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Abstract

In this study we are examining the climate change impacts on cereal yields in the North-West of Tunisia by focusing on the effect of increase in temperature on durum wheat yields. The index of growing degree days (GDDs) or the corresponding growing season length (GSL) is commonly used in agronomic studies to determine the effect of temperature on yields. The main goal of the current study is to analyse the effect of historical increase of temperature on GSL of durum wheat in North-West of Tunisia (Beja and El-Kef) and assess the future impact of climate change on wheat yields. We find that high temperatures correspond to a decrease in growing season length. Future increases in temperatures between 1.5 and 3.5°C may reduce the yield of wheat in the Beja district between 16% and 19%.

ملخص

نختبر في هذه الدراسة آثار تغير المناخ على غلة الحبوب في الشمال الغربي لتونس من خلال التركيز على تأثير الزيادات في درجات الحرارة على غلة القمح الصلب. ويشيع استخدام مؤشر درجة الايام الازمة للنمو (GDDS) أو طول موسم النمو (GSL) في دراسات الهندسة الزراعية لتحديد تأثير درجة الحرارة على الغلة. و الهدف الرئيسي من الدراسة الحالية هو تحليل التأثير التاريخي لزيادة درجة الحرارة على طول موسم النمو من القمح القاسي في شمال غرب تونس (باجة والكاف) وتقييم أثر تغير المناخ في المستقبل على غلة القمح. و من اجل تطوير استراتيجيات التكيف مع التغير المناخي المتوقع، من المهم تحديد، مع بعض الدقة، الآثار المحتملة لهذه التغيرات على إنتاج القمح الصلب في تونس. وجدنا أن درجات الحرارة المرتفعة تتوافق مع انخفاض في طول موسم النمو. لذا فقد تقلل الزيادات المستقبلية في درجات الحرارة ما بين 1.5 و 3.5 درجة مئوية من محصول القمح في منطقة البجا بنسبة تتراوح بين 16 ٪ و 19 ٪.

1. Introduction

Agriculture is the major source of income and employment for the 70 % of the world's poor in rural areas. It takes up more than one-third of the world's water withdrawals. Competition for these resources is increasing with the growth of population, cities, and demand for food. Climate change is altering the patterns of rainfall and temperatures that affect negatively the agriculture production. The depletion and degradation of these resources thus pose serious challenges to the capacity of agriculture to produce enough food and other agricultural products to sustain the livelihoods of rural populations and accommodate the needs of urban populations (World Development Bank, 2007).

Based on global model simulations and for a wide range of scenarios, global average water vapour concentration and precipitation are projected to increase during the 21st century. Besides, by the end of the 21st century, climate change could have substantial impacts on agricultural production and hence on the scope for reducing poverty (Slater et al, 2007).

These assumptions of climate warming can deeply affect the natural and fitted systems in the world and in particular those of Tunisia due to its geographical position and general orientation of the main relief. In fact, the South of Tunisia is being under the joint effect of these two elements. The North of the Tunisian Dorsal benefits from a Mediterranean climate, characterized by a hot and dry summer and relatively rainy winter.

The importance of environmental factors is asserted in the explanation of the low yields per hectare (Gonzales de Molina, 2002). A few studies have examined how rising temperatures have actually affected crop development and production in the field (Tao, 2006). For example, gradual temperature changes from 1982 to 1998 have caused in the United States an important impact on the yields of corn and soybeans (Lobell and Asner, 2003). In Philippines, rice grain yields were found to decline by 10% for each 1°C increase in growing-season minimum temperature in the dry season (January-April) from 1992 to 2003 (Peng et al, 2004). Empirical results on 60 crops in Taiwan show that the two climate variables (temperature and precipitation) have significant implications on many crop yields (Chang, 2001). A negative impact of temperature on yield was observed for several rice and maize producing countries (Lobell, 2007). However, differences in simulated yield increases due to doubling [CO_2] among models were small in comparison to the differences between simulated and observed yields for ambient conditions (Ewert et al, 2002). Crop adaptability to particular years as well as yield increment and yield stability was found to be crucial factors for future (Chloupek and Hrstkova, 2004).

In Tunisia, mean temperature has increased in the last several decades. So we have examined the climate change impacts on cereals yields in the North-west of Tunisia by focusing on the effect of increases in temperature on durum wheat yields. The index of growing degree days (GDDs) or the corresponding growing season length (GSL) is commonly used in agronomic studies to determinate the impact of temperaturge on yields. We study here the effect of historical increase of temperature on GSL of durum wheat in Beja and El-Kef and assess the future impacts of climate change on wheat yields.

This paper is organized as follows. Section 2 presents the study area and the data sources. The econometric model is briefly outlined in section 3. The results of our estimations and their interpretations are exposed in section 4 and the last section concludes and gives some policy implications.

2. Study area and data sources

Beja and El-kef are two districts of the Western North of Tunisia (Figure 1). Beja district has an altitude of 158 meters above sea level with a latitude and longitude of 3644 N and 911 E, respectively. El-Kef district has an altitude of 518 meters with a latitude and longitude of

3608 N and 842 E, respectively. The two districts have some differences in weather system. The weather system in Beja is dominated by a mild and relatively rainy winter and it is influenced by the Mediterranean .Whereas, the weather system in El-Kef is dominated by a hot and dry summer and characterized by modest rainfall in winter. Besides, Beja receives an annual total rainfall of 458 mm but El-Kef receives only 324 mm (Figure 2).

In Beja district, the mean annual temperature is 18°C while n El-Kef district, the mean annual temperature is 16°C. We notice an upward trend of this climatic variable from 1977 to 2004 (Figure 3).

According to the simulation made by climate specialists on the basis of the IPCC 6 scenarios, at the 2100 horizon, a potential increase of the temperature from 1.3 to 2.5°C, and an elevation of the sea levels from 38 cm to 55 cm will occur. Transposed on an equal scale to the Mediterranean scale, these assumptions of climate warming and sea level elevations could deeply affect the natural and fitted systems.

In the arid and semi-arid areas, the climate is characterized by its long dry season and by the irregularity of precipitations. Cultures dependent on rainfall are often subjected to hydrous deficits, of variable duration, caused by the exhaustion of the water reserves stored in the ground. This hydrous deficit affects ineluctably in a negative way the outputs of the cultures. In Beja, the sowed surfaces increase slowly while for El-Kef we notice a progressive decrease of these surfaces (Figure 4).

It is worthily noticeable that cereals are the main important sources of the human and animal nutrition in the North- Western of Tunisia as the wheat is the main food crop grown in the two districts. According to figure 5 we can show that the cereal yields follow a cyclic evolution. This cyclic evolution from 6 to 7 years reflects the periodicity of precipitations.

Moreover, time series daily data of rainfall and minimum and maximum temperatures, covering the period 1976/1977 to 2003/2004, were obtained from the Tunisian Institute of Meteorology. These series are used to measure the growing season length (GSL) after measuring growing degree days (GDDs). Wheat yield data for the same period were collected from the Tunisian General Direction of agricultural Investments and Development. For Beja, among the objectives of the cereal sector's development plan is increasing the area of cereal cultures to 8700 hectares—from 7500 hectares—thus increasing the cereal yields by 55 quintals. That is likely to increase the participation of the area of Beja in the national production of cereals to attain 25%. For the durum wheat yield in the two areas, we note that the mean yield does not exceed 20.5 quintals/hectare in Beja and almost 10 quintals for El-Kef (Figure 6)

3. Econometric model

3.1. Functional form

The transcendental form as suggested by Debertin (1986) was chosen for the analysis as shown in Eq. (1). In fact the relation between climate variables (cumulative rainfall and length of growing season) and wheat yield is likely to be non linear because the increase in temperature could be beneficial for wheat growth up to a certain limit (Hussain and Mudusser, 2007). The advantage of transcendental form is that it exhibits all three stages of production: increasing, constant and decreasing marginal returns (Y) for factors of production (X_1 and X_2). So that the rule of decreasing marginal productivity is verified:

$$Y = AX_1^{\beta_1} X_2^{\beta_2} \exp(\alpha_1 X_1 + \alpha_2 X_2) \qquad (1)$$

The dependent variable Y represents the yield; the independent variables X_1 and X_2 represent respectively, the GSL and the cumulus of rainfall; A is a constant term; β_1, β_2, α_1, α_2 are the regression coefficients to be estimated and "exp" is an exponential term. According to

(Beattie and Taylor, 1985) the coefficients β_1 and β_2 are assumed to be positive while $\alpha_1$and α_2 are assumed to be negative.

For attaining the maximum point on the production function, the first derivative should be equal to zero. The first order necessary conditions for X_1 and X_2 in Eq. (1) are:

$$\frac{\partial Y}{\partial X_1} = \left[\frac{\beta_1}{X_1} + \alpha_1\right].Y = 0 \tag{2}$$

$$\frac{\partial Y}{\partial X_2} = \left[\frac{\beta_2}{X_2} + \alpha_2\right].Y = 0 \tag{3}$$

Where $\frac{\partial Y}{\partial X_1}$ and $\frac{\partial Y}{\partial X_2}$ are the marginal physical productivities (MPPs) of X_1 and X_2, respectively. The values of X_1 and X_2 at which production is maximized (referred to here as X_1 optimum and X_2 optimum) are calculated by solving Eqs (2) and (3) independently for X_1 and X_2, respectively as follows:

$$X_1 optimum = -\frac{\beta_1}{\alpha_1} \tag{4}$$

$$X_2 optimum = -\frac{\beta_2}{\alpha_2} \tag{5}$$

Second order conditions for attaining the maximum point on the production function are met if $\frac{\partial^2 Y}{\partial^2 X_1} \langle 0$, $\frac{\partial^2 Y}{\partial^2 X_2} \langle 0$ and $\frac{\partial^2 Y}{\partial X_1^2} \cdot \frac{\partial^2 Y}{\partial X_2^2} \rangle \left(\frac{\partial^2 Y}{\partial X_1 X_2}\right)^2$

where $\frac{\partial^2 Y}{\partial X_1^2}$ and $\frac{\partial^2 Y}{\partial X_2^2}$ are second order partial derivatives of Y with respect to X_1 and X_2, respectively, and $\frac{\partial^2 Y}{\partial X_1 X_2}$ is the second order cross partial derivative of X_1 with respect to X_2.

3.2 Empirical model

The transcendental production function as given in Eq. (1) can be estimated in natural Logarithm form using the Ordinary Least Squares (OLS) method.

$$LnY_t = \beta_0 + \beta_1 LnX_{1_t} + \beta_2 LnX_{2_t} + \alpha_1 X_{1t} + \alpha_2 X_{2_t} + \beta_3 X_{3_t} + \varepsilon_t \tag{6}$$

Where Y_t: wheat grain yield (Kg/ha);

X_1: growing season length (GSL) in days;

X_2: amount of cumulative rainfall in mm;

X_3: time;

ε: random error;

Ln: is the natural logarithm;

3.3 The Baskerville-Emin method (BE)

To measure the GSL, the index of growing degree days was computed by Baskerville-Emin method (Nugent, 2000). According to this method, if the minimum daily temperature is greater than or equal to the base temperature (for durum wheat the base temperature equal to 5° C), then:

$$GDD_1 = T_{mean} - T_{base}$$

If $T_{mean} \langle T_{base}$ then $GDD_1 = 0$

If $T_{\min} \langle T_{base}$ then $GDD_2 = \left(\left(W * \cos(A)\right) - \left(\left(T_{base} - T_{mean}\right)\right) * \left(3.14/2 - A\right)\right)/3.14$

Where $T_{mean} = \left(T_{\max} + T_{\min}\right)/2$;

$W = \left(T_{\max} - T_{\min}\right)/2$;

$A = Arc\sin\left(\left(T_{base} - T_{mean}\right)/W\right)$.

T_{max} and T_{min} are the maximum and minimum temperatures respectively, and T_{base} is the base temperature below which crop growth ceases. Summing GDD_1 and GDD_2 produces the total GDD for the wheat season.

The GSL for wheat was then estimated by measuring the number of days from the date of planting to the date at which the crop would be able to accumulate GDDs of 1800.

4. Estimation Results and Interpretations

4.1 Temperature increasing and growing season length:

The increase of temperature in the two districts (Figure 3) causes the GSL to decrease. Beja and El-Kef districts show a decline of GSL during the period 1977 to 2004 (Figure 7). The average of GSL was 91days in Beja district and 127 days in El-Kef district. Farmers should delay the date of plantation of durum wheat to December to avoid the negative impact of the increasing of temperature.

4.2 Coefficients signification:

Regression results for Beja and El-Kef districts are shown respectively in Table 1 and Table 2. All coefficients had the right signs: β_1 and β_2 showed a positive sign and $\alpha_1$and α_2 were negative, suggesting that the first and the second order marginal conditions have been met. The Durbin Watson statistic was close to 2, so there isn't serial correlation in our regression. The independent variables in the transcendental form explain well the dependent variable. So climate change has an important impact on durum wheat in Tunisia. Indeed our results suggest that a temperature rise is not favorable for durum wheat yield. Climate variations are found to have a significant yield impact on durum wheat, while precipitation variations are mostly yield-decreasing.

4.3 Impact of growing season length on yield

To find the optimum of GSL we use Equation 4. The maximum yield in Beja district was found when the optimum GSL was 110 days. In El-Kef district the optimum of GSL is equal to 136 days which corresponds to an optimum yield of 1197 Kg/Ha (12% over the average of yield).

4.4 Impact of rainfall on yields

Durum wheat production under water deficit conditions has been the subject of several studies showing that this crop is characterised by specific resistance mechanisms against climatic constraints which encourage their growth and development as well as their yield (Slama et al, 2005). In our study the impact of rainfall on durum wheat yield is significant, in fact the increase (decrease) of the rainfall in Beja district (in the El-Kef district) had declined (had risen) the durum wheat yield as shown in Fig.2 and Fig.5.

4.5 Climate change scenarios results

Temperature increases in the range of 0.5 - 3.5°C with steps of 0.5°C per 15 years (IPCC, 2001). To forecast the impact of future increases in temperature in Beja and El-Kef districts under various climate change scenarios we estimate the transcendental production function as given in Eq.(6). The results are given in the Table 3 and Table 4.

In the two districts, the growing season length for durum wheat is reduced. If temperature increases by 1.5°C the growing season length for Beja is reduced from 108 to 105 days (3% under the average of GSL). For this scenario wheat yield is reduced from 1959 to 1831 Kg/Ha (a decreasing of 7%). Concerning El-Kef district we find that an increasing of 1.5°C in temperature for the next 45 years will reduce the growing season length 127 to 125 days but we will note an increase of the yield from 1058 to 1507 Kg/Ha (an increase of 30%). The last scenario (an increase of 3.5°C) will reduce the growing season length for the two districts. This increase of temperature may reduce the yield of wheat in the Beja district from 1959 to 1642 Kg/Ha (a decreasing of 16%) but in El-Kef district we note an increase of 6%.

5. Conclusions

This paper basically researches the impact of climate change on durum wheat yield in the North Western area using Beja and El-Kef districts as examples. Our empirical results show that the two climate variables (growing season length and rainfall) have a significant impact on durum wheat yield. We can say that future increases in temperatures between 1.5 and 3.5° C may reduce the yield of durum wheat in the Beja area between 16% and 19%. However in El-Kef district we note an increase of 6%. Hence we find that the observed climate change patterns and their impact are diverse both spatially and temporally. So the choice of good varieties of wheat and delaying the date of plantation to December will be the best solution to ameliorate the yield.

So far we have gained a number of important insights from our research. We focus our attention on two points which seem to be important for us:

- We have shown that econometric methods are useful in the study of climate change when applied rigorously and consistently.
- We hope that those results will be useful for the concerned decision makers to relieve some of the pressure of increasing food demand in MENA countries.

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Figure 1: Tunisia Map

Figure 2: Rainfall in Beja and El-kef during the Growing Season Length

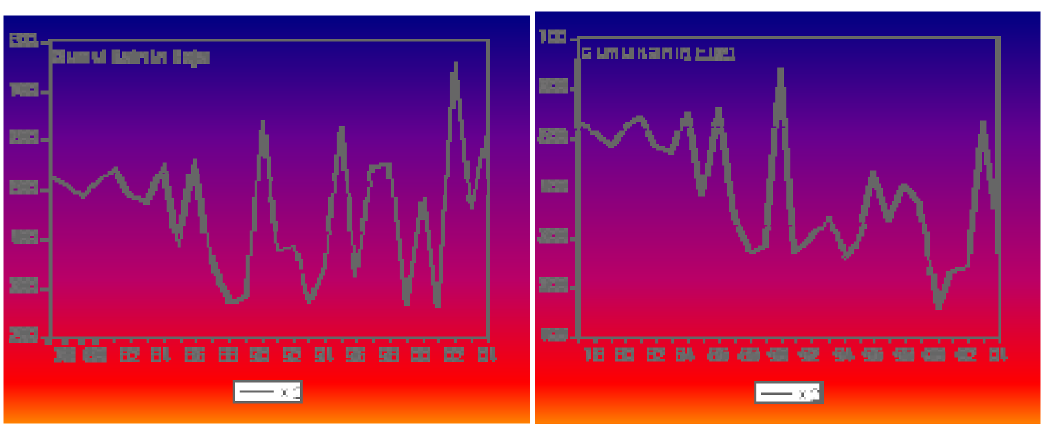
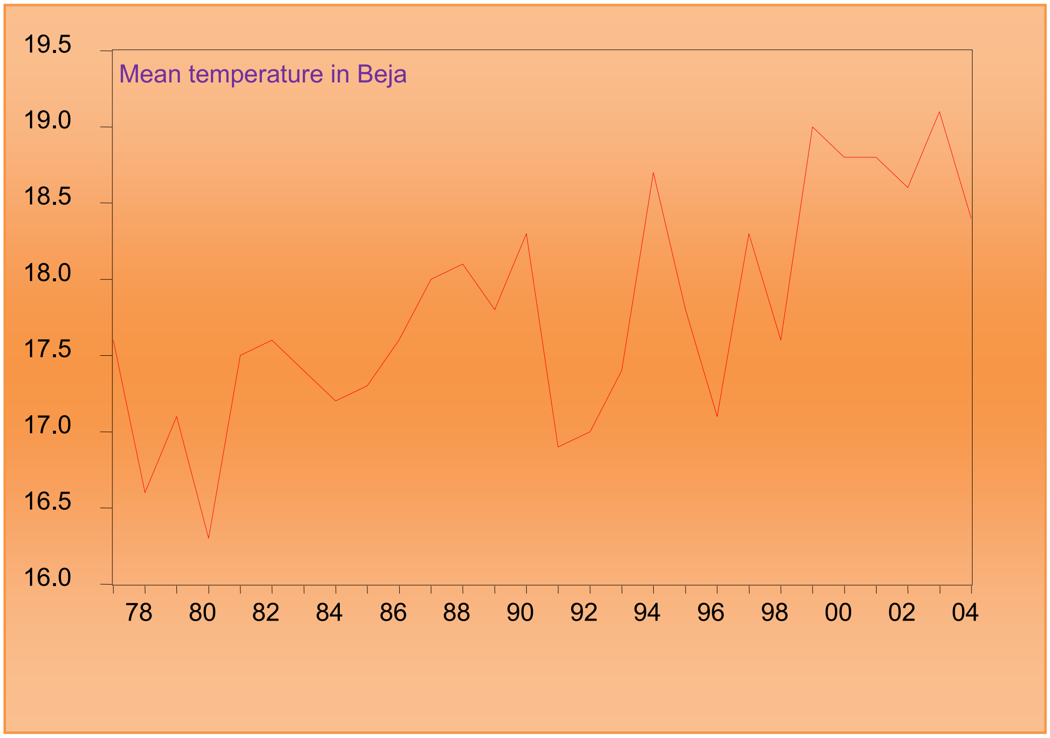


Figure 3: Annual Mean of Monthly Average Temperature in Beja and Elkef, 1977-2004



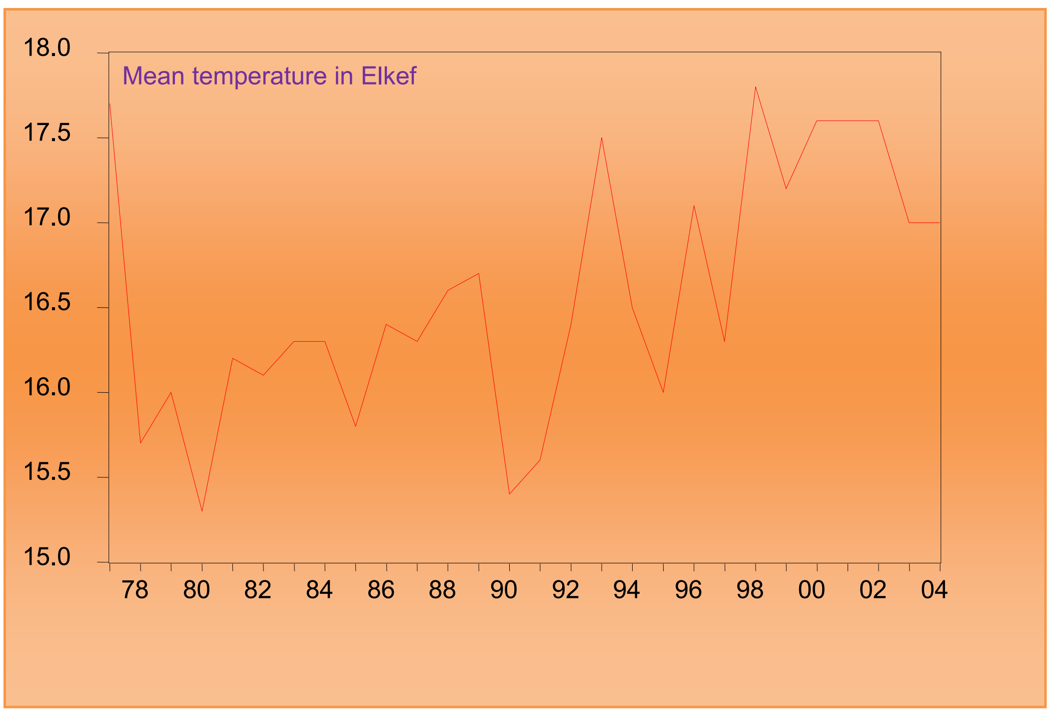
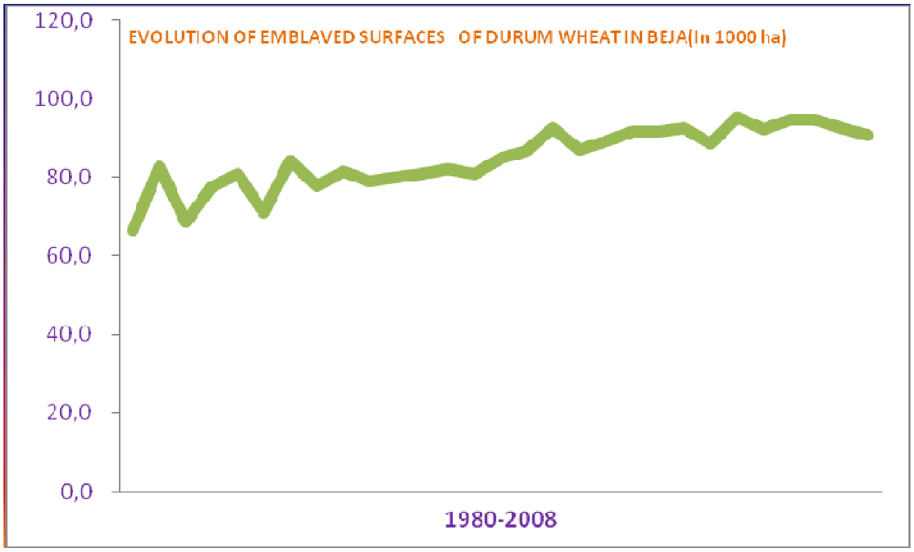


Figure 4: Evolution of Sowing Surfaces of Durum Wheat in Beja and Elkef



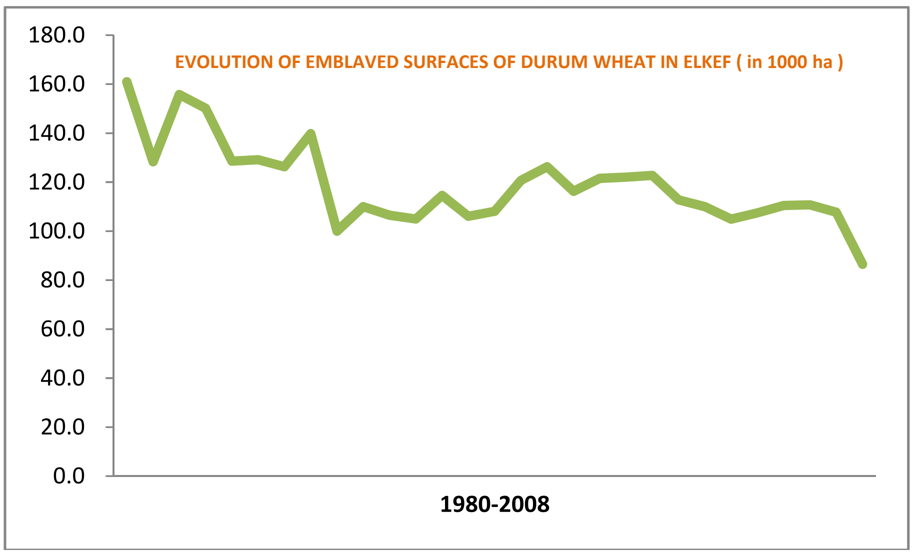
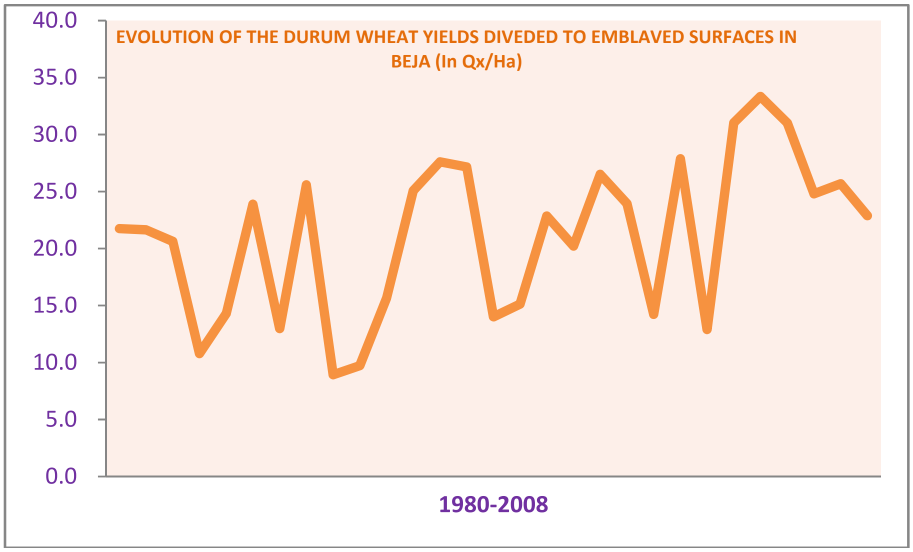


Figure 5: Annual Durum Wheat Yield in Beja and Elkef Districts



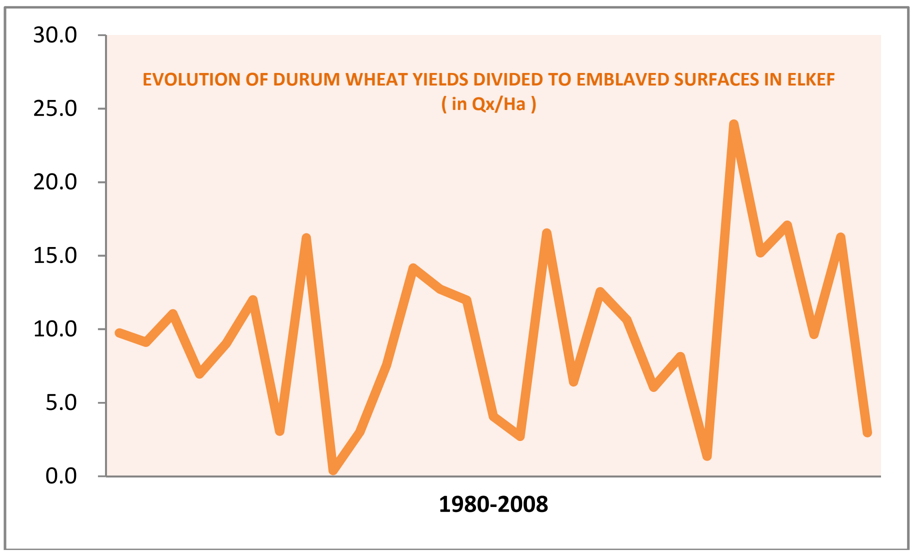
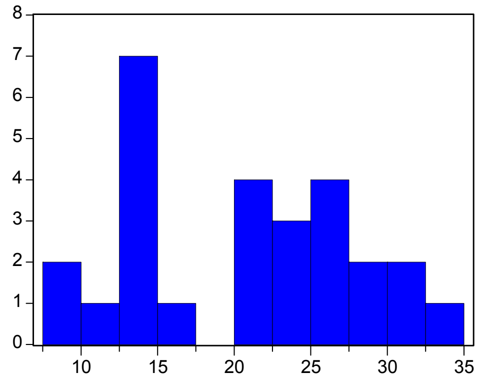
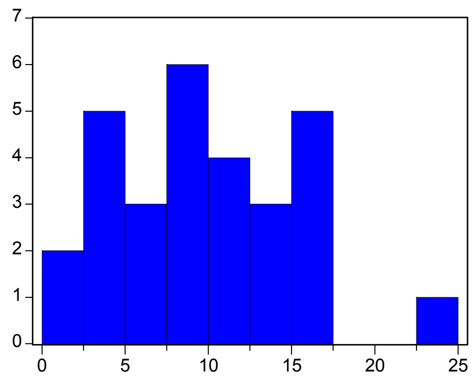


Figure 6: Histogram and Statistics for Durum Wheat Yield in Beja and Elkef

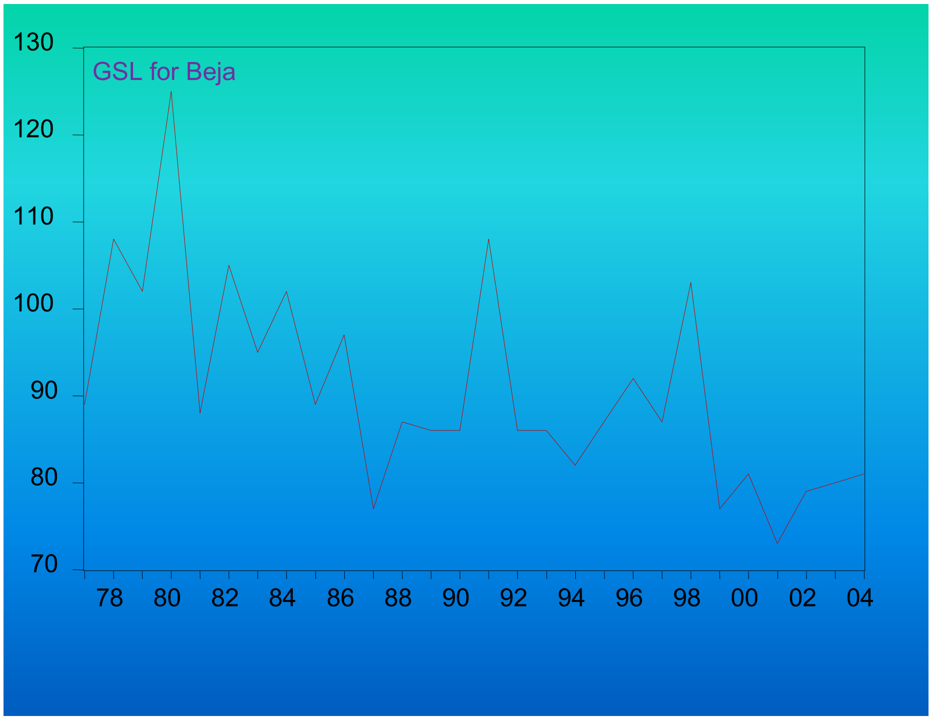


Series: REND	
Sample 1980 2008	
Observations 27	
Mean	20.50000
Median	21.64000
Maximum	33.34000
Minimum	8.920000
Std. Dev.	7.207825
Skewness	0.010455
Kurtosis	1.748569
Jarque-Bera	1.762330
Probability	0.414300



Series: RENDK	
Sample 1980 2008	
Observations 29	
Mean	9.669552
Median	9.640000
Maximum	23.95000
Minimum	0.390000
Std. Dev.	5.608974
Skewness	0.340579
Kurtosis	2.761455
Jarque-Bera	0.629396
Probability	0.730009

Figure 7: Growing Season Length (GSL) for Durum Wheat Crop in Beja and Elkef Districts



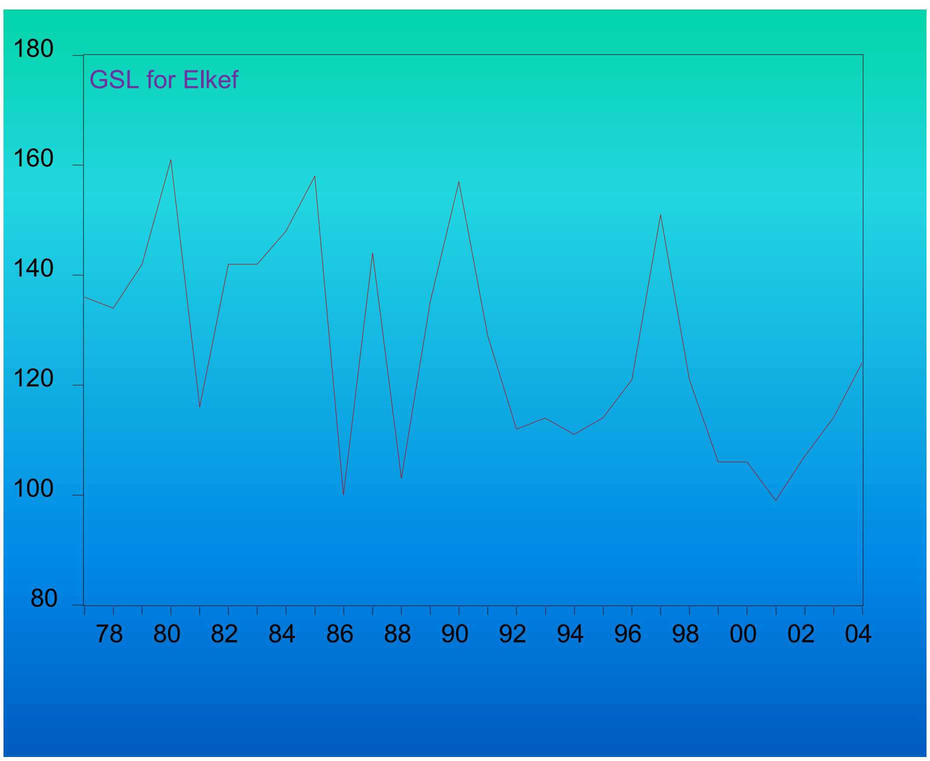


Table 1: Regression Results for Durum Wheat Yield in Beja District Using Time Series Data (1976/1977-2003/2004)

Variables	coefficients	Std.error	t-statistics	probability
Ln A (β0)	-24.52	20.43	-1.20	0.20
Ln growing season length (β1)	8.87	5.81	1.52	0.10
Ln rainfall (β2)	0.12	0.15	0.77	0.44
Growing season length (α1)	-0.08	0.05	-1.41	0.10
Rainfall (α2)	-0.00008	0.00007	-1.21	0.23
time (year number) (β3)	0.03	0.008	3.72	0.00
DW = 1.99				
GSL = 110 days				
R^2 =0.46				

Table 2: Regression Results for Durum Wheat Yield in El-Kef District Using Time Series Data (1976/1977-2003/2004)

Variables	coefficients	Std.error	t-statistics	probability
Ln A (β0)	-130.74	72.17	-1.81	0.10
Ln growing season length(β1)	40.74	19.47	2.09	0.06
Ln rainfall (β2)	4.50	2.83	1.59	0.10
Growing season length (α1)	-0.30	2.83	-2.02	0.07
Rainfall (α2)	-0.01	2.83	-1.85	0.10
time (year number) (β3)	-0.0009	0.04	-0.02	0.98
DW =1.99				
GSL = 136 days				
R^2 =0.62				

Table 3: Growing Season Length for Durum Wheat Crop in Beja and Elkef Districts under Various Climate Change Scenarios

Increase in average temperature (°C)	GSL (days) Beja	GSL(days) Elkef
0	105	136
1.5	83	125
2	79	72
2.5	74	84
3	71	80
3.5	68	76
Average of GSL of 28 years (days)	91	127

Table 4: Regression Results for Durum Wheat Yield in Beja and Elkef Districts under Various Climate Change Scenarios

Increase in average temperature (°C)	Durum wheat yield in Beja district (Kg/Ha)	Durum wheat yield in Elkef district (Kg/Ha)
0	1652	1197
1.5	1831	1507
2	1784	963
2.5	1722	625
3	1592	1237
3.5	1642	1125
Average of yield for 28 years(Kg/Ha)	1959	1058