pourcentage(\%)of\ total = \frac{Rainfed\ area\ of\ Region\ X}{Total\ Rainfed\ area\ of\ Morocco} \times 100$$

$$Irrigated\ pourcentage(\%)of\ total = \frac{Irrigated\ area\ of\ Region\ X}{Total\ Irrigated\ area\ of\ Morocco} \times 100$$

* Change in land under cereal production. Land cereal production occupied 5,460,480 ha in 2015 and 5,568,363 ha in 2017 [69,70].

The cereal land change rate (0.99) (Supplementary Materials) was calculated (Table 6) and used to estimate the projection of the total grain area from year to year based on Equation 6ia (Supplementary Materials). In addition, the *bour* and irrigated percentages to calculate the projection in *bour* and irrigated lands (as shown previously) were used. Therefore, based on the yield already calculated, the projection of agricultural production related to the change in the area of agricultural land was deduced according to Equation 6ib (Supplementary Materials). Projected production ($Qx$) was extracted based on projected land under cereal use (ha) and projected yield (*Qx/ha*).

**Table 6.** Rate of change of land cereal production of 2015 and 2017.

| Years | Land Cereal Production (ha) | Rate of Change (%) |
|---|---|---|
| 2015 | 5,460,480 | 0.99 |
| 2017 | 5,568,363 | |

## 3. Results

### 3.1. Control Situation

Table 7 describes the situation of the regional consumption and production as well as the total for all twelve regions. The results show that among the 12 Moroccan regions, only 4 had a surplus in production as compared to their local consumption. These four were the Fes-Meknes (R3), Rabat-Sale-Kenitra (R4), Beni Mellal-Khenifra (R5), and Casablanca-Settat (R6) regions. Together, these regions constitute the cereal reserve stock of Morocco and have a total surplus of 1,915,796.36 tons with highest production record in the Fes-Meknes region (898,700.30 tons). The regions of Rabat-Sale and Beni Mellal-Khenifra also constitute an important reserve for cereal, each one having a surplus about half that of Fes-Meknes region. The region of Casablanca-Settat produced an amount of 60,865.18 tons more than what it consumes locally. All other regions were in deficit with the Sous-Massa region having the largest deficit followed by the Draa-Tafillet and then the Marrakech-Safi region. The size of the deficit is a function of the local production and the population size. For example, the regions of Laayoune-Sakia El-Hamra and Dakhla-Oued d-Dahab had no production at all as they are located in non-productive arid zones. However, they had the smallest deficit of 69,748.38 and 29,181.67 tons, respectively, because of their small population sizes. Despite eight regions with a production deficit including two non-productive regions, Morocco's cereal production balance still remained positive with an excess of 634,897.61 tons.

**Table 7.** Control situation for 2014 consumption. Production and balance for cereal per region (kg).

| | Regions | Total Consumption (kg) | Total Production (kg) | Deficit (−)/Gain (+) (kg) | Deficit (−)/Gain (+) (kg)/1000 | Normalized Deficit |
|---|---|---|---|---|---|---|
| Region 1 | Tanger-Tetouan-Al Hoceima | 660,936,921 | 546,928,002 | −114,008,919 | −114,008.92 | 0.2 |
| Region 2 | Oriental | 429,829,401 | 315,888,459 | −113,940,942 | −113,940.94 | 0.2 |
| Region 3 | Fes-Meknes | 786,519,339 | 1,685,219,637 | 898,700,297 | 898,700.30 | |
| Region 4 | Rabat-Sale-Kenitra | 845,877,869 | 1,323,788,124 | 477,910,255 | 477,910.26 | |
| Region 5 | Beni Mellal-Khenifra | 472,001,931 | 950,322,560 | 478,320,629 | 478,320.63 | |
| Region 6 | Casablanca-Settat | 1,262,997,724 | 1,323,862,901 | 60,865,177 | 60,865.18 | |
| Region 7 | Marrakech-Safi | 846,949,856 | 673,809,301 | −173,140,554 | −173,140.55 | 0.4 |
| Region 8 | Draa-Tafilalet | 309,603,411 | 85,730,751 | −223,872,660 | −223,872.66 | 0.5 |
| Region 9 | Souss-Massa | 499,141,610 | 22,841,845 | −476,299,766 | −476,299.77 | 1.0 |
| Region 10 | Guelmim-Oued Noun | 82,984,903 | 2,279,044 | −80,705,859 | −80,705.86 | 0.2 |
| Region 11 | Laayoune-Sakia El Hamra | 69,748,379 | 0 | −69,748,379 | −69,748.38 | 0.1 |
| Region 12 | Dakhla-Oued Ed-Dahab | 29,181,669 | 0 | −29,181,669 | −29,181.67 | 0.1 |
| Morocco | | 6,295,773,012 | 6,930,670,622 | 634,897,611 | 634,897.61 | |

### 3.2. Population and Consumption Increase: Change in Affluence

In Morocco, the 2014 census recorded a total population of 33,848,242 people. The population is projected to continue to grow monotonically until the year 2065, where it will reach a total of 46,886,622 people. During this period, the population growth rate was estimated at 1.22% [65]. By 2024, the population will be 38,218,498 people and will reach 43,153,013 in 2034 (Figure 2). An increase in population necessarily increases the demand for cereal food, and, without change in consumption habits, this behavior will generate a growing deficit for this commodity. The 2014-to-2034 urban, rural, and total (urban and rural) change in consumption for Morocco is illustrated in Figure 3, and the values for 2014, 2024, and 2034 are reported in Table 8. Based on the 2014 total production and a constant per capita consumption rate of 186.00 kg/person [64], the increase in population will generate a deficit in cereal of 177,971 *Qx* in 2024 and a substantial deficit of 10,957,898 *Qx* by 2034, lowering thus the average annual available per capita quantity of cereal from 204.75 kg/p in 2014 to 160.61 kg/p in 2034 (Table 8).

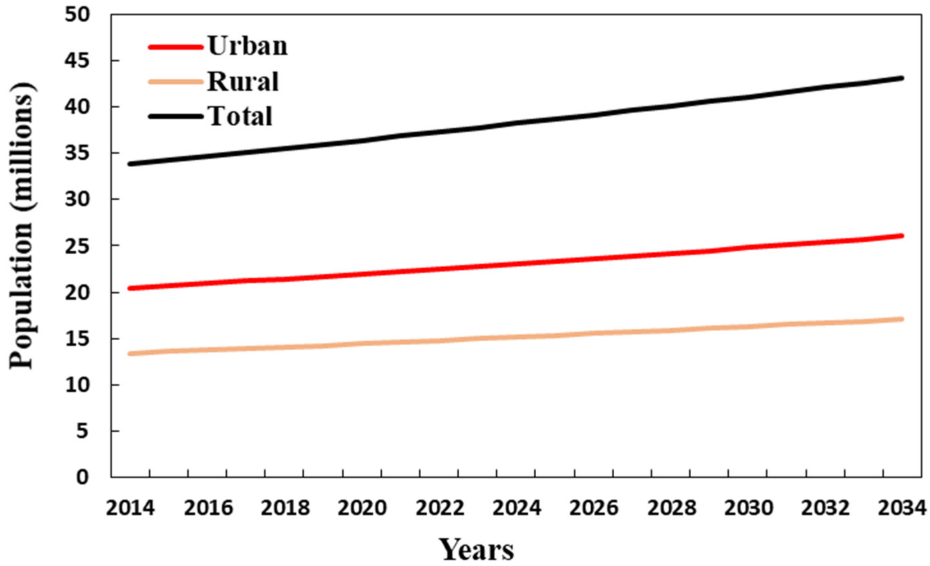


**Figure 2.** Population growth in Morocco during the period 2014–2034.

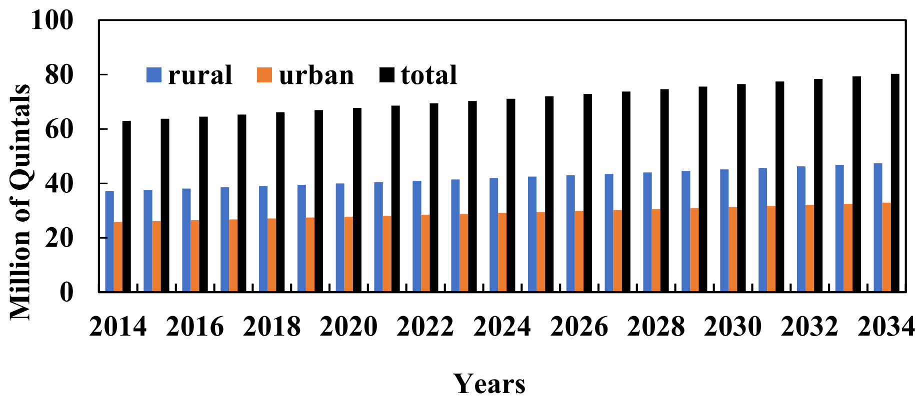


**Figure 3.** Change in consumption of Moroccan people as affected by changes in population.

**Table 8.** Population-driven consumption growth. Gains and deficits were calculated with respect to the 2014 production amount. All values are expressed in kg.

| Years | 2014 | 2024 | 2034 |
|---|---|---|---|
| Production | 69,306,706 | - | - |
| Population | 33,848,242 | 38,218,498 | 43,153,013 |
| Consumption | 62,957,730 | 71,086,407 | 80,264,604 |
| MAC/p (kg/p) | 186.00 | 186.00 | 186.00 |
| MAS/p (kg/p) | 204.76 | 181.34 | 160.61 |
| Gain(+)/Deficit(−) | 6,348,976 | −1,779,701 | −10,957,898 |
| Necessary change (%) | | 2.504 | 11.43 |
| Future values | | 181.34 | 160.61 |

Based on a comparison of 158 countries in 2013, Morocco ranked the highest in cereal consumption per capita with 254 kg/p [67], while Rwanda was the last on the scale with 46.8 kg/p. This represents a wide range in grain consumption habits, and with socio-economic development, it is expected that Morocco's urban population may adjust its dietary affluence and include less grains in their diets. If the Moroccan annual average per capita cereal consumption is aligned with that of neighboring Mediterranean countries (Spain, France, Italy, Greece, Tunisia, and Algeria) of 155 kg/p by 2034, Morocco will then guarantee its cereal food security. In order to achieve that, the population will have to reduce cereal food intake by 2.54% from 186.00 kg/p in 2014 to 181.34 kg/p in 2024 and another 11.43% from 2024 to 2034, taking the average per capita consumption to 160.61 kg/p and matching the production of 2014 (Table 8). Alternatively, Morocco's economy will have either to increase its production or import cereal.

In 2014, the cereal production was sufficient for Moroccan consumption based on 2014 (186.00 kg/p) (Consumption S1), the consumption scenario under Mediterranean affluence (Consumption S2), and consumption scenario under European affluence (Consumption S3). For 2024 and 2034, there will be a cereal deficit (especially in 2034),as it is shown in Figure 4, in which there was a need to lower 5 kg/p and 25 kg/p of the cereal quantity per person so that the 2014 production can satisfy the projected Moroccan population in 2024 and 2034.

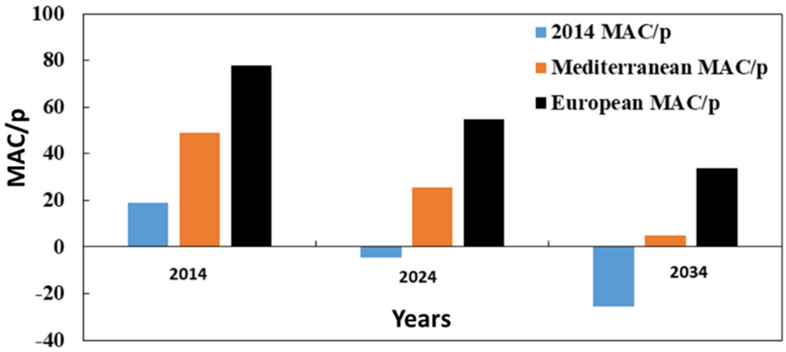


**Figure 4.** Moroccan, Mediterranean, and European MAC/p.

### *3.3. Impact of Climate Change on Temperature and Precipitation*

Climate change is real and unequivocal, as observed in recorded temperatures in many places worldwide. Africa in general and Morocco in particular are not spared by this drying and warming of their climate. Under different radiative concentration pathways and holding the growing area and technology constant, several models showed a positive warming trend and predicted a medium-term (2037–2056) decline ranging from 3.5% to 12.9% for winter wheat and 2.3% to 12.1% for winter barley across different climates. In semi-arid climate regions, the effects of heat stress on cereal yields are not easy to quantify because of the coupled water stress limitations, although the two effects are not independent. Consequently, the pattern in cereal land use is often assessed based on local growing-season precipitation amounts than the departure from the optimal growth temperature.

A study conducted in Tunisia with a climate similar to that of Morocco suggested that the attainable regional cereal yields during the 2000–2013 related to the wet growing season (January–April) showed a substantial decreasing trend with the warming increase. The yields decreased around 4.0, 2.6, and 3.2 kg/ha for each degree-day above a mean temperature of 15 °C for bread wheat, durum wheat, and barley respectively, and they were slightly larger than those obtained in France.

In this study, two scenarios were developed and discussed based on extreme values obtained from previous studies in which the variation of cereal production was highlighted as a function of increasing temperature and global warming (Table 9). As these values were developed over relatively large regions with their associated temperature and precipitation projections, the decrease in cereal production values in relation to the decrease in precipitation were developed in this study, and they are summarized in Table 10.

**Table 9.** Evolution in decrease in precipitation (mm) and yield (*Qx/ha*) in Morocco.

| Years | Annual Precipitation (mm) | Decrease in mm of Precipitation | Decrease in *Qx/ha* Yield |
|---|---|---|---|
| 2010 | 470 | - | - |
| 2024 | 409.36 | 60.64 | 3.03 |
| 2034 | 395.94 | 74.06 | 3.70 |

**Table 10.** Rate of cereal production decline with decreased precipitation (%).

| | 2024—Low-Impact Scenario | 2034—High-Impact Scenario |
|---|---|---|
| Rainfed | 23.55 | 28.75 |

The results of the projected decreased production in relation to the increased temperature and decreased precipitation are shown in Figures 5 and 6, which underline the decrease in kg at the level of all scenarios. In 2014, cereal production was zero in regions 11 and 12, and it was considered to be zero in 2024 and 2034 as well. Regarding the decrease in production with respect to increased temperature, the results underline that the production of cereals in Morocco will decrease by 15,062,965 tons in 2024 compared to that of 2014, and, in 2034, this production will decrease by 35,294,362 tons compared to 2014.

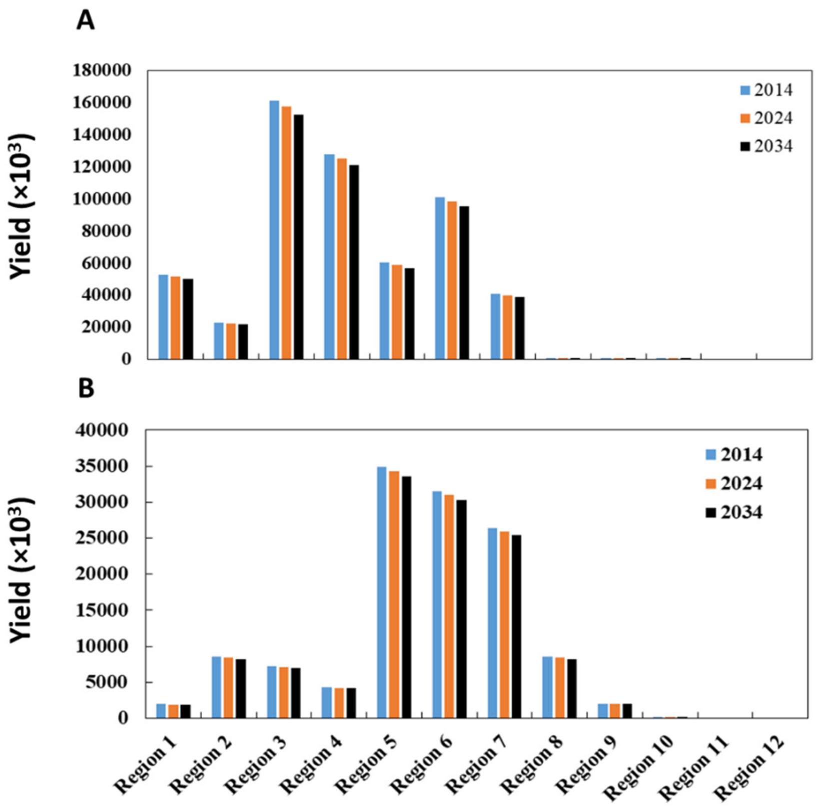


**Figure 5.** Rainfed (**A**) and irrigated (**B**) production with increasing temperature.

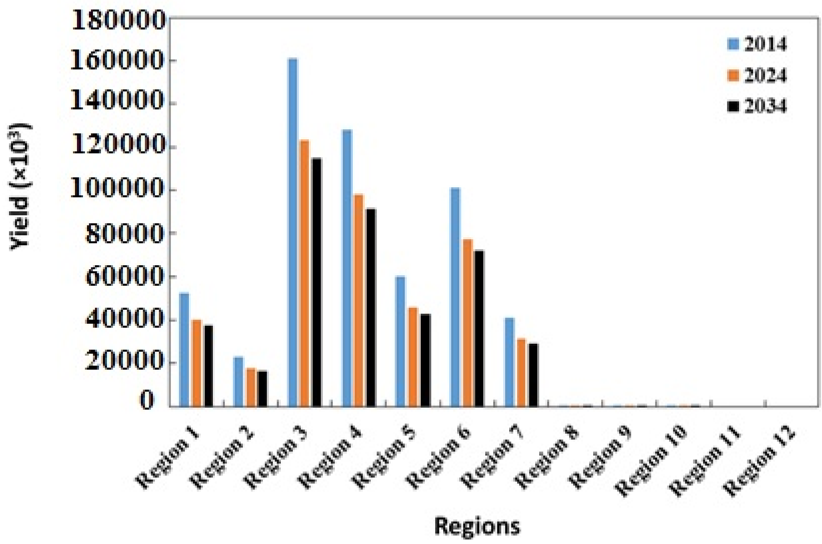


**Figure 6.** Rainfed production with decreased precipitation.

The decrease in rainfed production represents 87%, and that of the irrigated one represents 13% because, firstly, the *bour* lands in Morocco are the most dominant. Therefore, the greatest part of production comes from these lands. Secondly, these depend on, first, the degree of the climate, and, then, the increase in temperature according to the two scenarios worsens the climatic situation to lower cereal production more and more.

If we focus on the three major agricultural regions in Morocco, which are R3 (Fes-Meknes), R4 (Rabat-Sale-Kenitra), and R6 (Casablanca-Settat), all of the decreases in cereal production at the level of these regions compared to 2014 will be a decrease in rainfed production of 89,766.71 tons in 2024 and 210,756.63 tons in 2034. The decrease in irrigated production in these regions will be 14,830.52 tons in 2024 and 34,295.57 tons in 2034.

Regarding the decrease in production in relation to decreasing precipitation, two scenarios exist on (only) *bour* lands. For 2024 production, it will decrease by 172,124.59 ton and by 210,212.92 tons in 2034. For regions R3, R4, and R6, the total decrease in rainfed production compared to 2014 will be 118,334.77 tons in 2024 and 144,520.31 tons in 2034.

## 4. Discussion

### *4.1. World Panoramic Vision on the Production of Cereals and the Production Situation in Morocco*

Cereals have been considered the main component of human food since ancient times. More than 50% of the daily calorie intake in the world comes directly from the consumption of cereals [71]. Grains and cereal products are staple foods in most human diets [72,73] in developed and developing countries, providing much of the energy and food nutrients [74].

So, this food ranks first among products that make food safe for mankind. According to research done by the International Maize and Wheat Improvement Center (CIMMYT), the most important cereals are maize, rice, and wheat, which have provided food security on a global scale over the last half century, mainly by increasing yields of these crops and making them more resilient to drought, floods, pests, and diseases [75].

This study describes, for the first time, the production situation in 12 regions of Morocco. The results underline that the balance of cereal production in 2014 remained positive with a surplus of 634,897.61 tons despite eight regions with a production deficit including two non-productive regions in southern Morocco, being R11 and R12 or Laayoune-Sakia El-Hamra and Dakhla-Oued d-Dahab, respectively. Because the country has four major cereal production regions, being Fès-Meknes (R3), Rabat-Sale-Kenitra (R4), Beni Mellal-Khenifra (R5), and Casablanca-Settat (R6), the size of the deficit was established as a function of local production and the size of the population. If the population increases and production is negatively impacted by climatic conditions, the deficit will be more serious.

By taking wheat crops as an example, the world production for the 2012/13 season stood at 659.7 million tons against 702.4 million tons in 2011/12. This production fell by around 6%. This underperformance can be explained in large part by the impact of drought in Eastern Europe and Central Asia but also by lower crops in the Southern Hemisphere [76]. Regarding wheat production in Europe, it fell by 2.6% due to the drought that affected some countries in the center and southeast of the continent. However, in some countries in the Asian sub-region, record harvests were recorded in major producing countries, notably China and India [76]. In the Near East, the results were contrasted with good harvests recorded in Afghanistan and the Islamic Republic of Iran, while, in the other countries of the region, mixed results were noted due to droughts and social unrest [76]. Therefore, cereal production is always dependent on environmental, socio-economic, and political factors.

### 4.2. Increased Population Requires Significant Consumption

At the start of our era, the world population was 188 million people. Thanks to the industrial revolution and the development in the field of health, a large change has taken place [77]. This demographic expansion is expected to continue for several more decades before peaking at nearly 10 billion later in the 21st century [7,78]. Now, the world population is estimated to have reached 7.8 billion people as of March 2020 [65] and is expected to reach 8.5 billion by 2030 [7].

According to the results of this work, the population will be 38,218,498 people in 2024 and will reach 43,153,013 in 2034 (Figure 3). To live, the population must be nourished, and cereals were considered among the most important products in the world for ensuring food security. Wheat has been the number one domesticated food crop and was a basic staple item for European, North African, and West Asian populations 8000 years ago [79]. Today, wheat crops are produced and harvested on more land area than any other crops and continue to be the greatest significant human grain source; wheat production leads to other crops, such as potatoes, maize, and rice [80]. The increase in the population will generate a cereal deficit of 177.971 $Qx$ in 2024 and a substantial deficit of 10,957,898 $Qx$ by 2034. The population will have to reduce the food intake of cereals by 2.54% from 186.00 kg/p in 2014 to 181.34 kg/p in 2024 and another 11.43% from 2024 to 2034, which brings the average consumption per capita to 160.61 kg/p and corresponding to the production of 2014 (Table 2). The Moroccan economy will also have to increase its production or import cereals. Therefore, Morocco must intervene by improving the productivity of cereals and the ideal change in its eating habits. Several research studies have been established based on social needs and consumer behavior and habits [81,82]. Other research has shown that food choices may require consideration of various ethical challenges [83]. In general, consumers' food decisions prioritize their food preferences [81], which includes their diet, socio-economic level, or the availability of local products [77]. There is a very strong relationship between socioeconomic level and the diet chosen by the individual. Because a change in the structure of production is linked to improved income in low- and middle-income countries, mainly the different types of cereals are replaced by meat, fruits, and vegetables [84]. To fully understand food, its availability, and relational criteria, research has focused on the impact of dietary changes on the natural environment and the impact of environmental changes on all elements of food security [85], but of course there must always be the tendency to choose a healthy and balanced diet that should satisfy all social categories.

### 4.3. Climate Change Impacts on Production

Local and regional climatic conditions are a primary determinant of agronomic crop productivity. Plant metabolic processes are controlled by weather variables like maximum and minimum temperature, solar radiation, carbon dioxide concentration, and the availability of water [86–89].

This study dealt with climate change based on temperature and precipitation, as two scenarios were developed: the 2024 low-impact scenario and the 2034 high-impact scenarios. The results showed that cereal production will decrease. The cereal production in *bour* areas will decrease with increasing temperature and decreasing precipitation. The irrigated production will decrease with decreased precipitation as demonstrated in this study.

Previous analyses have described the Mediterranean and Northeastern Europe regions as the most prominent climate response hotspots, followed by high-latitude northern hemisphere regions and Central America [90–94]. Warming, particularly pronounced in summer and in the western Mediterranean, and changes in precipitation patterns are also documented, having occurred during the twentieth century [95–97]. The results evidence that future warming will occur all year round, being larger in summer than in winter and over land than over sea areas [98]. The Mediterranean region is likely to warm at a rate about 20% larger than the global annual mean surface temperature, with values particularly large in summer and in the continental areas north of the basin (where warming will be in general 50% larger than at global scale and locally even twice as large). Day temperatures are likely to increase more than night temperatures and summers more than winters, leading to an increase in amplitude of both daily and annual temperature ranges [92]. The most critical future issue for the Mediterranean environment in the reduction in precipitation, which, being in contrast with the general increase in the hydrological cycle, is the main characterization of the Mediterranean climate change "hotspot." [97]. In southern areas of the Mediterranean region, a large decrease in precipitation in all seasons and particularly in winter (–7 mm/K as a function of global warming) will likely negatively affect a large variety of crops and the accumulation of water in the reservoirs, which mainly occurs in this season. For crops, drought, which is mainly caused by a lack of water supply, is a major natural hazard for rainfed farming systems [99–101].

In comparison with other previous studies, the impacts of climate change on Moroccan agriculture are quite significant. The present article contributes to this literature by assessing and comparing the climate change vulnerability of Morocco and linking it to its social implications. A particular focus was placed on the impact of climate change on agriculture. On average, crop yields of wheat grains and sugar are expected to decline by 10% by 2050, representing 53% of total agricultural production and 50.5% of total arable land [102,103]. It has been shown that a temperature increase of 1 °C would lead to a 6% drop in world wheat production for example [103].

In Morocco, 10% on average is the percentage decrease in wheat yields of wheat grains in 2050 and sugars due to climate change [103]. According to research carried out in Morocco by the National Institute of Agronomic Research (INRA) as part of the Adaptation to Climate Change in Agriculture in the Maghreb (AGRIMAP) project, they have shown that temperatures will increase and that precipitation will decrease in an accelerated manner. On average, temperatures will increase by 1.3 °C (±0.2°C) by 2050 and by 2.3 °C (±0.9°C) by the 2090 horizon compared to 2010. In addition, the rainfall will decrease by 11% (±0.5%) by 2050 and by 16% (±1.3%) by 2090 compared also to 2010. These variations in temperature and precipitation levels will influence the length of crop growth, which will decrease by 30 days in 2050 and 90 days in 2090 compared to 2010 [97]. In 2050, the growing period will be from November to April, and, for 2090, it will last from January to March. Therefore, this reduction in the growing period will have very important consequences on crop yields. Yield forecasting is important for knowing how to react to ensure food security and to forecast yields earlier in the season and at a finer spatial scale [104]. Indeed, it is also used to predict the yields of cereals and other crops, and several studies have used methods of combining multi-source datasets and machine learning algorithms [105–107].

To date, considerable efforts have been made by scientists to better understand the causes and effects of climate change in recent years on a global scale [108]. This was summarized by studies on computable general equilibrium models to fully understand the impacts of climate change [108–111]. Other research has targeted certain countries [112–114]. Furthermore, some studies used dynamic models that take into account the worsening effects of climate change over time [113,114]. The impact of climate change on agricultural production was highly considered. Studies have shown that this impact depends on various factors such as the climate model used, the location of the country, its adaptive capacity, etc. [109,115]. Therefore, the results of other studies around the world have highlighted the harmful or beneficial impacts of climate change on agricultural production based on the carbon factor and fertilization. Agricultural production decreases if we do not take into account the effects of climate change on carbon fertilization [109,116]. Other regions like Canada, Europe, northern China, and northern Russia have increased their agricultural production because the effects of climate change on carbon fertilization were taken into consideration [115]. Several studies indicate a significant decrease in agricultural production over time when the effects of climate change on carbon fertilization are not considered [109,116].

## 5. Conclusions

The main objective of this study was to develop a land-system model linked to the environment and the socio-economic level that projects their consequence on current and potential land cover and use change over the next 10 years in order to consider further actions.

The pilot data on which this study was based included the statistics of cereal production and area in 2014, the Moroccan population census, surveys of food consumption of the cereal product in 2014, and climate data linked to cereal production. In Morocco, the most productive regions were, in order from most to least productive, Fes-Meknes (R3), Rabat-Sale-Kenitra (R4), Beni Mellal-Khenifra (R5), and Casablanca-Settat (R6). They constitute the grain reserve of the country. All other regions, in particular, Souss-Massa, Laayoune-Sakia El-Hamra (R11), and Dakhla-Oued Ed-Dahab (R12), were in deficit. However, the balance of cereal production in Morocco remained positive with a surplus of 634,897.61 tons.

The Moroccan economy will also have to increase its production or import cereals. Therefore, it is necessary to increase the cereal production under climatic constraints and demographic development. Accordingly, the suitable and brilliant solution would be the strength of the irrigated sector, which plays a primordial role in the agricultural development of the country. In this case, it is necessary to consider the water-saving irrigation techniques such as drip irrigation. Indeed, it is mandatory to seed the agricultural areas with the most productive varieties of wheat. Moreover, more attention should be given to small- and medium-sized farms in order to integrate them into modern and industrial agriculture by giving them the necessary supports, notably those belonging to regions with a grain deficit. Genetic improvement also appears to be a relevant solution provided that it is subject to the policy of protecting health and the environment. Regarding the mode of consumption, the growing population should strive for sustainable food consumption, and the impacts on health are also very important in this regard. We must respond to changes in consumption habits with initiatives that promote healthier and more sustainable consumption patterns. We must also raise awareness and acquire knowledge about a healthy, balanced diet that meets the needs of all social classes, and research must be carried out and encouraged on the impact of climate change on cereals as a primary human food product regarding all the elements of food security.

**Supplementary Materials:** The following equations used in this manuscript are available online at https://www.mdpi.com/article/10.3390/su132111943/s1.

**Author Contributions:** Conceptualization, N.A. and M.M.; methodology, M.M.; software, N.A.; validation, M.M. and M.Y.K.; formal analysis, N.A.; resources, M.M. and S.A.; data curation, N.A.; writing—original draft preparation, N.A. and R.L.; writing—review and editing, R.L. and M.E.J.; supervision, M.M.; project administration, M.M. All authors have read and agreed to the published version of the manuscript.

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