Climate Variability and Crop Production in Libya (North West Region)

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Abstract

Climate variability is considered as the most serious challenge threatens the ecosystem, whether in developing or developed countries. Climate variability affects the agro ecological and growing conditions of crops and livestock that may add significantly to the development challenges of ensuring food security and reducing poverty. In this study, the climate data for the period (1945-2010) was investigated to determine the manifestation of climate variability in the northwest of Libya and its effect on agriculture. The results indicate that the drop in rainfall volumes and irregular distributed over the season and temperature increasing over the study period are the most important consequences of climate variability in Libya, which has a negative influence on the country's agriculture sector. Time trend of rainfall and temperature were analyzed and the impacts of climate change on agriculture were discussed. Moreover, Pairwise Granger causality test analysis were used to examine the causal relationship between climatic conditions in Libya. The results further indicate that there is an unidirectional relationship existed between changes in temperature and the production of dates and tomatoes, and unidirectional causality runs from rainfall to onion, potatoes olive and ground peanut.

1. Introduction

Climate change is considered as the most serious challenge threatens the ecosystem, whether in developing or developed countries. Climate change has been defined as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods" (UNFCCC, 1992). The impacts of climate change on agriculture is one of the serious effects that may add significantly to the development challenges of ensuring food security and reducing poverty. Climate change, which is attributed to the natural climate cycle and human activities, has adversely affected agricultural productivity in Africa (Ziervogel *et al.*, 2006). The detection of trends in meteorological data, in particular rainfall and temperature are essential for the assessment of the impacts of climate variability and change on agriculture of a region. Climate change will impact agricultural commodity production globally due to the effects on plant growth and yield caused by elevated CO_2, higher temperatures, altered precipitation and transpiration regimes, and increased frequency of extreme events, as well as modified weed, pest and pathogen pressure (Masters, 2010).

National Intelligence Council report (NIC., 2009) stated that according to climate model estimation for North Africa the temperature will be increased over the next 20 years probably at a rate higher than the estimated global average. The model also indicates a decrease trend of precipitation in the Mediterranean coast. The model simulation estimated a percent decrease of 6% in annual average rainfall. (NIC) report (2009) added that the main affected sectors by climate change in Libya are water resources, agriculture, rangeland, livestock and human health. Global climate change might be cause changes in hydrological cycle such as increases in storms and droughts as a result changes in both a volume and geographical distribution of rainfall. This in turn affects agriculture crop patterns and food production; this may threaten food security and increasing the poverty (EL-Tantawi, 2005).

Libya is exposed to adverse effects of climate change due to prevailing arid and semi-arid climate conditions, frequent drought and overdependence on rainfed agriculture. Rainfall is the most important parameter of climate which may control agriculture production. The rainy season in Libya starts usually in autumn to winter and end in spring, while rarely rains in the summer. Increasing the variability and uncertainty of precipitation over Libya may cause critical moisture stress on crops production and reduce yields especially that a large proportion of water lost through evaporation without any benefit to agriculture because of the high temperature, while only a small percentage of rainfall infiltrates to groundwater.

Climate in Libya plays an important role in determining land utilizations and in forming water balance. It is clear that Libya had been affected by climate change in many aspects, in particular, agriculture production, rangeland and livestock production, water resources, and human health. This study will focus on the impact of climate change on agricultural and water resources.

1.1 Impacts on water resources

Climate changes could aggravate existing problems of water resources and cause a decline in water quality through increasing concentrations of pollutants and sea water intrusion on coastal groundwater aquifers. The changes of precipitation combined with increased evaporation would directly reduce runoff and groundwater levels. The problem of water resources will be compounded by increases in demand driven by socio-economic factors. Problems of saline intrusion would be further exacerbated by reductions in runoff and by increased withdrawals in response to higher demands.

1.2 Impacts on agricultural soils

Climate change is expected to affect soil in many ways. First the change in temperature and rainfall patterns is also damaging the physical structure of soils. The organic matter in particular is being affected, its balance being crucial to the nutrient balance of the soil, its stability, the amount of water it can hold, and the populations of soil organisms. Additionally, the changes are likely to leave some soils more vulnerable to damage by erosion.

1.3 Impacts on crop production

Climate variability and change can be affect crop productivity into ways: First, abiotic stresses (i.e. increasing temperature, decreasing water availability, increasing salinity and inundation) and biotic stresses (such as increases in pests and diseases), Second, changes in the atmospheric concentration of carbon dioxide, acid deposition and ground level ozone. Hence, a key challenge is to assess how crops will respond to simultaneous change to the full range of biotic and abiotic stresses (Matthew, 2010). Crop simulation modelling studies based on future climate change scenarios in India indicated that significant losses are likely in rainfed wheat in South and South-East Asia (Fischer et al., 2002). For example, a 0.5°C rise in winter temperature would reduce wheat yield by 0.45 ton/ha in India (Shukla, 2003). Climate change can affect other parameters, such as land degradation risks in agricultural areas, soil erosion, and contamination (Shahbazi et al., 2009).

1.4 Climate Variability and Change in the Study Area

The climate in the study area has witnessed a clear change. Most descriptions of climate deal with temperature and precipitation characteristics because these two major climatic elements usually apply more impacts on environmental conditions and human activities other than elements do, such as wind, humidity, and sunshine hours (El-Tantawi,2005). Mean, minimum, maximum monthly temperature and precipitation data for the period (1945-2010) were investigated to determine the manifestation of climate change in Libya.

Precipitation in Libya ranges from light to negligible. Less than 2% of the country receives enough rainfall for settled agriculture, and 93% of the land receives less than 200 mm/year. The highest rainfall occurs in the north-western region (Jabal Nafusah and Al Jifara Plain) and in the north-eastern region (Jabal al Akhdar). Only in these two areas does the average annual rainfall exceed the minimum of 250-300 mm considered necessary to sustain rainfall-dependent agriculture. Rain falls during the winter months, but great variability is observed from place to place and from year to year. The heaviest precipitation occurs in the Jabal al Akhdar in the north east, where annual rainfall ranges from 450 to 700 mm. All other areas of the country receive less than 450 mm (FAO, 2007). The average annual rainfall during the period

(1945-2010) for the study area is shown in figure 1. In the coastal lowlands, where 80% of the population live, the Mediterranean Sea and the desert are the dominant climatic influences, with warm summers and mild winters. Along the north-western coastal region, mean temperatures in summer range between 32°C and 36°C; temperatures are even higher to the south. In the northern part of the north-eastern region, mean temperatures in summer range from 28°C to 32°C. In winter, minimum temperatures are below 0°C (FAO, 2007). Figure 2 shown the mean annual temperature for the study area.

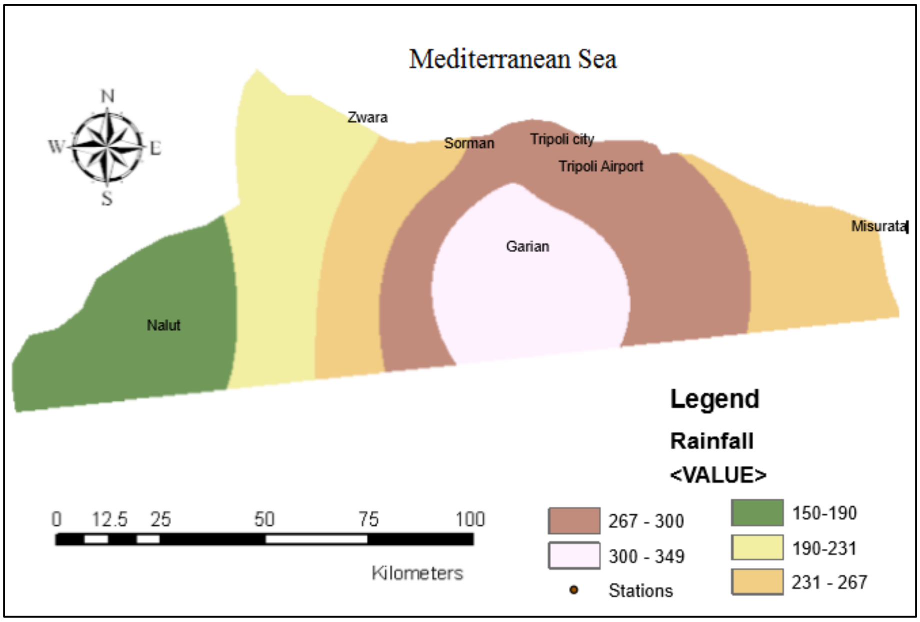

Figure 1: The annual rainfall

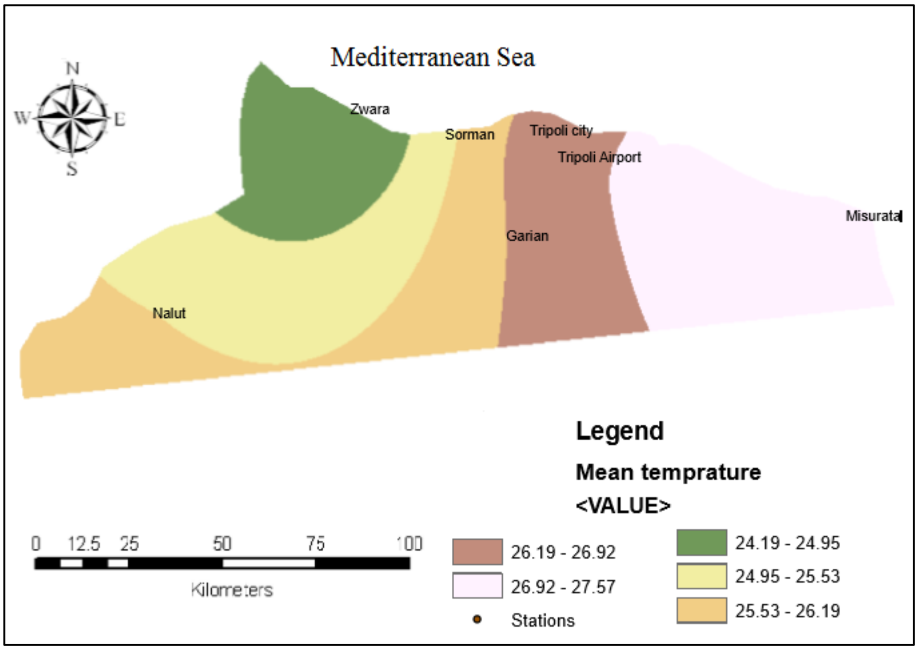

Figure 2: The mean annual temperature

2. Data and Methodology

2.1 The study area

The study area is called Jeffara plain. It is located in the northwest of Libya (*Figure 3*). The study area is a flat area of triangle shape, its width (distance from the sea) varies between 8 and 115 km. The total area is about 17,000 km²; it is bordered by the Mediterranean Sea in the north, the Tunisian border in the west and Jabil (mountain) Naffusah in the south. The study area lies between 12° 00´ - 15° 00´ E longitude and 31° 52´ - 32° 54´ N latitude. The plain lies in the agriculturally productive region of north Libya, where more than 50% of the country's population is concentrated (ALfarrah, *et al*, 2011). The main reasons for this concentration are the availability of fertile soils and seasonable, moderate climatic conditions compared with other places in the country.

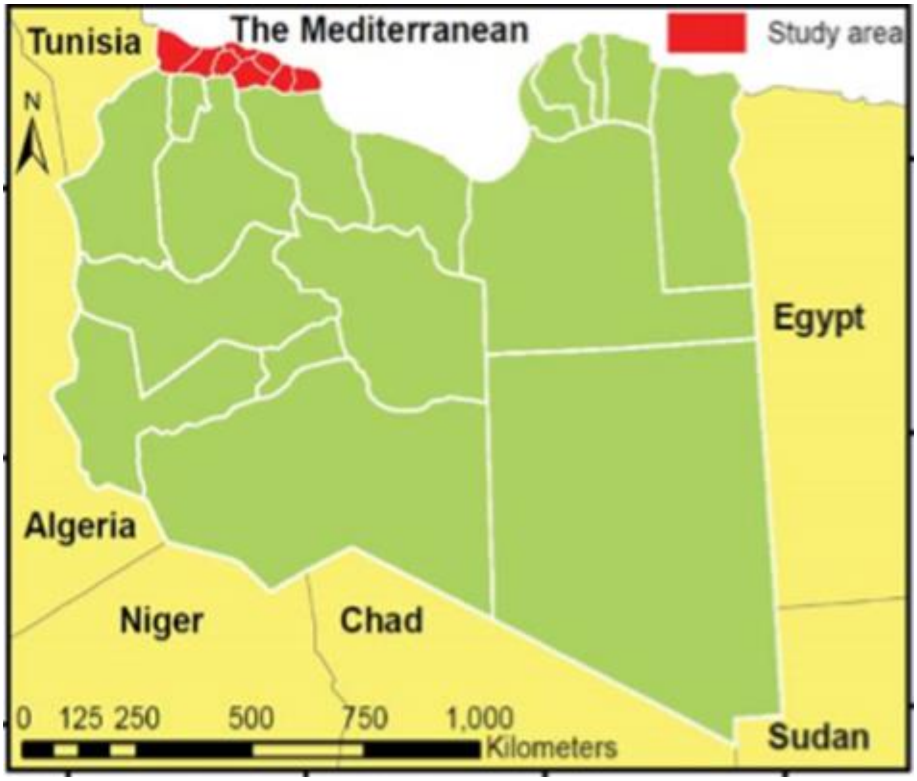

Figure 3: location of the study area

2.2 Meteorological parameters and trend analysis.

The Mann-Kendall (MK) test was applied to detect the significance of trends in temperature and precipitation data at (7) meteorological stations represented the study area. These data for the period (1945-2010) are analyzed using the Mann-Kendall test. The Mann-Kendall (MK) test was recommended by the World Meteorological Organization (Mitchell et al., 1966) and applied extensively in hydrology science (El Kenawy et al., 2009., Tayanc et al., 2009., and Agena, 2014). The significance of the trends is calculated using the MAKESENS Microsoft Excel template developed by the Finnish Meteorological Institute: Helsinki (Salmi et al., 2002). Kriging tool in ArcMap was used as Interpolation tool to predict the trend values of cells at locations that lack sampled points. It is based on the principle of spatial autocorrelation or spatial dependence, which measures degree of relationship/dependence between near and distant objects (Childs,2004). Moreover, Pairwise Granger causality test analysis were used to examine the causal relationship between crop production and mean temperature and rainfall in the study area. The analysis was conducted using the data on annual rainfall, mean temperature, and production of dates, onions, potato tomato, olive, ground peanut and orange between 1970 and 2010 for the North West of Libya region. All the data were obtained from the Libyan National Meteorological Center and the Food and Agriculture Organization (FAO, 2015).

Granger causality analysis is a method for investigating whether one time series can correctly forecast another (Granger, 1969). We employed the pairwise Granger's concept of causality to test the relationship between the model variables (climate conditions versus annual agricultural production commodities) as a multivariate Vector Autoregressive model (VAR) consisting of two time-series X and Y, as follows:

$$Y_t = \alpha + \sum_{i=1}^{n} \beta_i X_{t-i} + \sum_{i=1}^{n} \lambda_j Y_{t-i} + U_{1t} \ldots\ldots\ldots(1)$$

$$X_t = \alpha' + \sum_{t-1}^{n} \phi_i X_{t-i} + \sum_{t-1}^{n} \gamma_j Y_{t-i} + U_{2t} \ldots\ldots\ldots(2)$$

Where,

Y_t *= climate elements (temperature and rainfall) at time t*

X_t *= production of (selected commodities) at time t*

U_{1t} *and* U_{2t} *= error terms and are uncorrelated.*

The direction of causality between variables can be determined by the Granger-causality test. The basic idea is that a regression of Y on other variables (including its own past values) if we include past or lagged values of X and its significantly improves the prediction of Y then we can say that time series X is Granger cause time series Y. A similar definition applies if Y Granger-causes X. X is said to Granger-the cause Y if computed F statistic is statistically significant at the conventional level (Gujarati, 2001).

3. Results and discussion

3.1 Trends analysis of temperature and rainfall.

Analysis of the annual data from 1945-2010 was undertaken by dividing the whole period in two, providing two periods for analysis of (1945-1975) and (1976-2010), this permits consideration of general long term changes and differences in rates of change. The statistical significances levels are (*** = 0.001 level of significance, ** = 0.01 level of significance, * = 0.05 level of significance, + = 0.1 level of significance), where the blank cell, is > 0.1, which means there is a 10% probability that making a mistake with rejecting HO of no trend, with the alternative hypothesis, H1, where there is an trend; increasing or decreasing monotonic.

3.1.1 Trends of mean annual temperature

All of meteorological stations in the study area have experienced an upward trend in mean temperature during the period (1945–2010), with trends ranging between 0.18 and 0.34 °C /decade based on the Spearman's (Rho) rank correlation test. Only Misrata station recorded outlier figure from the rest of the stations, with small trend 0.08 °C/decade (Table 1). For the period (1945-1975) all stations have experienced non-significant trend except at Tripoli city station which reported significant upward trend, with (0.38 °C/decade), where Misratha station indicated negative trend (-0.34 °C/decade). For the recent period (1976-2010) the picture was completely different, which have experienced a rapid warming at all stations. Trends ranged between 0.16 and 0.70 °C/decade at Tripoli city and Misratha respectively. Figure 4 shown the trends values of mean annual temperature for the study area.

Table 1: *Values of the Mann-Kendall statistic (Q) for annual mean temperature, with statistically significant levels at the synoptic stations in North West of Libya*

Time series	1945-2010			1946-1975			1976-2010		
Station	mean	sig	Q	mean	sig	Q	mean	sig	Q
All stations	19.9	***	0.025	19.5		-0.002	20.2	***	0.056
Tripoli city	20.4	***	0.021	20.1	***	0.038	20.7	***	0.016
Tripoli Airport	20.6	***	0.021	20.3		0.001	20.9	***	0.040
Misratha	20.5	+	0.008	20.5	***	-0.034	20.5	***	0.070
Grian	18.1	***	0.018	17.8	+	-0.025	18.2	***	0.064
Nalut	19.2	***	0.025	18.8		0.005	19.5	***	0.041
Zwara	20.0	***	0.034	19.5		-0.004	20.5	***	0.063
Sorman	20.1	***	0.037	19.6		-0.024	20.6	***	0.054

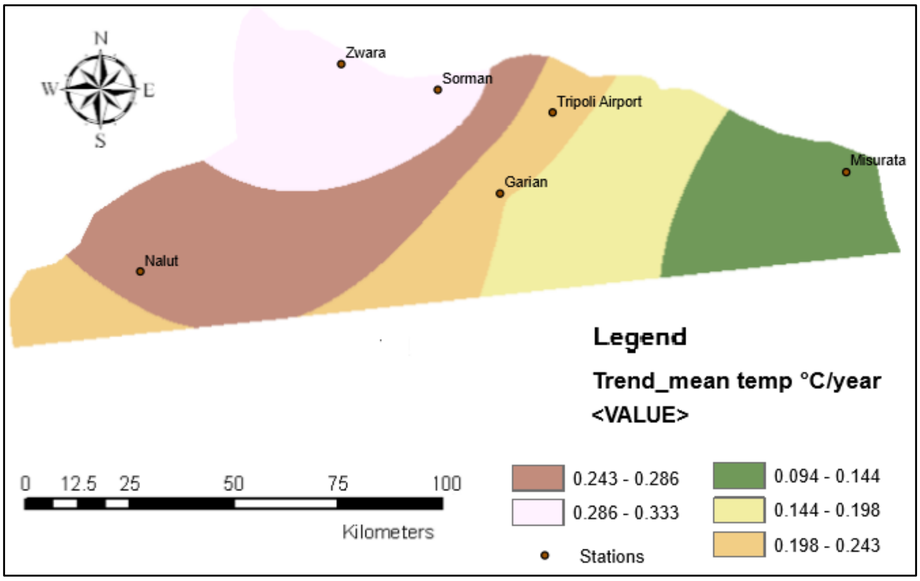

Figure 4: The trends values of mean annual temperature (1945-2010)

3.1.2 Trends of annual minimum temperature

Positive trends of annual minimum temperatures have been computed at all stations during the first period (1945-2010) and the last period (1976-2010) (Table 2). The trends ranged between 0.22 and 0.54 °C/decade with very high significant at level

0.001 for the long term period (1945-2010). Only Grian station has negative trend (-0.13 °C/decade) at significant level 0.1. For the period (1945-1975) non-significant trend prevailed at most of the stations, while increasing trends were observed only at the Tripoli city. Decreasing trends were observed at Misratha and Grian with significant at level 0.1 and 0.01 respectively. Trends of annual mean minimum temperature from 1976-2010 showed a rapid warming at all stations. Trends ranged between 0.37 and 1 °C/decade. Most trends were above 0.50 °C/decade.

Table 2: *Values of the Mann-Kendall statistic (Q) for annual minimum temperature, with statistically significant levels at the synoptic stations in North West of Libya*

Time series	1945-2010			1945-1975			1976-2010		
Station	mean	sig	Q	mean	sig	Q	mean	sig	Q
All stations	14.7	***	0.033	14.2		0.005	15.1	***	0.069
Tripoli city	15.5	***	0.054	14.9	***	0.053	16.2	***	0.090
Tripoli Airport	14.0	***	0.022	13.7		0.010	14.3	***	0.037
Misratha	15.9	***	0.024	15.6	*	-0.015	16.1	***	0.101
Grian	13.0	+	-0.013	13.2	**	-0.035	12.7	+	0.052
Nalut	13.8	***	0.031	13.3		0.010	14.3	***	0.038
Zwara	15.4	***	0.054	14.6		-0.003	16.1	***	0.072
Sorman	14.7	***	0.054	13.9		-0.005	15.4	***	0.061

3.1.3 Trends of annual maximum temperature

Positive significant trends in annual maximum temperature are prevailed at all study stations during the long term period (1945-2010), with nearly similar average trend at (0.21 °C /decade). Non-significant trends of annual mean maximum temperature were recorded at Tripoli city and Misratha, with 0.08 and -0.06 °C /decade. For the short term period (1945-1975), negative non-significant trends were shown at all stations except at Misratha station was high significant with -0.05 °C /decade (Table 3). In the short term period (1976-2010), all stations have experienced positive significant trend ranging between 0.34 to 0.84 °C /decade at Tripoli airport and Grian.

Table 3: *Values of the Mann-Kendall statistic (Q) for annual maximum temperature, with statistically significant levels at the synoptic stations in North West of Libya*

Time series	1945-2010			1945-1975			1976-2010		
Station	mean	sig	Q	mean	sig	Q	mean	sig	Q
All stations	25.1	***	0.021	24.8		-0.012	25.3	***	0.051
Tripoli city	25.3		0.008	25.3		0.017	25.3	***	0.048
Tripoli Airport	27.1	***	0.020	26.8		-0.011	27.3	**	0.034
Misratha	25.1		-0.006	25.3	**	-0.055	24.9	***	0.038
Grian	22.8	***	0.029	22.5		-0.014	23.1	***	0.084
Nalut	24.5	***	0.021	24.2		-0.004	24.8	***	0.046
Zwara	22.8	***	0.019	22.5		-0.019	23.1	***	0.052
Sorman	25.6	***	0.021	25.3		-0.021	25.8	***	0.039

3.1.4 Trend of annual rainfall

The total annual rainfall, which is other important climate element in this study, has changed during the last 66 years. The Mann Kendal test identifies positive increases in annual rainfall (1945-2010) at three of the seven stations ranging between 0.08 and 2.1 mm/decade at Grian and Sorman respectively. Negative trends are found at Tripoli Airport, Misratha, Nalut and Zwara with non-significant except Misratha (*) (Table 4). The annual total rainfall for the period (1945-1975) is analysed, the results indicate that there is positive trends in annual rainfall at four stations with non-significant values ranging between 3.6 to 23.8 mm/decade (Table 4). Negative non-significant trends were recorded at Tripoli city, Misratha and Nalut. Negative trends of the annual rainfall total have been observed at all stations during the recent short term period (1976-2010) ranging between 17.9 to 53 mm /decade at Sorman and Grian respectively (Table 4). Figure 4 shown the trend of annual rainfall for the period (1945-2010).

Table 4: *Values of the Mann-Kendall statistic (Q) for annual rainfall, with statistically significant levels at the synoptic stations in North West of Libya*

Time series	1945-2010			1945-1975			1976-2010		
Station	mean	sig	Q	mean	sig	Q	mean	sig	Q
All stations	267		-0.123	259		0.47	273	*	-3.25
Tripoli city	334		0.146	316		-2.14	350		-2.84
Tripoli Airport	271		-1.16	282		1.55	261	**	-4.0
Misratha	274	*	-0.23	267		-1.46	281		-1.81
Grian	343		0.008	336		4.2	350	*	-5.3
Nalut	145		-0.082	135		-0.705	154	+	-1.86
Zwara	231		-0.10	221		2.38	241	*	-4.22
Sorman	247		0.216	231		0.36	256		-1.71

3.2 Crop response to climate change

During the last decade the notion of Granger causality has been used quite frequently to analyze specific causality issues in the climate system. More recently, Granger causality was used to analyze the causes of the recent rise in global temperature. (Attanasio et al 2013) The dynamic pairwise Granger causality test was undertaken to establish the link as well as to measure the effect of past changes in the climate on the annual production of, dates, onion, potatoes, tomatoes, olive, ground peanut and orange in the north west of Libya. The results of the Granger causality analysis carried out using an optimal lag length of two are given in tables 5 and 6. An unidirectional relationship existed between changes in temperature and the production of dates and tomatoes, (Table 5).

Table 5: Granger causality test result: output and temperature

Null hypothesis	F-statistic	P-value
Temperature does not Granger-cause DATES	2.795	0.075
DATES does not Granger-cause Temperature	0.459	0.635
Temperature does not Granger-cause ONION	1.365	0.268
ONION does not Granger-cause Temperature	3.330	0.047
Temperature does not Granger-cause POTATO	1.010	0.374
POTATO does not Granger-cause Temperature	4.827	0.014
Temperature does not Granger-cause TOMATO	2.467	0.099
TOMATO does not Granger-cause Temperature	1.289	0.288
Temperature does not Granger-cause OLIVE	0.866	0.429
OLIVE does not Granger-cause Temperature	1.056	0.358
TEMP does not Granger-cause GROUND PEANUT	2.394	0.106
GROUND PEANUT does not Granger-cause TEMP	0.912	0.411
Temperature does not Granger-cause ORANGE	2.210	0.125
ORANGE does not Granger-cause Temperature	1.039	0.364

*, ** represent $p < 0.1$ and < 0.05 respectively.

Table 6 indicates that there is an unidirectional causality runs from rainfall to onion, potatoes olive and ground peanut. However, there is no directional causation from rainfall to dates, tomatoes, orange, ground peanut and tomatoes.

Table 6: Granger causality test result: output and RAINFALL

Null hypothesis	F-statistic	P-value
Rain does not Granger-cause DATES	1.603	0.216
DATES does not Granger-cause Rain	2.506	0.096
Rain does not Granger-cause ONION	3.035	0.061
ONION does not Granger-cause Rain	5.121	0.011
Rain does not Granger-cause POTATO	2.468	0.099
POTATO does not Granger-cause Rain	6.640	0.003
Rain does not Granger-cause TOMATO	0.095	0.909
TOMATO does not Granger-cause Rain	0.940	0.400
Rain does not Granger-cause OLIVE	3.035	0.061
OLIVE does not Granger-cause Rain	5.121	0.011
Rain does not Granger-cause GROUND PEANUT	0.641	0.532
GROUND PEANUT does not Granger-cause Rain	6.110	0.005
Rain does not Granger-cause ORANGE	1.779	0.184
ORANGE does not Granger-cause Rain	0.703	0.501

*, ** represent $p < 0.1$ and < 0.05 respectively.

Conclusions and recommendation

In general, mean, minimum and maximum temperatures have increased significantly over the long term period (1945-2010) and the last short term (1976-2010), with considerable increases in minimum temperature over the last 33 years. However, negative trends prevailed at most stations during the first short term period (1945-1975) (Figure 5). For the rainfall, non-significant positive trends of annual rainfall totals were observed in the period (1945-1975), while significant negative trends were computed at all stations from (1976-2010).

Agriculture in Libya is one of the most sensitive sectors to climate variability and change, as the available water and land resources are limited and the most of the country's land is arid and semi-arid. Over the last three decades there has been a variability in temperature and rainfall were shown from the study. The granger causality approach showed that, there is a relationship between changes in a temperature and rainfall (weather parameters) and production of, onion, olive, dates, tomatoes, ground peanuts, orange and potatoes.

These empirical relationships should be used to forecast how production would change in different climate scenarios. Libyan authorities should pay more attention to the expansion of planting crop varieties that are resistant to drought and heat and focus on research aimed at developing such varieties.

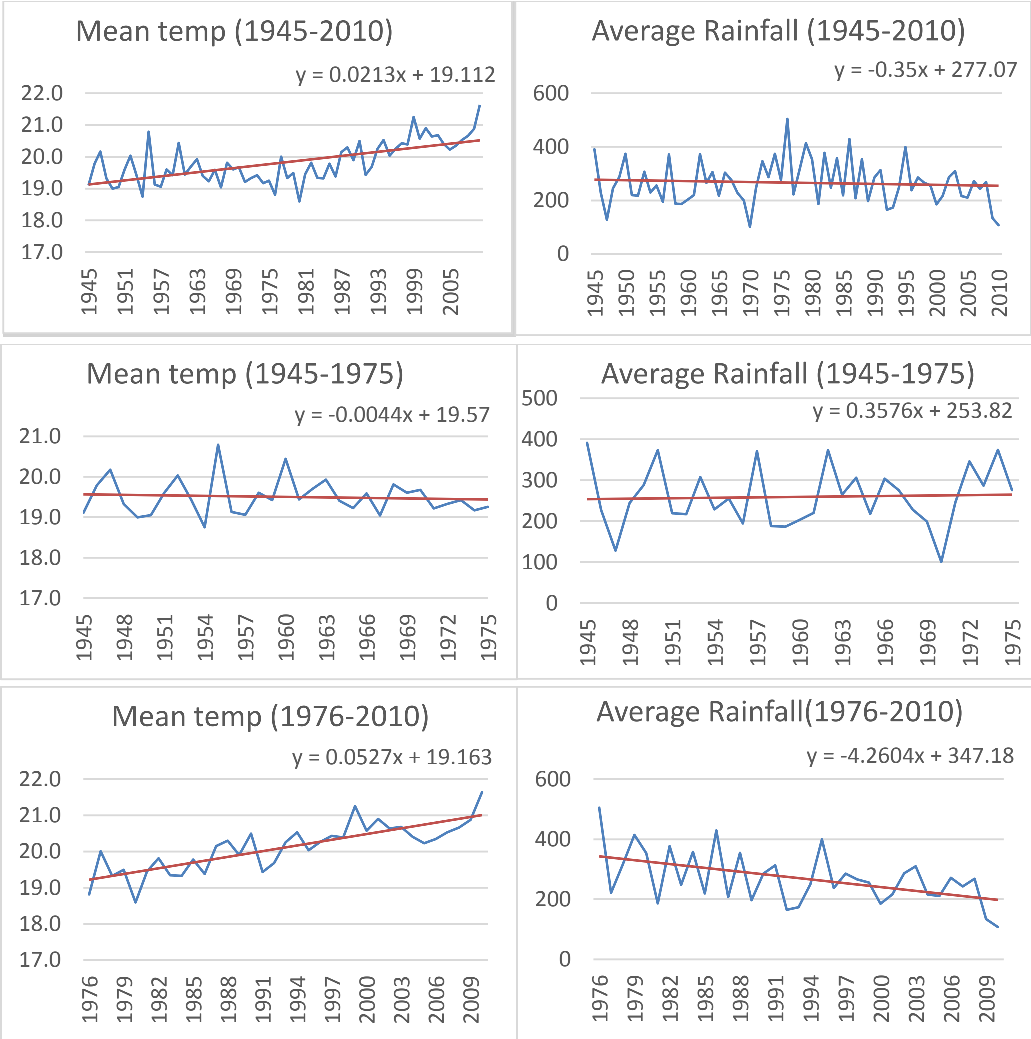

Figure 5: The trend of mean temperature and rainfall for different periods

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