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Research Paper

Assessment of wheat yields under climate change based on RCA4 model simulations in Tiaret region, Algeria

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ABSTRACT

This study focuses on analyzing the effects of rainfall and temperature variability on wheat production in the Tiaret region of Algeria and evaluating the future climate change and its impact on winter wheat yields. We analyzed the temporal variability of rainfall, temperatures and wheat yield using long term data. The future climate change projection data for two projected periods (2021-2050 and 2071-2099), under two representative concentration pathways (RCP 4.5 and RCP 8.5) were obtained from the Africa-Cordex regional climate model. The Pettitt test highlighted a decrease of 30% in annual rainfall during 1950-2020 and an increase of 1.3°C in maximum temperature from 1980 to 2020. The Pearson coefficient correlation showed a significant positive correlation between yields and mean rainfall and a negative significant correlation with maximum temperature. Future average yields estimated by multiple linear regression with rainfall and temperature showed that the yields will drop by 38% if no adaptation measures are undertaken.

Keyword: Climate change, Regional climate model, Wheat yield, Multiple regression model, Algeria.

Several studies have recognized that climate change is as a major factor impacting agricultural productivity, with far-reaching consequences for crop growth patterns and yields across diverse agro-climatic regions around the world (Tripathi *et al.,* 2016; Howden *et al.,* 2007), creating significant obstacles to achieving global food security (FAO, 2021; IPCC, 2021). Cereals play a critical role as primary and strategic crops due to their status as staple foods for a significant portion of the global population. With the global population expected to reach 9.8 billion by 2050, a substantial increase in cereal production, ranging from 70% to 100%, will be necessary to meet the food demands of this growing population. (Godfray *et al.,* 2010). Algeria's national cereal production reached 43 million quintals at the end of the 2019-2020 campaign, up from 27.6 million quintals in 2021. However, this production only partially covers the population's needs, estimated at 10 million tons (MADR, 2022).

Algeria has experienced an intense and persistent drought since 1975 which impacted the entire country particularly northwestern Algeria. Examination of time series data for precipitation indicates a disruption beginning in the 1970s, and the 1980s decade saw the most deficient levels of precipitation (Meddi *et al.,* 2010; Taibi *et al.,* 2017). Annual temperatures have also increased in Algeria by approximately 0.7°C since the 1980s (Taibi *et al.,* 2022; Zeroual *et al.,* 2017). In this context, it is imperative to study the impact of climate change on winter wheat yields in the semi-arid regions of Algeria, which serve as the country's primary cereal-producing zones which are vulnerable to climate variability due to its semi-arid conditions, making it a critical region for assessing the influence of climate factors on agricultural productivity. The multiple linear regression model is the most commonly statistical technique applied for analyzing the relation between wheat yields and agroclimatic parameters (Singh *et al.,* 2021; Dadhwal *et al.,* 2023; Gupta *et al.,* 2022; Aravind *et al.,* 2022).

Hence, our study is aimed to provide insights into how changing rainfall and temperature variability has influenced winter wheat yields in the Tiaret region in past and what would be the impact of climate change on wheat in future. An appropriate adaptive strategy

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can be taken to ensure sustainable cereal production in Algeria under the challenges posed by global climate change.

MATERIALS AND METHODS

Study location

Tiaret is located in the West part of Algeria at an altitude of 1,150 meters, with a climate characterized by two distinct seasons: a harsh winter and a hot, dry summer, with average temperatures reaching 37.2°C in summer and 24°C in winter. Under normal conditions, the wilaya receives 300 to 400 mm of annual rainfall, with seasonal fluctuations ranging from 157 mm in winter to 31 mm in summer. The agricultural sector is predominantly based on the “cereal-livestock” farming system, which plays a crucial role in agricultural production and economic growth. The steppe environment is characterized by high altitudes, with an average of 1,100 meters, where the highest steppes reach 1,300 meters, and the lowest range between 1,000 and 1,100 meters, indicating moderate elevation differences of less than 200 meters.

Data set

The monthly time series data of rainfall (1950 to 2020) and temperature (mean, min, and max) from 1983 to 2020 of Tiaret were obtained from the National Office of Meteorology (ONM). The wheat yield data were provided by the Tiaret Directorate of Agricultural Services (DSA). The future climate change data based on the simulation of the RCA4 model (Rossby Centre Atmosphere Model, Version 4) forced by the global circulation model MPI-ESM-LR under two climate scenarios (RCP4.5 and RCP 8.5) for two projected periods (2021-2050 and 2071-2099). were downloaded from the Cordex-Africa website with a resolution of 50 km (https://cordex.org).

Statistical analysis

To assess the temporal variability of rainfall and temperature during the observed period, the statistical test of Pettitt (1979) has been used. The Pearson correlation was worked between wheat yield and various climatic factors. Multiple linear regression was used to model the relationship between one or more independent (climatic) variables and a single dependent (wheat yield) variable by relating the observed input data to the resulting value through determining a linear equation which will relate the two (Fashoto *et al.,* 2021).

RESULTS AND DISCUSSION

Climate variability analysis

To analyze the temporal variability of rainfall and

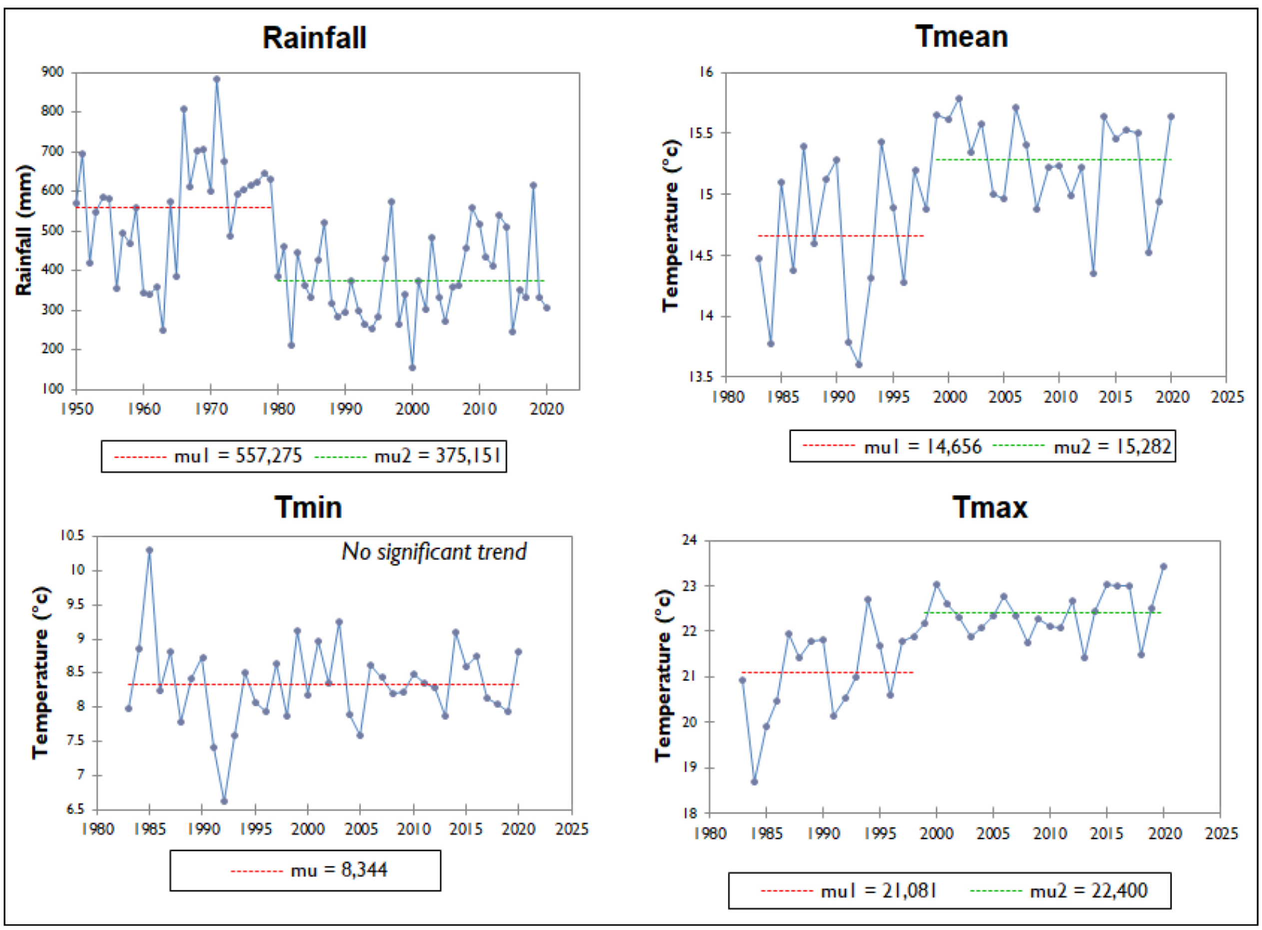

Fig. 1: Annual rainfall and temperature (mean, min, max) variability detected by the Pettitt test. The red line represents the average before the breakpoint, and the green line represents the average after the breakpoint. mu1 is the average before break and mu2 is the average after break point.

Table 1: Changes in monthly rainfall (%), mean temperature (Tmean, °C), maximum temperature (Tmax, °C) and minimum temperature (Tmin, °C) according to Pettitt test at α=5% significant level from November to June.

Months	Rainfall		Tmean		Tmax		Tmin	
	Break point	Rate change	Break point	Rate change	Break point	Rate change	Break point	Rate change
November	1979	- 52,83	-	-	-	-	-	-
December	-	-	-	-	-	-	-	-
January	-	-	-	-	-	-	-	-
February	-	-	-	-	-	-	-	-
March	-	-	-	-	-	-	-	-
April	1986	- 48,47	-	-	1998	2,07	-	-
May	1981	- 51,76	-	-	1997	1,92	-	-
June	1993	- 52,81	1997	1.7	1997	2,42	-	-

Table 2: Pearson correlation coefficient between yields and climatic variable (*significant values at α=5% significant level).

Variables	Wheat yields
Rainfall	0.50*
Maximum temperature	-0.41*
Minimum temperature	-0.01
Mean temperature	-0,27

temperature, the Pettitt test was applied to the annual and monthly time series. This analysis focused on the growth period of winter wheat, which spans from November to June. At the annual scale, the results showed a decrease of 30% in rainfall since 1980 and an increase of 0.6°C in mean temperature and 1.3°C in maximum temperature since 1999. Meanwhile, no significant change was observed in minimum annual temperature (Fig. 1). At the monthly scale, results showed a decrease of about 50% of rainfall during April and May, along with an increase of approximately 2°C in maximum temperature (Table 1). In June, the decrease of rainfall exceeds 50%. This is attributed to the low rainfall recorded during this month.

Effect of climate variability on wheat yields

The Pearson correlation coefficient analysis (Table 2) showed a significant positive correlation between wheat yield and annual rainfall (r = 0.50*) and a significant negative correlation with maximum temperature (r = -0.41*). The changes in rainfall and temperature significantly affect the phenological stages of crop development. During the flowering stage to maturity stage of wheat crops, the increase in temperature associated with a decrease in rainfall will cause reduced synthetic activity and CO_2 assimilation, impacting grain filling and causing a significant reduction in wheat yield (Beauvais *et al.,* 2019). Additionally, a high temperature increases evapotranspiration and affects negatively soil moisture.

Based on the significant correlation a multiple linear regression between wheat yields, rainfall (R), and maximum temperature (Tmax) was developed with the multiple correlation coefficient of R=0.71, indicating a moderate to strong positive relationship. The coefficient of determination (R^2) of 0.5 suggests that about 50% of the variation in wheat yields can be explained by the model. The equation for the multiple linear regression is as follows:

Yield (q ha^{-1}) = 0.024*R – 0.584*Tmax + 17.48 (R^2= 0.50)

This equation was further used to predict the wheat yield in future using climate change projection data.

Climate projection and impact on wheat yields

The climate change projection data indicated that under the RCP 4.5 scenario, a decrease in rainfall by 8% in 2050 and up to 14% by 2100 is projected. The increase in the maximum temperature of approximately 1.7°C by 2050 and around 3.3°C by 2100 have been projected. Under RCP 8.5, the model projected a decrease in rainfall of 22% to 40% by 2050 and 2100, respectively while temperature are expected to increase by 2°C to 4.9°C during mid and late century (Table 3). According to the projected future evolution of rainfall and temperature, the wheat yields are expected to decrease by approximately 7% and 16% by 2050 and 2100, respectively, under RCP 4.5 and 17% to 38% under RCP 8.5 (Table 3).

Climate change significantly impacts wheat development and growth, leading to reduced yields in various regions across

Table 3: Projected change in rainfall (%) and temperature (°C) and change in wheat yield (%) during two periods under RCP 4.5 and RCP 8.5

Variables	Mean values	RCP 4.5		RCP 8.5.	
		2021-2050	2071-2099	2021-2050	2071-2099
Rainfall (mm)	301.6	-8.0	-14.0	-22.0	-40.0
Maximum temperature (°C)	20.0	1.7	3.3	2.0	4.9
Wheat yield (q ha^{-1})	13.3	-7.0	-17.0	-16.0	-38.0

Africa (Knox *et al.,* 2012). Several studies have reported negative impact of climate change on wheat yield across the world (Wang *et al.,* 2018; Gammans *et al.,* 2017; Eruygur and Özokcu, 2016).

CONCLUSION

The findings of this study reveal several important insights into the impact of climate change on wheat yields in the Tiaret region. A significant rise in temperature and a reduction in rainfall have been observed. The analysis demonstrated a significant negative correlation between wheat yields and maximum temperature and positive correlation with rainfall. The model projected increase in temperature and decrease in rainfall under both RCPs 4.5 and 8.5 which would adversely impact the wheat yields in Tiaret and a reduction in yield by 17% to 38% by the end of the century is expected. These changes underscore the pressing need to address the vulnerabilities of wheat production systems to climate variability in Tiaret. It is imperative to implement effective adaptation measures to mitigate the adverse effects of climate change and enhance wheat yields.

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Data availability: Simulated data of Cordex regional climate model are available on the following website: https://cordex.org

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