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The effect of climate change on the production of irrigated and non-irrigated plants: A short and long term ARDL modelling for the case of Tunisia

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Abstract - We propose to analyze the direct effect of climate change on the agricultural production of irrigated and non-irrigated plants, in the short and long term, in Tunisia. The methodological is based on the Autoregressive Distributed Lag (ARDL) model. The originality of this method is that it allows time dynamics to be taken into account in the explanation of a variable, thus improving forecasts and economic policies to be implemented in the short and long term. To this end, we used a highly disaggregated database describing the evolution of average temperature, rainfall, fertilizer, agricultural labor and the surface area of each plant in Tunisia over a long period, from 1984 to 2019.The results found reveal that, in the long term, there is a strong positive correlation between cereal production and rainfall in the governorates of North-West Tunisia. Contrary to the results found by the cereal crop, our results show that the average temperature has a positive effect on vegetable production. They also show that rainfall generally has a greater effect on vegetable and cereal production in the long term than in the short term. Our results also show that long term fruit production shows remarkable declines in the most fruit-producing governorates following an increase in rainfall and fertilizers, while an increase in production has taken place following an increase in labor force and agricultural area.

JEL Classification
Q54, O13, C21

Key-words
Agricultural production
Climatic change
ARDL model
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INTRODUCTION

A unanimous and clear observation, the climate of our planet is changing. This natural phenomenon is affirmed and proven by scientific research, there is no longer any ambiguity. In fact, we are already observing climatic meteorological disturbances, unprecedented for several decades. The main thing, at present, would be to estimate the potential effects of this change, which will be felt at all levels (Yang Chwen Ming, 2015).

Although the observed climate change has had an impact on all natural and human systems on all continents (IPCC, 2014) by affecting, negatively or positively, the economy, human well-being and the environment, this change is very little perceptible and the extent of its threats remains difficult to grasp by human perception.

Tunisia is considered as a Mediterranean-Saharan climate transition zone. It lies between the temperate European domain (Hufty, 2001) in the north of the Mediterranean and the subtropical African domain (Leroux, 2001) in the south, where the great Sahara begins. (Treyer, 2000 ; IPCC 2001).

It is a very irregular climate in time and space. Rainfall in the north of the country is relatively more important in quantity, while in the south, not only is it low, but also, the variability is great with very low minima and relatively very high maxima sometimes with multiple damages. The temperature is also quite variable. The winter in Tunisia is not very cold with temperatures ranging between 8°C and 15°C and can reach almost zero degrees in the highlands; the summer, on the contrary, is hot and dry with average temperatures ranging between 22°C and 35°C and can even exceed 40°C in the south of the country.

In addition, Tunisia is part of the Mediterranean region, which according to the studies of the Intergovernmental Panel on Climate Change (IPCC), is among the "hot-spot" areas of climate change. These are areas that would be harder hit than the rest of the planet. The results of research by the Mediterranean network of experts on climate and environmental change (MedECC), predicted that in these regions, the expected effects would be particularly significant and the environmental and socio-economic impacts would be likely to be very pronounced. Arid and semi-arid lands are expected to suffer more from climate change.

The impact of climate change can then be transmitted from one economic sector to another and can affect different macroeconomic aggregates. On the one hand, agriculture is the economic sector most strongly influenced by weather and climate (IPCC, 2001; Lobel et al., 2008). On the other hand, this sector is a source of many food products that are included in the basket of consumer goods.

Several works have been treated in the empirical literature to analyze the effects of climate change on agricultural production. Within this framework, empirical studies have been considered according to two approaches, partial equilibrium models and general equilibrium models.

The work carried out by Bosello et al. (2017) provides an economic assessment of the impacts of climate change on the four major crops that characterize Nigerien agriculture. The computable general equilibrium model is used to show that climate change is negative for Nigeria with production losses. Indeed, total agricultural production in 2050 will decline from 4.8% to 7.4%, while the northern regions of Nigeria and cereal cultivation will be more penalized. On the other hand, climate change will reduce Nigeria's development potential.

Wood and Mendelsohn (2014) show that an increase in temperature and rainfall during the rainy season is correlated with a loss of farm income. However, during the cooler, drier season the high temperature increases net agricultural income in northern Guinea and southern Senegal.

Alboghdady and El Hendawy (2016) analyze the impact of climate change and variability on agricultural production for 20 countries in the Middle East and North Africa (MENA) region. The results show that an increase in winter temperature led to a 1.12% decrease in agricultural production.

Despite increasing productivity in the case of developed countries, Europe is suffering from the impacts of climate change on agriculture. Using the Ricardian approach, Bozzola et al. (2017) the results revealed that a 1°C increase in temperature in spring increases land values by 37%. For rains, a decrease in rainfall has strong negative effects in autumn and winter.

According to IFPRI (2009), "In developing countries, climate change will lead to a decline in the production of the most important crops; this decline will be particularly felt in South Asia".

Abidoye, Kurukulasuriya, Reed and Mendelshon (2017) show that seasonal temperature and rainfall affect annual net income, such as Sri Lanka, which is particularly vulnerable with losses in each climate scenario, Bangladesh would also have either a large gain or a large loss. Similarly, Lee, Nadolnyak and Hartarska (2012) show that rising temperature and rainfall during the summer increase agricultural production in tropical Asian countries, while high temperatures in autumn are detrimental in South and Southeast Asia.

American agriculture is very vulnerable to climate change. Taking into account the IPCC (2014) forecasts, Assuncao and Chein (2016) show that climate change is likely to aggravate regional disparities between Brazilian municipalities and states. They also show that the 6.57% increase in average temperature and the 0.71% decrease in rainfall have led to an 18% reduction in agricultural productivity. Nevertheless, the impact of climate change is far greater than the impact on the south.

According to Lu et al. (2017) who examine the impact of intra-seasonal weather conditions on irrigated agriculture and crop production in southern Alberta, Canada. The authors show that warming and increased precipitation tend to increase crop yields on drylands while increased precipitation in June and July tends to have opposite effects on crop yields on irrigated land.

The originality of this work is to develop a new and original analysis that allows assessing the impact of rainfall and temperatures on the production of irrigated and non-irrigated plants in the short and long term. To achieve this objective, we use econometric methods adapted to the nature of economic data. These methods are based on the ARDL approach of Pesaran et al. (2001) which has several advantages. Firstly, it makes it possible to estimate the short- and long term elasticities of the effect of climate change on agricultural production. Second, it is appropriate to test co-integration between variables not integrated in the same order. Thirdly, the model belongs to the category of dynamic models that allow to capture temporal effects (adjustment delays, anticipation, lag effect, etc.).

The objective of this work is to assist policy makers, for the implementation of agricultural policy, sustainable development in agrarian areas, local water resource management policy and the prediction of the direct effect of climate change on agricultural production in the short and long term are paramount to anticipate the risks of climate change on agriculture and intervene effectively in the most affected governorates.

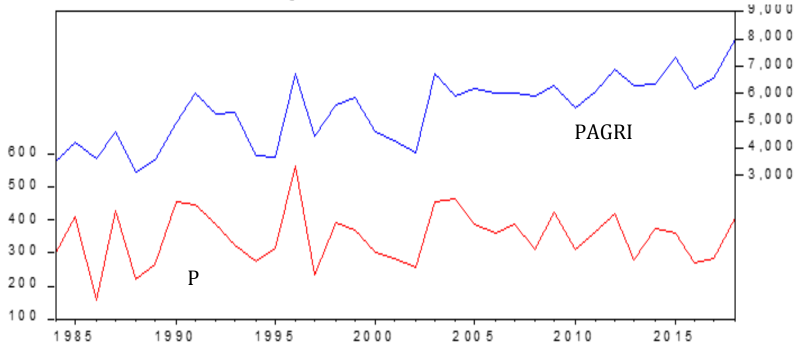
This paper is organized as follows: the first section is devoted to descriptive analysis. The second section is reserved for the presentation of the model and the data used. In the last section, the different results found are discussed.

1. DESCRIPTIVE ANALYSIS

1.1. Relationship between rainfall and agricultural production

Figure 1 visualizes the evolution of annual rainfall levels with the evolution of the levels of overall annual agricultural production, and Figures 2 to 5 with certain fresh consumer products of agricultural origin: potatoes, citrus fruits, cereals and olives.

Figure 1. Relationship between rainfall and overall agricultural production



From 1986 to 1987, for example, the level of rainfall recorded jumped from 157.6mm to 426.7mm; a 170% growth rate, the increase in the level of agricultural production was from 3630.306 million tonnes to 4575.737 million tonnes, an increase of 26%. The increase in the quantity of cereals observed was remarkable, from 6060 thousand quintals to 19229 thousand quintals, i.e. a growth rate of 217%, and the quantity of olives observed increased to 570,000 T in 1987, against 144,380 T in the previous year. This growth rate is 295%.

The year 1996 is the most rainy year since 1984, during this year, the level of rainfall reached an average of 564.8 mm, against 318.6 mm the previous year, that is an increase of 77%. The corresponding global agricultural production reached 6690.740 million tonnes, cereals 28672 thousand quintals, Potatoes 270,000 tonnes and tomatoes 700,000 tonnes, against respectively 3676.087 million tonnes, 6196 thousand quintals, 233,000 tonnes and 580,000 tonnes, representing leap of 82% for production, 363% for cereals, 16% for potatoes and 21% for tomatoes.

Figure 2. Relationship between rainfall and potatoes

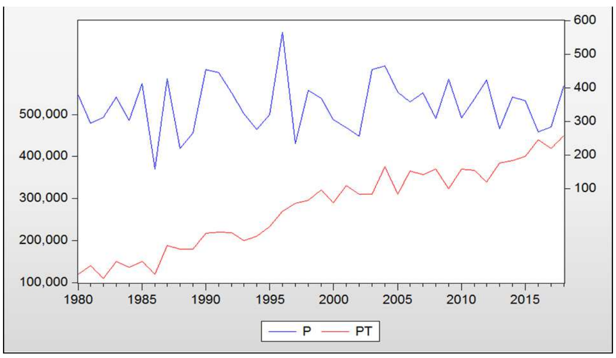


Figure 3. Relationship between rainfall and citrus fruits

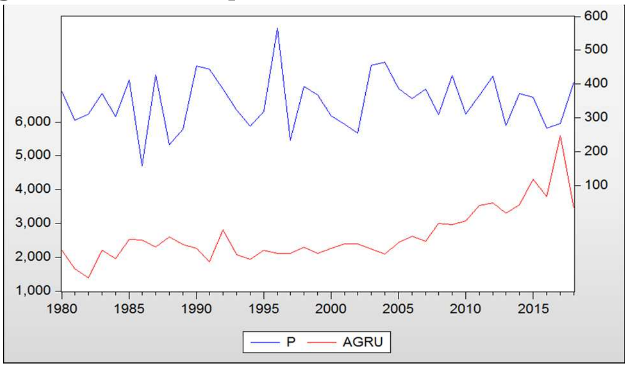


Figure 4. Relationship between rainfall and cereals

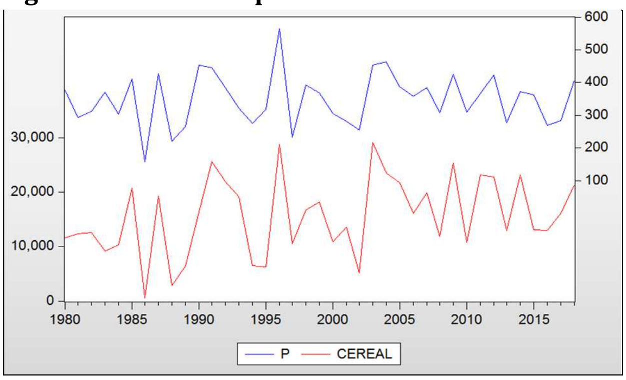
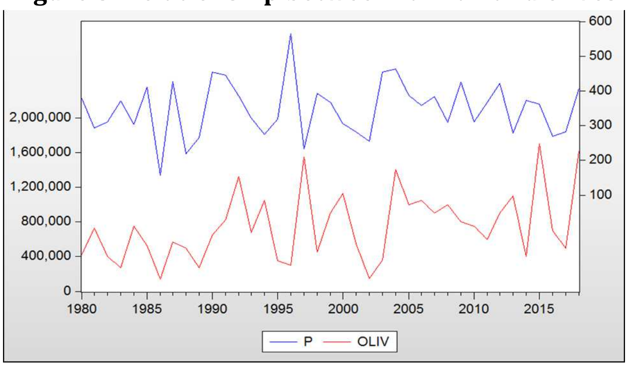


Figure 5. Relationship between rainfall and olives

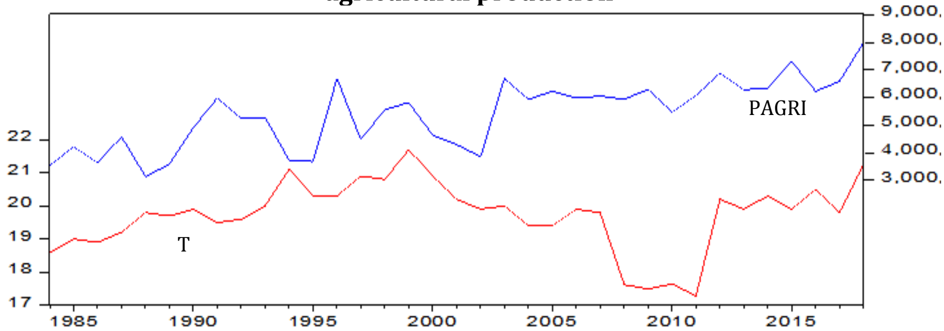


While between 2000 and 2002, the level of rainfall recorded fell from 281.6 mm to 254.9 mm, a decline of 10%, the corresponding level of agricultural production fell from 4632.450 million tonnes to 3852.680 million tonnes, a decrease of 17%; the quantity of cereals during this season was remarkable at 5140 thousand quintals only as against 13542 thousand quintals the previous year, i.e. a 163% drop; the level of olive production went from 550,000 T to 150,000 T, a drop of 267%, and the same for potatoes from 330,000 T to 310,000 T, i.e. a 6% drop.

1.2. Relationship between temperature and agricultural production

Figure 6 illustrates the variation in average annual temperature, starting with the annual estimate of overall agricultural production, and Figures 7 to 10 with crop income for selected consumer agricultural products.

Figure 6. Relationship between temperature and overall agricultural production



We can see that during certain seasons the negative impact of a rise in temperature on agricultural production can be more or less visible. This impact could well be explained by the connection of the rise in temperature with low rain generally accompanied by a decrease in cloud cover and an increase in the number of days of insolation. This prolonged heat damages growing plants and increases the amount of water evaporated. Also, the impact of the temperature in one crop year may well be reflected with a slight time lag in the quantities of the following calendar year's crops.

In 1988, the rise in temperature to 19.8°C, which is above the average of the series (19.6°C), resulted in a drop in the level of agricultural production from 4575.737 million tonnes to 3128.863 million tonnes (a drop of 32%). The drought affected cereal production in particular, which reached 2,898 thousand quintals against 19,289 thousand quintals the previous year, and it did not spare olives (500,000 T. against 570,000 T. the previous year) and other consumer agricultural products such as potatoes (180,000 T. against 188,000 T.) and tomatoes (400,000 T. against 485,000 T.).

Similarly, following two successive dry years in 1993 (T°=20°C) and 1994 (T°=21.1°C), the level of recorded agricultural production fell in 1995 to 3676.087 million tonnes, compared with 5275.469 million tonnes in 1993, a drop of 30%.

In 1999, the annual average temperature reached a remarkable 21.7°C and then continued to rise for two successive years to 20.9°C and 20.2°C. This was reflected in the 2002 calendar year harvest, in which agricultural production fell to 3852.680 million tonnes, compared to 4286.691 million tonnes in the previous year, with the cereal harvest being hit hardest this year, falling to 5140 thousand quintals. The annual quantities of olive and potato production also fell to 150 thousand tonnes against 550 thousand tonnes and 310 thousand tonnes against 330 thousand tonnes respectively, as a result of these years of drought.

On the contrary, in 2011, the annual average temperature level fell to 17.28°C, following a drop in this level for three successive years previously (to 17.62°C in 2008; 17.49°C in 2009 and 17.64°C in 2010), while the level of agricultural production rose from 5467.038 million tonnes in 2010 to 6067.091 million tonnes in 2011.

Figure 7. Relationship between temperature and potatoes

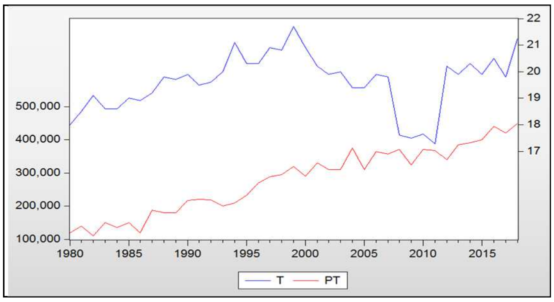


Figure 8. Relationship between temperature and citrus fruits

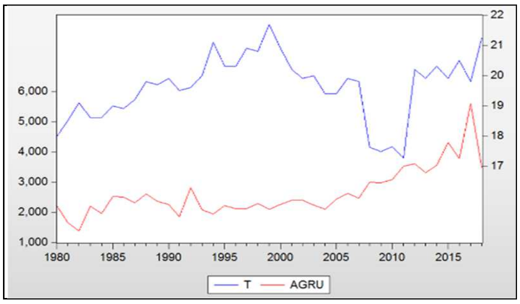


Figure 9. Relationship between temperature and cereals

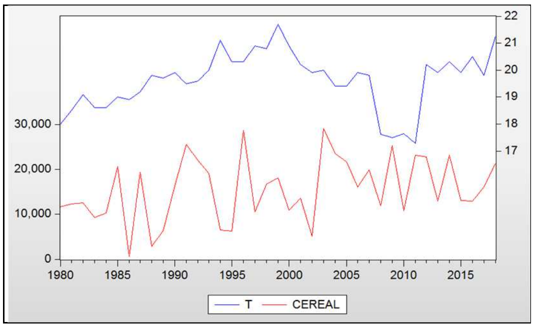
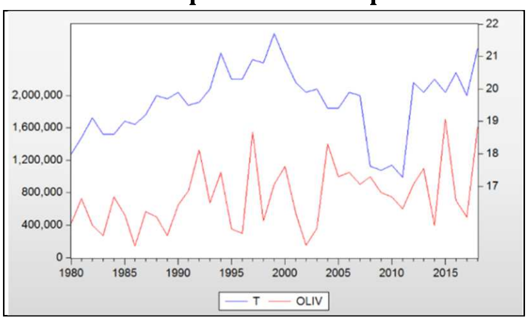


Figure 10. Relationship between temperature and olives



A more in-depth analysis of the effect of climatic variables on field crops in Tunisia, using the principal component analysis (PCA) method, reveals the following results.

Rainfall seems to be more correlated with cereal cultivation with an equal correlation (0.71), which can also be seen in Graph 4. This strong correlation between rainfall and cereal production is justified, given that cereals are a non-irrigated crop, which means that their growth is essentially dependent on rainfall levels.

Conversely, the relationship between temperature and cereal production is not significative (-0.057). This can be justified by the fact that cereal production in Tunisia takes place mainly during March, April and May, a period in which the temperature is close to the annual average.

In sum, the results of the descriptive analysis showed that rainfall has a positive impact on the agricultural production of certain crops, particularly non-irrigated plants (cereals and olives). On the other hand, the effect of temperature is hardly observable but seems to be negative for some years, for example, in the 2000s when drought seriously affected agricultural yield.

Unlike non-irrigated plants which are strongly linked to the direct impact of climate change, irrigated plants are indirectly dependent on rainfall and temperature variation. However, they are directly dependent on the effect of climate change via dams, water tables, wadis, rivers, etc.

2. PRESENTATION OF THE ESTIMATING MODEL

We propose to test the hypotheses according to which short and long term weather variations have an impact on the growth of agricultural production in Tunisia. This will be done by focusing on the analysis of the production of certain plants with a higher contribution to agricultural production, namely cereals, fruits and citrus fruits:

For this purpose, the ARDL model is as follows:

$$Y_t = \varphi + a_1 Y_{t-1} + \ldots + a_p Y_{t-p} + b_0 X_t + \ldots + b_p X_{t-p} + e_t$$

$$Y_t = \varphi + \sum_{i=1}^{p} a_i Y_{t-i} + \sum_{j=0}^{q} b_j X_{t-j} + e_t$$

Co-integration between series assumes the existence of one or more long term equilibrium relationships between them, which can be combined with the short term dynamics of these series in an error-correction model (VECM) that takes the following form:

$$\Delta Yt = A0 + \sum_{i=1}^{i=p} ai\ \Delta Yt - i + \sum_{i=1}^{i=q} bi\ \Delta Xt - i + b0\ \Delta Xt + Et$$

In our analysis, we consider three models where we define for each one a dependent variable namely cereal production, vegetable production and fruit production and independent variables which are labour, average temperature, rainfall, fertilizer and area.

In our case, the representation of an ARDL model is as follows:

$$\mathbf{\Delta Cereal}_t = \alpha_0 + \sum_{i=1}^{p} \alpha1\ \Delta Cerealt - i + \sum_{i=0}^{q} \alpha2\ \Delta Tt - i + \sum_{i=0}^{q} \alpha3\ \Delta Pt - i + \sum_{i=0}^{q} \alpha4\ \Delta Lt - i + \sum_{i=0}^{q} \alpha5\ \Delta Et - i + \sum_{i=0}^{q} \alpha6\ \Delta St - i + \beta1\ Vegetable - 1 + \beta2\ Tt - 1 + \beta3\ Pt - 1 + \beta4\ Lt - 1 + \beta5\ Et - 1 + \beta6\ St - 1 + \varepsilon_{it} \quad (1)$$

$$\mathbf{\Delta\ Vegetable}_t = \alpha_0 + \sum_{i=1}^{p} \alpha1\ \Delta\ Vegetable\ t - i + \sum_{i=0}^{q} \alpha2\ \Delta Tt - i + \sum_{i=0}^{q} \alpha3\ \Delta Pt - i + \sum_{i=0}^{q} \alpha4\ \Delta Lt - i + \sum_{i=0}^{q} \alpha5\ \Delta Et - i + \sum_{i=0}^{q} \alpha6\ \Delta St - i + \beta1\ Vegetablet - 1 + \beta2\ Tt - 1 + \beta3\ Pt - 1 + \beta4\ Lt - 1 + \beta5\ Et - 1 + \beta6\ St - 1 + \varepsilon_{it} \quad (2)$$

$$\mathbf{\Delta Fruit}_t = \alpha_0 + \sum_{i=1}^{p} \alpha 1\ \Delta \mathrm{Fruitst} - \mathrm{i} + \sum_{i=0}^{q} \alpha 2\ \Delta \mathrm{Tt} - \mathrm{i} + \sum_{i=0}^{q} \alpha 3\ \Delta \mathrm{Pt} - \mathrm{i} + \sum_{i=0}^{q} \alpha 4\ \Delta \mathrm{Lt} - \mathrm{i} + \sum_{i=0}^{q} \alpha 5\ \Delta \mathrm{Et} - \mathrm{i} + \sum_{i=0}^{q} \alpha 6\ \Delta \mathrm{St} - \mathrm{i} + \beta 1\ \mathrm{Fruit}_{t-1} + \beta 2\ \mathrm{T}_{t-1} + \beta 3\ \mathrm{P}_{t-1} + \beta 4\ \mathrm{L}_{t-1} + \beta 5\ \mathrm{E}_{t-1} + \beta 6\ \mathrm{S}_{t-1} + \varepsilon_{it} \quad (3)$$

with P: precipitation in mm, T: the average temperature in °C, S: Surface area and E: Fertilizer; Δ : First difference operator; α0, α1, α2 ... α6: short term effect.

We can select an optimal ARDL model by choosing an optimal delay number for each variable, this choice is made on the basis of information criteria (AIC, SBC, FPE or HQ). Thus, the coefficients of the long term relationships can be estimated, once these are established, the error correction model (ECM) can then be estimated, stationarity and co-integration are previously verified.

The data used in this work are derived from the Tunisian National Institute of Statistics (INS) and the Tunisian Institute of Competitiveness and Quantitative Studies (ITCEQ). The source of the data concerning agriculture is the Ministry of Agriculture, Water Resources and Fishing, General Directorate of Studies and Agricultural Development (DGEDA). Finally, climate data are derived from the National Institute of Meteorology (Institut National de la Météorologie). These annual data cover the period from 1984 to 2019.

The table 1 presents the agricultural production of each crop (the endogenous variables), the most productive governorates of the crop and the climatic requirements of each crop.

Table 1. Regional database by crop

Crop	Period	Governorate	Temperature/ Rainfall
Cereal	1984/2019	Ariana, Manouba, Ben Arous, Tunis, Nabeul, Bizerte, Béja, Jendouba, Siliana, El Kef, Zaghouane, Kairouane, Sousse, Mounastir, Mahdia, Bouzid, Kasserine, Gafsa, Gabes, Kebili, Tozeur, Médenine and Tataouine	From November 15 to June 30
Vegetable	1984/2019	Ariana, Manouba, Ben Arous, Tunis, Nabeul, Bizerte, Béja, Jendouba, Siliana, El Kef, Zaghouane, Kairouane, Sousse, Mounastir, Bouzid, Sfax, , Gabes, Tozeur, and Médenine	From January to December (Agricultural year)
Fruit	1984/2019	Ariana, Manouba, Ben Arous, Tunis, Nabeul, Bizerte, Béja, Jendouba, Siliana,El Kef, Zaghouane, Kairouane, Sousse, Mounastir, Mahdia, Bouzid, Kasserine, Sfax, Gafsa, Gabes, Kebili, Tozeur	From January to December (Agricultural year))

3. ECONOMETRIC RESULTS

3.1. Stationarity test of the variables

The stationarity or unit root test is essential in any econometric treatment. It makes it possible to highlight the stationary or non-stationary character of a series by determining a deterministic or stochastic trend, in order to ensure the stationarity of the selected variable.

However, the most widely used unit root tests were developed by Fuller (1976), then Dickey and Fuller (1979), Kwiatkowski, Phillips, Schmidt and Shin (1992) and the Andrews and Zivot/AZ. The null hypothesis of the ADF test is that the variable is non-stationary whereas that of the KPSS test is that the variable is stationary.

The results in Table 2 clearly prove the rejection of the null hypothesis of stationarity for the fertilizer, work and temperature series. The first difference is that these series become stationary. With the exception of cereal production, area and rainfall which are stationary in level. The results obtained then reveal the possibility of the existence of a co-integrating relationship between the different variables studied.

Table 2. Unit root tests

	ADF test			Andrews et Zivot/AZ Test		
Variable	**In level**	**In first difference**	**Order of integration**	**In Level**	**In first difference**	**Order of integration**
Model 1						
Cereal production	-5.928 (0.000)	-	I(0)	-6.910 (0.010)	-	I(0)
Temperature	-2.414 (0.145)	-6.922 (0.000)	I(1)	-3.955 (0.170)	-8.175 (0.010)	I(1)
Rainfall	-7.160 (0.000)	-	I(0)	-8.167 (0.010)	-	I(0)
Cereal work	-1.947 (0.307)	-7.936 (0.000)	I(1)	-5.466 (0.010)	-	I(0)
Cereal fertilizer	-2.186 (0.214)	-7.119 (0.000)	I(1)	-5.661 (0.010)	-	I(0)
Cereal area	-5.415 (0.000)	-	I(0)	-6.739 (0.010)	-	I(0)
Model 2						
Vegetable production	-1.432 (0.553)	-6.653 (0.000)	I(1)	-4.462 (0.253)	-7.585 (0.010)	I(1)
Temperature	-2.378 (0.385)	-6.819 (0.000)	I(1)	-4.643 (0.176)	-7.892 (0.010)	I(1)
Rainfall	-7.242 (0.000)	-	I(0)	-8.035 (0.010)	-	I(0)
Vegetable work	-6.869 (0.000)	-	I(0)	-5.411 (0.010)	-	I(0)
Vegetable Fertilizer	-3.788 (0.029)	-	I(0)	4.851 (0.010)	-	I(0)
Vegetable Area	-3.565 (0.012)	-	I(0)	-6.536 (0.010)	-	I(0)
Model 3						
Fruit Production	0.099 (0.961)	-9.30 (0.000)	I(1)	-4.859 (0.114)	-7.500 (0.010)	I(1)
Temperature	-6.278 (0.000)	-	I(0)	-7.045 (0.010)	-	I(0)
Rainfall	-6.382 (0.000)	-	I(0)	-7.170 (0.010)	-	I(0)
Fruit Work	-5.621 (0.000)	-	I(0)	-3.627 (0.010)	-	I(0)
Fruit Fertilizers	-1.122 (0.695)	-8.833 (0.000)	I(1)	-7.324 (0.010)	-	I(0)
Fruit Area	-3.556 (0.000)	-	I(0)	-4.151 (0.111)	-11.16 (0.010)	I(1)

For vegetables, the results show that the variables rainfall, labour, fertiliser and area are stationary in level, while the vegetable production and temperature variables became stationary only after a first difference and are integrated of order 1, I(1). In line with the results found previously, the Andrews and Zivot test results for model 2 are consistent and similar to those found for the ADF test.

The first difference is that the variables of fruit production and fertilizer become stationary, so they are integrated in order one. Moreover, the rainfall, temperature, surface area and labour series are stationary in level since the calculated statistics are below the critical values of 1% and 5%. Therefore no variables are integrated of order two or higher. This proves that there may be co-integrating relationships between the variables and confirms our choice to use the Bounds test ARDL approach to verify this co-integration.

3.2. Co-integration study: optimal ARDL and Bounds test

The underlying idea of co-integration is that, in the short term, the variables may have a divergent evolution (they are therefore non-stationary), so they will evolve together in the long term. There is then a stable long term relationship between the different variables. This long term relationship is called the co-integrating relationship.

After confirming the stationary nature of the variables at a given level of integration and determining the number of lags, it is possible that some variables may be co-integrated, hence the Granger or Johnson co-integration test to detect whether or not co-integrating relationships exist between the variables in the model.

Co-integration is now being studied using the method of Pesaran et al. (2001) and that of Narayan (2005) for a small sample, bearing in mind that the adoption of the Johansen test is admitted in cases where the series are integrated of the same order, whereas the "bounds test to co-integration" or "bounds test to co-integration" is adopted in cases where the series are integrated of two different orders I(0) and I(1), but it should be specified that this does not exclude the adoption of the "bounds test" in cases where the series are integrated of the same order.

3.3. Estimation and validation of the optimal ARDL model

Starting from 6 variables for each model we can be confronted with several possible models, corresponding to different combinations of the variables. The ARDL method estimates [p+1]k regressions where p is the maximum number of lags and k the number of variables in the equation, hence the automatic selection of an optimal ARDL, for our case was based on the Akaike Information Criterion (AIC).

The results show that for model 1, ARDL (3,4,3,4,3,4) is the most optimal among the 19 others presented, as it offers the lowest AIC value. ARDL(4,4,4,4,1,2) and ARDL(3,2,2,3,3) represent respectively the models retained for vegetable and fruit production.

The results (Table 3) of the estimations of the optimal ARDL model for the different plants are presented in the following table.

The results of the diagnostic tests of the estimated ARDL model are presented in Table 4. The different test results lead us to conclude that there is no autocorrelation of the errors, there is no heteroskedasticity and there is normality of the errors, which means that the models have been well specified.

3.4. Cointegration test at the terminals of Model ARDL

Table 5 provides values for the Bounds test, which uses the Fisher test to test co-integration assumptions. Thus, we test the null hypothesis of the absence of co-integration against the alternative hypothesis of the existence of a co-integrating relationship in the traditional approach of Pesaran et al. (2001) and in the approach of Naranyan (2005) for small samples.

The results of the procedure show that the Fischer statistic is well above the upper bound for the different significance thresholds. We therefore reject the H0 hypothesis of the absence of a co-integrating relationship and conclude that there is a long term relationship between the different variables in the agricultural production function for the different plants, by its main determinants.

Table 3. ARDL Estimations

Model 1 : ARDL(3,4,3,4,3,4)			Model 2 : ARDL(4,4,4,4,1,2)			Model 3 : ARDL(3,2,2,3,3,3)		
Variables	Coef.	Prob.	Variables	Coef.	Prob.	Variables	Coef.	Prob.
D(cereal(-1))	-1.345	0.002	D(Vegetable(-1)	-0.071	0.732	D(Fruits(-1))	0.713	0.002
D(cereal(-2))	-0.504	0.022	D(Vegetable (-2))	0.160	0.465	D(Fruits(-2))	0.458	0.750
D(cereal(-3))	-0.377	0.026	D(Vegetable (-3))	-0.069	0.727	D(Fruits(-3))	-0.396	0.021
D(T)	0.870	0.042	D(Vegetable (-4))	0.692	0.004	D(T)	17.358	0.000
D(T(-1))	0.215	0.490	D(T)	-0.331	0.290	D(T(-1))	-9.165	0.083
D(T(-2))	1.164	0.015	D(T(-1))	0.218	0.585	D(T(-2))	-7.913	0.091
D(T(-3))	-0.699	0.099	D(T(-2))	0.134	0.737	D(P)	1.004	0.152
D(P)	0.411	0.041	D(T(-3))	0.609	0.154	D(P(-1))	0.893	0.213
D(P(-1))	0.550	0.043	D(T(-4))	0.656	0.061	D(P(-2))	1.275	0.075
D(P(-2))	0.438	0.049	D(P)	0.145	0.054	D(L)	-5.831	0.070
D(P(-3))	0.352	0.026	D(P(-1))	0.137	0.072	D(L(-1))	0.135	0.966
D(P(-4))	0.059	0.050	D(P(-2))	0.130	0.026	D(L(-2))	4.747	0.154
D(L)	-0.229	0.335	D(P(-3))	0.125	0.064	D(L(-3)	5.502	0.128
D(L(-1))	0.503	0.229	D(P(-4))	0.087	0.081	D(E)	0.242	0.604
D(L(-2))	0.344	0.171	D(L)	0.002	0.992	D(E(-1))	-0.591	0.248
D(L(-3))	0.816	0.027	D(L(-1))	0.280	0.363	D(E(-2))	-0.618	0.200
D(E)	0.067	0.246	D(L(-2))	0.653	0.061	D(E(-3))	1.448	0.009
D(E(-1))	0.114	0.050	D(L(-3))	0.342	0.323	D(S)	-1.390	0.308
D(E(-2))	-0.015	0.823	D(L(-4))	0.440	0.198	D(S(-1))	1.279	0.426
D(E(-3))	0.816	0.024	D(E)	-0.026	0.563	D(S(-2))	2.096	0.198
D(E(-4))	-0.087	0.267	D(E(-1))	-0.124	0.064	D(S(-3))	4.323	0.010
D(S)	0.777	0.000	D(S)	0.147	0.260			
D(S(-1))	1.164	0.002	D(S(-1))	-0.132	0.288			
D(S(-2))	0.425	0.011	D(S(-2))	0.180	0.205			
D(S(-3))	0.301	0.057						
D(S(-4))	0.081	0.153						
C	-38.885	0.004	C	-13.546	0.007	C	-24.066	0.060
R^2	0.999		0.994			0.985		
Adjusted- R^2	0.997		0.975			0.957		
F	470.01	0.000		53.093	0.000	35.072		0.000

Source : Author (our estimates on Eviews 10).

Table 4. Diagnostic tests of the ARDL model

Test hypothesis	Tests	Model (1)	Model (2)	Model (3)
		Values (probability)	**Values (probability)**	**Values (probability)**
Autocorrelation	Breusch-Godfrey	3.338 (0.058)	2.186 (0.207)	8.679 (0.35)
Heteroskedasticity	Breusch-Pagan-Godfrey	1.149 (0.318)	0.837 (0.656)	1.060 (0.588)
	Arch-test	0.116 (0.734)	0.830 (0.369)	0.382 (0.540)
Normality	Jarque-Bera	1.273 (0.528)	2.500 (0.286)	6.600 (0.30)
Specification	Ramsey (Fisher)	0.338 (0.58)	0.168 (0.998)	0.642 (0.785)

Source : Author (our estimates on Eviews 10).

Table 5. Co-integration test at the terminals

Variables	Cereal production		Vegetable production		Fruit Production	
F-stat calculated	13.913		7.077		23.07	
Critical threshold	Born <	Born >	Born <	Born >	Born <	Born >
1%	3.06	4.15	4.13	5.76	3.90	5.41
5%	2.39	3.38	2.91	4.19	2.80	4.01
10%	2.08	3	4.13	5.76	2.33	3.14

Source : Author (our estimates on Eviews 10).

3.5. Short term coefficients

Based on the results of the estimations of the optimal ARDL model for the different plants found previously, we will present the results of the short term equilibrium relationship for each plant.

The production function may include labour as the main determinant of production. This variable, which appears to be important, will positively affect the agricultural production of all three plants. However, its macroeconomic effect has shown a rather elaborate positive side. Moreover, it is clear from the ARDL model estimated in the short term that the labour factor only positively affects the production of cereals, vegetables and fruits after three and four years.

Table 6. Results of estimating CT coefficients

Model ARDL(3,4,3,4,4,3)			Model ARDL(4,4,4,4,1,2)			Model ARDL(4,4,0,4,4,4)		
Variables	Coef.	Prob.	Variables	Coef.	Prob.	Variables	Coef.	Prob.
D(cereal(-1))	0.881	0.000	D(Vegetable (-1))	-0.783	0.003	D(Fruits(-1))	-0.061	0.35
D(cereal(-2))	0.377	0.001	D(Vegetable (-2))	-0.623	0.000	D(Fruits(-2))	0.396	0.002
D(T)	0.870	0.000	D(Vegetable (-3))	-0.692	0.000	D(T)	3.510	0.000
D(T(-1))	-0.465	0.009	D(T)	-0.331	0.129	D(T(-1))	-7.913	0.016
D(T(-2))	0.699	0.002	D(T(-1))	-1.400	0.000	D(P)	1.004	0.022
D(P)	0.411	0.000	D(T(-2))	-1.265	0.001	D(P(-1))	1.275	0.004
D(P(-1))	0.731	0.000	D(T(-3))	-0.656	0.008	D(L)	-5.831	0.007
D(P(-2))	0.292	0.005	D(P)	0.145	0.001	D(L(-1))	10.249	0.001
D(P(-3))	0.059	0.079	D(P(-1))	0.168	0.006	D(L(-2))	5.502	0.033
D(L)	-0.229	0.072	D(P(-2))	0.037	0.303	D(E)	0.242	0.431
D(L(-1))	1.160	0.000	D(P(-3))	0.087	0.008	D(E(-1))	-0.830	0.024
D(L(-2))	0.816	0.001	D(L)	-0.002	0.987	D(E(-2))	-1.448	0.000
D(E)	0.067	0.009	D(L(-1))	1.437	0.001	D(S)	-1.390	0.146
D(E(-1))	0.210	0.000	D(L(-2))	0.783	0.015	D(S(-1))	2.227	0.026
D(E(-2))	-0.194	0.003	D(L(-3))	0.440	0.060	D(S(-2))	4.323	0.000
D(E(-3))	-0.087	0.007	D(E)	-0.026	0.309	Coint Eq(-1)	-0.224	0.000
D(S)	0.777	0.000	D(S)	0.147	0.053			
D(S(-1))	0.808	0.000	D(S(-1))	0.180	0.041			
D(S(-2))	0.383	0.000	Coint Eq(-1)	-0.287	0.000			
D(S(-3))	0.081	0.000						
Coint Eq(-1)	-3.227	0.000						

Source: Author (our estimates on Eviews 10).

In terms of the impact of surface area, this factor has a positive and significant effect in the 24 governorates. It is of national importance and positively affects long term production. This expected economic result reveals that the area in the production process is an extremely important factor in increasing the agricultural production of irrigated and non-irrigated plants in Tunisia. However, an exception of the individual impact in vegetable production indicates that in the short term area used may negatively influence vegetable production in these regions. Consequently, at least two years must pass before it is expected that the agricultural area will stimulate vegetable production.

Contrary to expectations, fertilizers have a significant and negative effect on the production of different plants. Firstly, this short term negative effect can be explained by the fact that the quantity of fertilizers is not sufficient to increase agricultural production due to the increase in fertilizer prices at the international level, which can consequently affect the demand for fertilizers at the national level. Secondly, there is a lack of adequate training for farmers, i.e. most farmers are workers who are not trained in the use of fertilizers and who use agricultural calendars that are too old and poorly adhered to, which can negatively affect quality and subsequently production as a whole.

In light of the above results, it is concluded that the average temperature represents a transmission channel through which a rise in temperature has a negative effect on agricultural production in the short term, especially for cereals and fruit. However, the time dimension is an important variable not to be ignored here. Over time, the effects of this variable are mixed: three years and two years respectively for cereals and fruits must be allowed to pass before concluding that temperature represents a negative external effect on the production of irrigated and non-irrigated plants in Tunisia. This result can be explained by the fact that high temperature accelerates plant development by shortening the length of its phenological cycle and causes a decrease in yield (Delecolle et al., 1999).

On the other hand, the direct effect of climate change on cereal production is captured by the coefficient of the climate change indicator (rainfall), which appears to have a positive but statistically significant sign.

With regard to irrigated plants, the results of the ARDL model estimates show that the direct effect of climate change has a positive and significant effect, but with low elasticity that is close to zero. The results of the short term equilibrium relationship estimates are in line with the theory and our expectations.

3.6. Long term coefficients

Table 7 summarizes the results of long term estimates for the full panel of exogenous variables expressed in logarithm. These coefficients are only the long term elasticities of fertilizer work, area, mean temperature and rainfall on irrigated and non-irrigated crop production in Tunisia.

Labour is one of the economic variables that can positively influence agricultural production. It is integrated into the production function as an explanatory variable. The latter is measured in 1000 persons. The results of the estimation via the ARDL model show that labour is significant. In the long term, in terms of the results specific to the different plants, we note that labour has a significant and positive impact on cereal production in all the governorates studied, where a 1% increase in labour leads to a 0.44% increase in production. Thus, our conclusions are similar to our expectations and perspectives.

With regard to fruit and cereal crops and reading the results of the estimations of the long term equilibrium relationship using the ARDL method, we can first of all see that the impact of the area on the production of the latter is in line with the conclusions of economic theory. Contrary to expectations, fertiliser has a negative and statistically significant effect on fruit production. It can be seen that the long term results confirm the results found in the short term but differ according to the plants.

Estimation of the long term relationship shows that the direct effect of climate change as measured by rainfall positively and significantly affects cereal production for the entire panel. At the level of irrigated plants, rainfall has a positive effect on all plants with the exception of fruits, which show negative but insignificant signs. These results show the important role that rainfall plays as a channel for transmitting the direct effect of climate change on cereal production. This is in line with most studies in the Maghreb countries and the Mediterranean basin (Plan Bleu, 2008).

Unlike the results found previously and in line with expectations, temperature has a negative and significant effect on cereal production. A 1% increase in the average temperature during the growing period of the plant contributes to a decrease in cereal production of 0.48%. In this context and concerning the direct effect of average temperature on irrigated plant production, it is noted that temperature has a negative effect on fruit production, where the estimated long term elasticity shows that a 1% increase in average temperature will reduce fruit production by 3.30%. This result is in line with the work of Zouabi and Péridy (2015).

Table 7. Results of estimation of long term coefficients

Dependent variable	**Dependent variable : LCereal**		**Dependent variable : LVegetable**		**Dependent variable : LFruits**	
Variables	Coef.	Prob.	Coef.	Prob.	Coef.	Prob.
Modèle ARDL(3,4,3,4,4,3)						
Temperature	-0.480	0.002				
Rainfall	0.524	0.011				
Labour	0.444	0.027				
Fertilizers	-0.008	0.737				
Surface	0.852	0.000				
Model ARDL(4,4,4,4,1,2)						
Temperature			4.477	0.159		
Rainfall			1.568	1.080		
Labour			5.982	0.048		
Fertilizers			-5.526	0.404		
Surface			-0.579	0.208		
Model ARDL (4,4,0,4,4,4)						
Temperature					-3.306	0.000
Rainfall					-2.037	0.121
Labour					7.187	0.000
Fertilizers					-2.401	0.004
Surface					6.210	0.001

Source: Author (our estimates on Eviews 10).

This result underlines the need for action to adapt to climate change. Such an initiative can roughly maintain production at current levels and avoid the negative impact of rising temperatures and water shortages for agricultural crops.

Our results show that climatic effects and climate variability on food production should be considered as a serious threat in Tunisia. The results found reveal that in the long term, there would be a strong positive correlation between cereal production and rainfall.

The results of the long term equilibrium relationship reveal that cereal production is strongly dependent on rainfall in the most cereal-producing governorates, namely Beja, Jendouba, El Kef and Siliana.

However, there is a strong correlation between temperature and fruit production in the Sahel and Southern governorates. In contrast to the results found for cereal crops, our results show that rainfall harms vegetable production.

They also show that the two variables fertiliser and area have stronger effects in the central regions than in the northwestern governorates.

CONCLUSION AND POLICY IMPLICATIONS

In this paper, we analysed the direct effect of climate change at the regional level on cereal, citrus and fruit production in the short and long term using a disaggregated microeconomic database covering the period 1984-2019. The ARDL technique was used for this purpose and the co-integration tests of Pesaran et al. (2001) in the production function framework were applied.

To this end, we conducted a descriptive analysis of the effects of climatic hazards on the production of irrigated plants, namely vegetables and fruits. In contrast to the results found for non-irrigated plants (cereals), the results of the analysis revealed that there is a low dependency between the production of these plants and the direct effect of climate change measured by rainfall and temperature. This can be explained by the important role played by the available water resource; more specifically dam water and groundwater in the production of irrigated plants.

Based on a sample of 24 governorates, and integrating the direct effects of climate change in the short and long term, the negative and significant effect of temperature on cereal production was highlighted. This negative effect of temperature is greater in the long term in the northern regions than in the central and southern regions. This factor negatively affects the behaviour of farmers in the governorates most affected by this phenomenon, i.e. the most cereal-producing governorates. As far as the rainfall channel is concerned, the results of the estimates are in line with our intuition and economic theory,

We have also shown that taking into account the direct effect of climate change on the production of irrigated plants reveals unprecedented results. The first step is to test the effect of climatic hazards on fruit in the short and long term in a more detailed manner. The results revealed that the impact of temperature on fruit production has a direct negative effect at the macro spatial level. It thus shows the importance of taking into account the effects of externalities and dependence between governorates.

As far as vegetable cultivation is concerned, the estimation of the long term relationship shows that the direct effect of climate change as measured by rainfall positively and significantly affects vegetable production for the whole panel. Moreover, the estimated long term elasticities show identical results to those found in the short term.

These findings show that the adoption of any economic and agricultural policy to improve citrus fruit production in the governorates of Nabeul and Bizerte must take into consideration the effect of future climate change in the governorates that emit the water from the dam and not the receiving governorates.

Similarly, we analysed the spatial location of agricultural production of irrigated and non-irrigated plants in Tunisia. The results at the micro spatial level show that the movement of the localisation of agricultural production of irrigated and non-irrigated plants shows that there is a spatial dynamic between governorates in terms of agricultural production in Tunisia. The results of the global autocorrelation test for irrigated and non-irrigated plants in Tunisia show the presence of a positive spatial autocorrelation between the variables.

The above findings lead us to make a few recommendations that may provide even partial solutions to the consequences of climate change. These findings point to the need for a long term agricultural policy in order to reduce or limit the economic and social consequences of climate change. These policies should be oriented according to the productive potential of the governorates and the nature and degree of impact generated by the modification of climate variables, failing which they could have limited or even negative repercussions.

The authorities can also use other techniques such as developing crops with the same or higher yields, but with less water requirements for their growth or, in extreme cases, promoting genetically modified (GM) crops to compensate for water shortages and lack of rainfall, following the example of countries such as China and India.

The role of the Ministry of Agriculture, in this context, is crucial in the medium and long term. Indeed, Ministry of Agriculture officials must intervene with farmers located at dams or wadis, providing them with support and advice adapted to the nature of the problems that arise. This support can be in the form of actions to substitute initially non-irrigated products such as rice, by others important in terms of percentage in the exports of products of the Tunisian economy, products such as olives, cereals or citrus fruit and which can withstand climate change.

However, the intervention of the authorities must be materialised by offering the necessary irrigation equipment from the state to farmers with good training in the field in order to make better use of the new machines and consequently increase agricultural production. These measures must be part of a plan to make up the shortfall resulting from the negative effect of climate change in the short and long term on agricultural production in the governorates most affected by this phenomenon.

Consequently, they will have to be based on preliminary studies in collaboration with all the actors intervening in the economic and environmental fields in order to be sustainable.

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L'effet du changement climatique sur la production des plantes irriguées et non irriguées en Tunisie : une modélisation ARDL à court et à long terme

Résumé - Nous proposons d'analyser l'effet direct du changement climatique sur la production agricole des plantes irriguées et non irriguées, à court et à long terme, en Tunisie. Pour ce faire, un modèle ARDL (Auto Regressive Distributed Lag model) est utilisé. L'originalité de cette méthode est qu'elle permet de tenir compte de la dynamique temporelle dans l'explication d'une variable, améliorant ainsi les prévisions et les politiques économiques à mettre en œuvre à court et à long terme. Nous avons utilisé une base de données très désagrégée décrivant l'évolution de la température moyenne, les précipitations, les engrais, la main d'œuvre agricole et la superficie des cultures en Tunisie de 1984 à 2019. Les résultats révèlent qu'à long terme il existerait une forte corrélation positive entre la production de céréales et les précipitations dans les gouvernorats du Nord-Ouest de la Tunisie. A l'inverse, l'élévation de la température moyenne exerce un effet positif sur la production des légumes. Les précipitations ont de manière générale un effet plus important sur la production de légumes et de céréales à long terme qu'à court terme. Nos résultats montrent aussi que la production des fruits à long terme connaît des baisses sensibles dans les gouvernorats les plus producteurs de fruits suite à une hausse des précipitations et de l'utilisation des engrais, alors que la production a crû suite à une augmentation de la main d'œuvre et de la superficie agricole.

Mots-clés
Production agricole
Température
Précipitations
Modèle ARDL
Tunisie