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Impact of Climate Change on Cultivated Areas and Crop Yields for Cereals and Pulses in the Zaër Region (Morocco)

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ABSTRACT

On the one hand, this study assesses the evolution of climatological parameters in the Zaër region between 1986 and 2021 and, on the other hand, it studies the effect of climatic variations on cereal and leguminous crop yields between 2000 and 2020, in order to further elucidate the consequences of their fluctuations on crop yields and to mitigate their regression process by making it possible to analyze favorable adaptation strategies for agricultural systems that can be envisaged for the coming decades. The methodology is based on the use of trend curves and statistics (averages and standard deviations) to analyze changes in climatic parameters and their effects on yields. The results show that the average temperature in the Zaër region is set to rise from 19°C in 1986 to 22°C in 2020. Higher temperatures mean lower yields of rainfed cereals and pulses, and average rainfall varies between 330 mm in 1986 and 570 mm in 2021, with rainfall increasing the likelihood of crop failure in the short term and reducing production in the long term. In addition, the rainy season is short (4 to 5 months per year). These characteristics make Zaër's agriculture very sensitive to climate-related threats. Studying seasonal climate forecasts before each rainy season can help farmers to minimize rainfall hazards and thus optimize their crop yields.

Keywords: agriculture, climate change, semi-arid regions, crop yield, cultivated area.

INTRODUCTION

Morocco's agricultural sector, and more specifically the cereals and pulses sections, play a vital and central role in the Moroccan economy. Agriculture in the semi-arid of Zaër region has extremely diverse soils, but these are limited by water resources, which fluctuate greatly depending on climatic variability [CGIAR, 2009, Ndiaye et al., 2011]. Agriculture in the region is exposed to climate change [Giorgi, 2006], the effects of which on yields of non-irrigated crops are likely to become more pronounced now and, in the future, i.e., increased variability in agricultural production and reduced yields of the main crops (cereals and pulses) [Génin, 2016]. These climatic changes in the region show a rise in temperatures of 1 to 2°C and an increase in aridity. This study confirms the upward trend in temperatures during spring and summer, and also shows a drop from November to February, highlighting an insignificant decline in rainfall and its spatial and temporal variability. Similarly, trends in rainfall intensity and the duration of wet spells are heterogeneous, with the frequency of intense rainfall predominating. This reflects the nature of the region's semi-arid climate, which is characterized by cold days and nights and an increase in the number of hot days and nights. Rain-fed agriculture is therefore extremely sensitive to climate change [Douguedroit, Messaoudi, 1998], particularly in terms of the level of water resources and their variability (during the rainy season and from one year to the next). Agriculture is vulnerable to climate change, which threatens the future of agriculture and, above all, the methods used to characterize climate change. This also leads to a shift and reduction in plant growth periods, accompanied by degradation and loss of productive land.

The aim of this article is to address the issue of climate change, which is currently occurring and will continue to do so in the future, and its effects on agricultural yields and production in the Zaër region (study area). The study of seasonal climate forecasts before each rainy season can help farmers in the region to minimise rainfall hazards and thus optimise their agricultural yields.

METHODS

Study area

The Zaër region is part of the central Moroccan plateau, an agricultural area where rain-fed crops (cereals and pulses) are highly intensified. It has a Mediterranean climate, with cool, wet winters and hot, dry summers (Fig. 1). The rural communes covered by the study area had almost 69,978 inhabitants [RGPH, 2014] spread over a total area of 2015 km^2, giving an average density of 34.7 inhabitants per km^2. The distribution of the population by commune is uneven, showing a concentration in the commune of Merchouch with 39.1 inhabitants per km^2, further away is the commune of Moulay Driss Aghbal with a density of 22.4% inhabitants per km^2. The study region is characterised by rain-fed agriculture dominated by cereals and pulses. Agricultural activity is developed in the areas of: Had Brachoua, Merchouch, Aïn Sbit, Moulay Driss Aghbal and Jamaa Moullablad. The presence of cereal and pulse crops is required by the geology and geography of the study area, particularly since the region uses the bour as an irrigation system [El Omari et al., 2023]. It is therefore impossible to grow other crops on a large scale in the region. Cereals are mainly soft wheat, durum wheat and barley; pulses are mainly lentils, broad beans, peas and chickpeas.

Climatic data (rainfall and temperature)

The characterization of the climate of the study region and its evolution is based on the use of data from the Rommani meteorological station, located within the study region and having the following coordinates: latitude: 33°30’00’’N, longitude: 6°42’00’’ and altitude: 313m. These measurements were collected and supplied by the Office National du Conseil Agricole de Rommani (ONCA). The rainfall data are spread over a 35-year period between 1986/87 and 2020/21, and

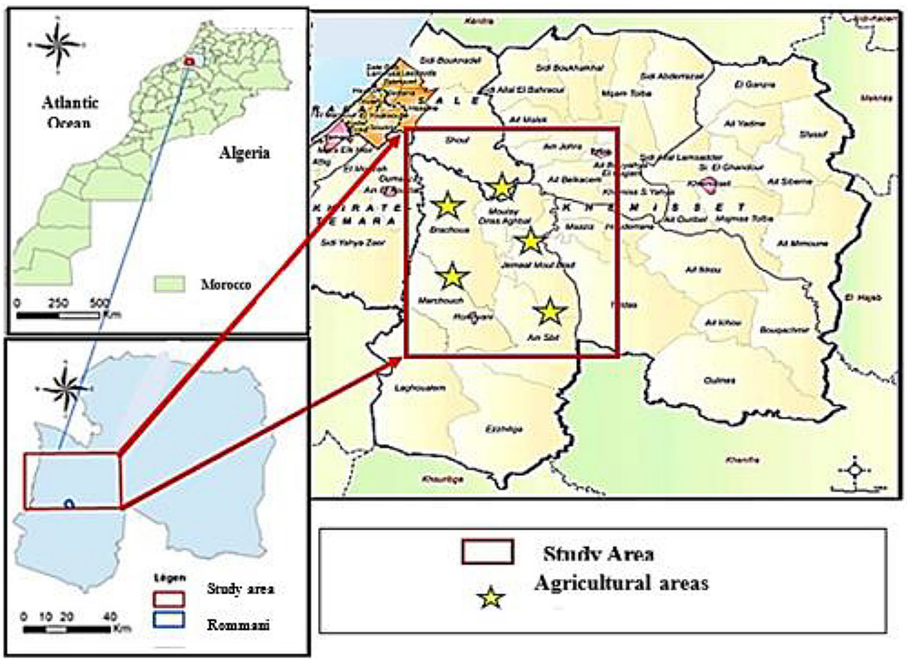

Figure 1. Map of agricultural areas studied in the Zaër region

the temperature data are spread over a 42-year period between 1979/1980 and 2020/2021.

Agricultural data

The agricultural data for the study area relating to rainfed crops are based on the agricultural yields of cereals (common wheat, durum wheat and barley) and legumes (lentils, broad beans, peas and chickpeas) recorded in the five village areas (Had Brachoua, Merchouch, Aïn Sbit, Jamaa Moullablad and Moulay Driss Aghbal) in the study area. Easily accessible data on cereal and pulse yields were obtained from the Office National du Conseil Agricole (ONCA). They concern yields at the time of harvest, which are calculated from samples taken in the fields over a period ranging from 2000/2001 to 2019/2020. The aim is to use these results to estimate crop yields in the future.

DATA ANALYSIS METHOD

Rainfall variability

Average monthly rainfall data for the study area are shown in Table 1, showing irregular rainfall from month to month.

Potential evapotranspiration (PET)

Potential evapotranspiration is determined by mathematical formulae. Several methods can be used, but Thornthwaite's (1948) method has the advantage of being simple and suitable for different latitudes. Table 2 summarizes the calculation of ETP (mm) for each month. To obtain the corrected ETP, the calculated ETP values are multiplied by a correction factor F (m, Φ) which is a function of month and latitude. The study region has a latitude of 33°30'00''N.

Actual evapotranspiration (AET)

AET is calculated using the Thornthwaite method [Thornthwaite, 1955] (Table 3). Water balance (WB) is the expression of the difference between rainfall (P) and potential evapotranspiration (PET) for a given soil over a given period, generally one month.

Aridity Index (De Martonne index)

The results of the calculation of this index are shown in Table 4 [De Martonne, 1942].

The Standardised Precipitation Index (SPI)

The SPI is therefore the most suitable means of rapidly detecting the phenomenon of drought [McKee et al.,1993].

Temperature

The average monthly temperatures recorded in the study region are shown in Table 5.

RESULTS

The rainy period in the Zaër region extends from October to April (Table 1, Fig. 2) and accounts for almost 90% of the precipitation recorded throughout the year, while the dry period

Table 1. Average monthly rainfall at the Rommani station and its contribution to average annual rainfall (1986–2021)

Month	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Precipitations (mm)	13.0	40.1	61.3	59.2	61.9	49.1	44.2	32.3	20.4	3.8	0.1	0.5
Contribution (%)	3.4	10.4	15.9	15.3	16	12.7	11.5	8.4	5.3	1	0.03	0.13

Table 2. Monthly potential evapotranspiration

Month	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
T(°C)	24.5	20.9	16.6	13.3	12.2	13.1	15.7	17	21.3	24.5	28	27.3
i (°C)	11.09	8.72	6.15	4.40	3.86	4.30	5.65	6.38	8.97	11.09	13.58	13.07
ETP (mm)	114.17	81.37	49.88	31.13	25.91	30.15	44.31	52.47	84.77	114.16	151.66	143.71
F (m, Φ)	1.03	0.97	0.88	0.86	0.88	0.86	1.03	1.09	1.19	1.20	1.22	1.15
ETP corrected	117.59	78.93	43.90	26.77	22.8	25.92	45.63	57.20	100.88	137	185.03	165.27

Table 3. Results of AET calculations using the Thornthwaite water balance method

Month	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
P (mm)	13	40.1	61.3	59.2	61.9	49.1	44.2	32.3	20.4	3.8	0.1	0.5
ETP (mm)	117.59	78.93	43.90	26.77	22.8	25.92	45.63	57.20	100.88	137	185.03	165.27
BH (mm)	-104.59	-38.83	17.4	32.43	39.1	23.18	-1.43	-24.9	-80.48	-133.2	-184.93	-164.77

Table 4. Evolution of the monthly aridity index in the study area

Month	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
P_m (mm)	13.0	40.1	61.3	59.2	61.9	49.1	44.2	32.3	20.4	3.8	0.1	0.5
T_m (°C)	24.5	20.9	16.6	13.3	12.2	13.1	15.7	17	21.3	24.5	28	27.3
I_m	4.5	15.6	27.7	30.5	33.5	25.5	20.6	14.4	7.8	1.3	0.03	0.16

Table 5. Average monthly temperatures recorded at the Rommani station (1986–2021)

Month	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
T. Max (°C)	33.9	29.9	24.8	20.8	19.9	20.3	24	24.9	30.3	34.1	38.2	37.2
T. Min (°C)	15	11.8	8.3	5.7	4.5	5.9	7.4	9.1	12.2	14.8	17.7	17.4
T. Moy (°C)	24.5	20.9	16.6	13.3	12.2	13.1	15.7	17	21.3	24.5	28	27.3

extends from June to September. The maximum rainfall is recorded in November and January, with 61.3 and 61.9 mm respectively, while the minimum is recorded in July and August (0.1 and 0.5 mm). Thus, there is an excess of precipitation during the winter and autumn and an aggravated deficit during the summer. This is confirmed by the interpretation above. The study region is characterized by an irregular distribution of seasonal rainfall, with abundant rainfall in winter (44.1% of annual rainfall), followed by autumn and spring, and a summer drought with just 4.4% of total rainfall (Fig. 3). According to Musset's indicator, the seasonal pattern is of the HAPE type (winter, autumn, spring, summer). A study of the annual rainfall totals recorded at the Rommani station shows that, over the period covered, rainfall has been scanty and irregular. The annual average is 385 mm, with a maximum annual value of around 707.2 mm recorded in 2009/2010, while the lowest cumulative rainfall was recorded in 1999/2000, with a value of 210.5 mm (Fig. 4). This analysis reveals six intervals of relatively long dry periods alternating with fairly short wet periods:

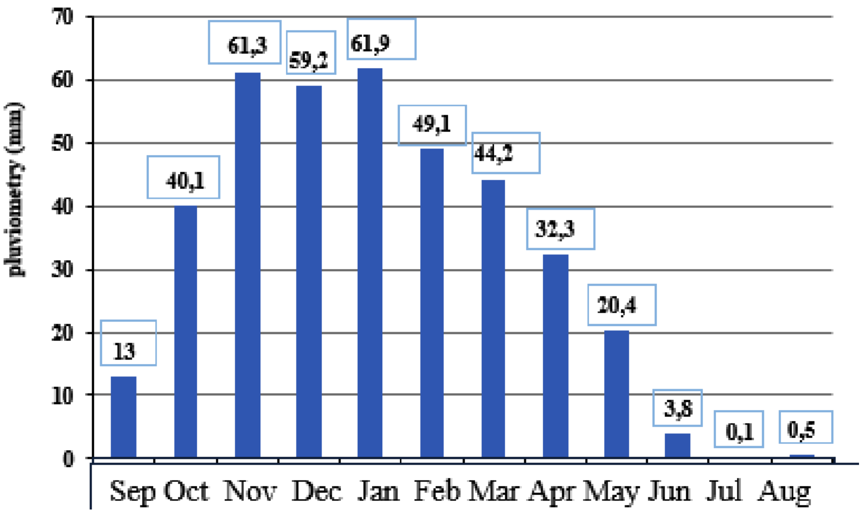

Figure 2. Average monthly rainfall in the Rommani region over the period 1986–2021

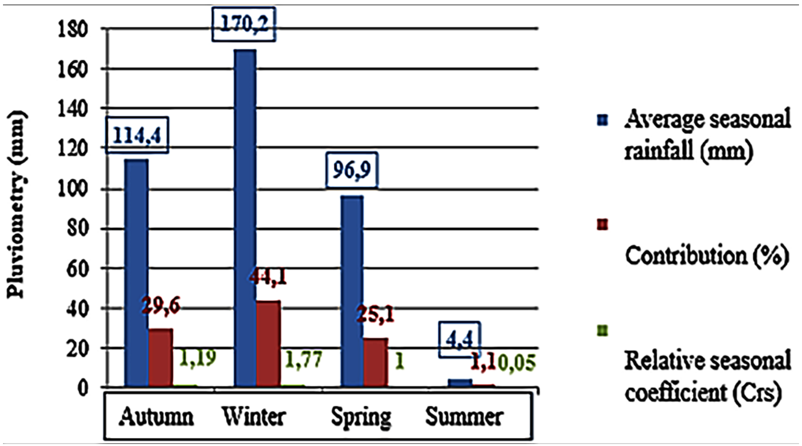

Figure 3. Seasonal distribution of rainfall and its contribution to mean annual rainfall in the study region between 1986/87 and 2020/21

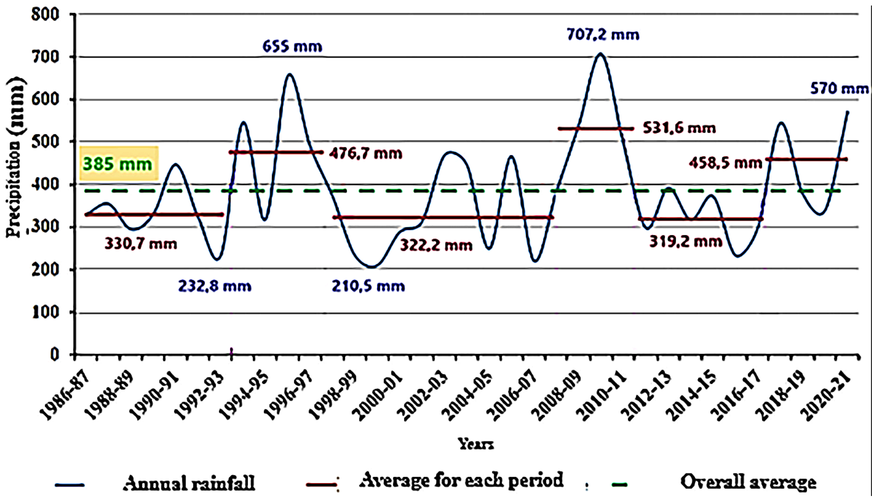

Figure 4. Changes in annual rainfall in the Rommani region over the period 1986–2021

- the first period spans 7 years, from 1986/87 to 1992/93. It was relatively dry, with average rainfall of 330.7 mm, and a minimum of 232.8 mm recorded in 1992/93;
- a second fairly wet period, lasting 4 years between 1993/94 and 1997/98. Rainfall averaged 476.7 mm, with a maximum of 655 mm recorded in 1997/98;
- a decade considered to be the driest the region has ever seen began towards the end of 1998 and continued until 2006/07. Despite a few years with little rain, rainfall generally fell sharply, averaging 322.2 mm, with a minimum of around 200 mm;
- the 4-year period between 2007/08 and 2010/11 can be considered the wettest the study region has seen. The average annual rainfall rose to 531.6 mm, with maximum rainfall of 707.2 mm recorded in 2009/2010;
- a new dry period lasting 6 years began in 2011/12 and continued until 2016/17, with average rainfall of around 319.2 mm;
- a final period considered wet, from the end of 2017 until 2021, despite fluctuations in rainfall rates, with a minimum of 340 mm recorded in 2019/20 and a maximum of 570 mm in 2020/21.

Analysis of ETP data

According to Table 2, PTE varies gradually over the year, with the lowest value in January (22.8 mm) and the highest in July (185.03 mm). The water balance, at -621.02 mm per year, reflects the climatic deficit and consequently an increased degree of drought. This will have an impact on agricultural yields in the region. The agricultural deficit extends over a six-month period (May to October) and peaks in July. This is the month when the ETP value is at its highest.

Analysis of ETR data

Actual annual evapotranspiration, at 373.79 mm, is close to the value of average annual precipitation (385.9 mm), with the result that the amount of water that runs off or infiltrates to feed the groundwater remains very low (12.11 mm/year). From Table 5, it would appear that in the case of our study region, with an average annual rainfall of 385 mm and an average annual temperature of 19.4°C, we obtain a degree of aridity equal to 13.1, which, according to De Martonne's classification, indicates a semi-arid climate, which will become arid over time as the region's climate changes [Gommes et al. 2009]. The months of June, July, August and September form an arid to hyper-arid period with an index of less than 5, which is related to the high temperatures and lack of rainfall. Aridity decreases during November, December, January, February and March, with high humidity in January, due to the drop in temperatures and heavy rainfall at this time of year (Fig. 5).

Analysis of SPI data

Figure 6 shows moderately dry, normal and wet episodes alternate with different frequencies and intensities. The drought begins when this index begins to be systematically negative and ends when it becomes positive. Over the 35 years analyzed, according to the [McKee et al., 1995] classification, there was a balance between dry and wet years, with 17% each, while normal years accounted for 66%. The most striking droughts in terms of their intensity, but which remain moderate, are those of 1998/99 and 1999/20. The wet

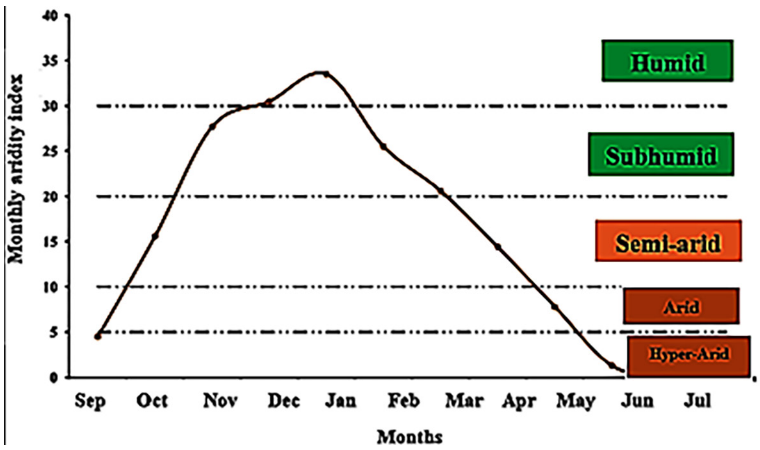

Figure 5. Monthly variation in aridity index

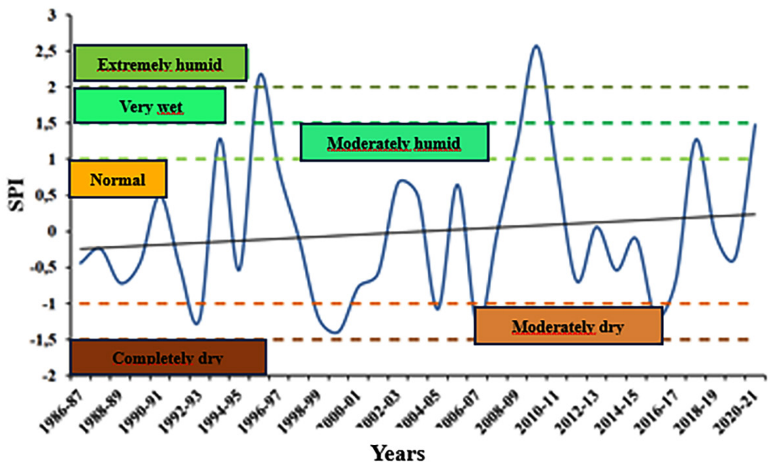

Figure 6. Evolution of the SPI index at Rommani (1986/87–2020/21)

to extremely wet periods span the years 1995 to 1997 and 2008 to 2011, with a remarkable peak of (+2.57) in 2009/2010. Over the period (1986–2021), the average monthly temperatures, shown in Table 5 and Figure 7, reveal that December, January and February constitute the coldest triplet, with a minimum of 4.5°C recorded in January. June, July, August and September are the hottest months, with a maximum temperature of 38.2°C recorded in July.

Analysis of temperature data

The average annual temperature at the Rommani station is around 19.4°C; the peak in annual temperatures was recorded during 2019/20, with a value of 22.5°C, while a minimum of 17.8°C was measured during 1991/92 (Fig. 8). Differences in average temperatures are generally moderate, but in reality, minimum temperatures can fall very low in winter, with a record of 0.3 in January 2000; very high maximum temperatures can also be recorded in summer, with a peak of 49.71°C in July 2021.At the Rommani station, analysis of the average, minimum and maximum temperature curves between 1986/87 and 2020/21 reveals four periods:

- an initial cool period, which began in 1986/87 and only eased after 1993/94. The difference in temperature compared with normal is estimated at -0.9°C. The average temperature during this period fluctuated around 18.5°C, with an average maximum of 26.6°C and an average minimum of 10.4°C. Extreme temperatures can reach 38.6°C and 2.8°C;
- a second warmer period, between the 1994/95 and 2002/03 agricultural years. The temperature difference from normal is estimated at +1.2°C. The average temperature for this period

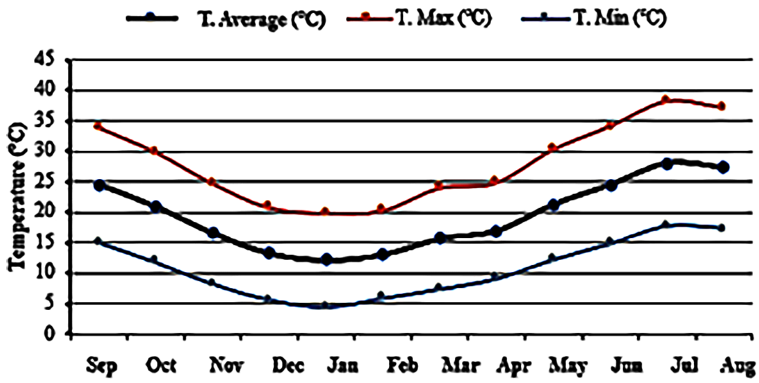

Figure 7. Monthly variation in average, minimum and maximum temperatures in the Rommani region over the period 1986–2021

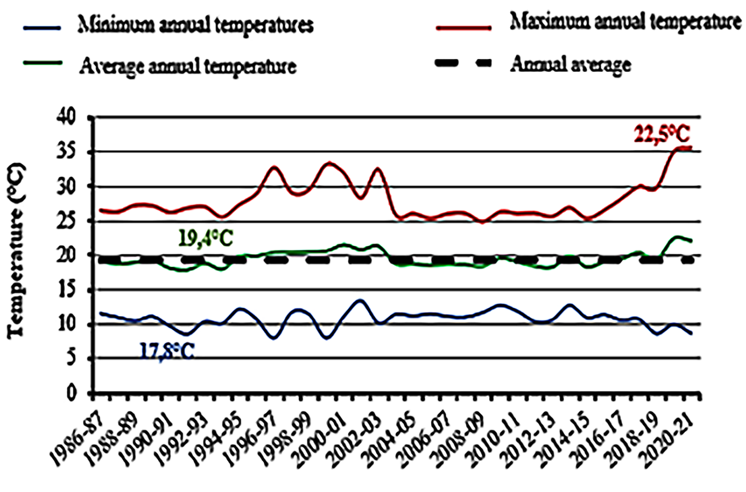

Figure 8. Trends in interannual minimum, mean and maximum temperatures at Rommani (1986/1987–2020/2021)

was 20.6°C, between an average maximum of 30.4°C and an average minimum of 10.8°C. The increase is most marked in the maximum temperatures, which are 3.80°C higher than in the previous period. Extreme temperatures can reach 46.2°C and 0.3°C;

- a third period, between the agricultural years 2003/04 and 2015/2016, marked by a drop in temperatures of 0.7°C compared with the average. The average temperature for this period is 18.7°C, between an average maximum of 26°C and an average minimum of 11.4°C. Extreme temperatures can reach 44.1°C and 0.5°C. The study carried out by Ouharba in 2015 [Ouharba et al., 2015] over the period 2003/2008 confirms the irregularity of monthly average temperatures, in line with the results obtained.
- the latest period, from 2016/17 to 2020/21, is characterized by a warming of 1.3°C compared with the average. The average temperature for this period is 20.7°C, between an average maximum of 31.7°C and an average minimum of 9.8°C. The warming is most marked in the maximum temperatures, which rise by an average of 5.7°C. Extreme temperatures can reach 49.7°C and 2.4°C. Overall, the temperature rose by an average of 2.2°C between 1986/87 and 2020/21 (Fig. 9). An increase in temperature can accelerate the decomposition of organic matter in the soil, reducing its carbon stock and, consequently, its fertility. The physiological response of the crop to a rise in temperature sometimes results in a shortening of the length of its development cycle and hence a drop in crop yield [Bellia, 2003].

Changes in cultivated areas and agricultural yields

Cereals (common wheat, durum wheat, barley)

Common wheat yields fell while the area under cultivation increased in the Zaër region. Common wheat yields fell from 10.64 tons per hectare, i.e., 44.16% below the average for the 2000–2001 decade, to 4.62 tons per hectare, i.e., 27% below the average for the 2019–2020 period. The region saw an increase of 30.4 tons per hectare, or 12% less than the average for the decade 2013–2014. The area under soft wheat increased from 5,400 hectares, i.e., 34% below the average for the 2000–2001 decade, to 7,400 hectares, i.e., 40% below the average for the 2019–2020 period (Fig. 10). Wholesale durum wheat yields have been rising for years, while the area under cultivation has been falling in the region. Durum wheat yields fell from 10 tons per hectare, i.e., a deviation from the average of 40.46%, to 4.32 tons per hectare, i.e., a deviation from the average of 15.21%, during the period 2000–2001. Durum wheat yields reached a maximum of 23.6 tons per hectare, i.e., a deviation from the average of 16.30%, during the period 2014–2015. The area under durum wheat fell from 1,600 hectares, or 40.74% below the average, in 2000–2001 to 1,000 hectares, or 40.71% below the average, in 2019-2020. This indicates that in order to deal with the decrease in water supplies and changes in the areas that are suitable for growing cereals, we must improve our ability to adapt rain-fed crops in the Zaer region.

Barley yields have fallen while the area under cultivation has increased. In the Zaër

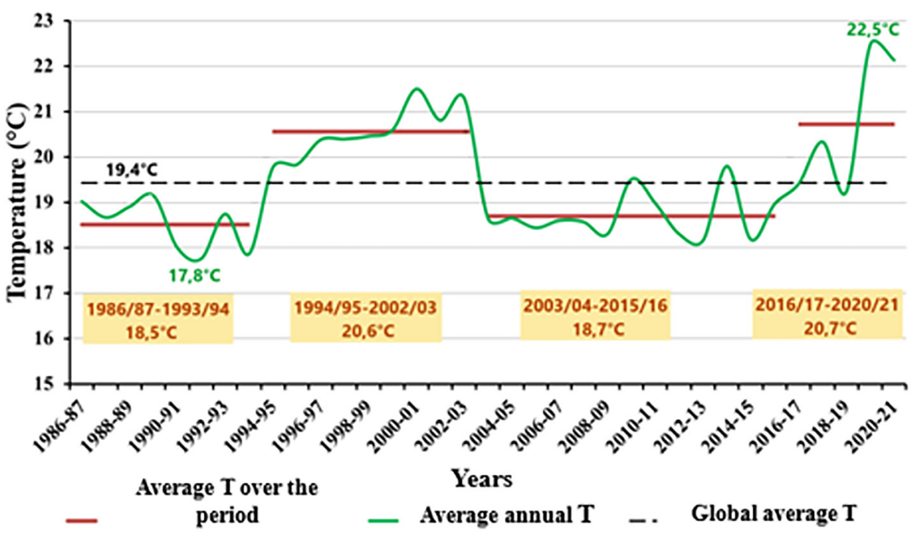

Figure 9. Variation in average temperatures in the Zaër region (1986–2021)

region, barley yields fell from 14.29 tons per hectare, i.e., 18.84% below the average for the 2000–2001 decade, to 4.32 tons per hectare, i.e., 16.23% below the average for the 2019–2020 period. The highest barley yield recorded for the 2012–2013 decade was 28 tons per hectare, i.e., 4.37% below the average. The area under barley increased from 1,800 hectares, or 43.03% less than the average for the 2000–2020 decade, to 2,000 hectares, or 35.76% less than the average for the 2019–2020 period.

Pulses (lentils, broad beans, peas and chickpeas)

For lentils, yields are falling while the area under cultivation is increasing. In the Zaër region, lentil yields fell from 10.7 tons per hectare, i.e., a 36.7% deviation from the average during the 2000–2001 decade, to 2.64 tons per hectare, i.e., a 36.12% deviation from the average during the 2019–2020 period. 17.2 tons per hectare, i.e., a 4.86% deviation from the average, is the highest yield recorded in the region during the 2007–2008 decade (Fig. 11). The area under cultivation increased from 1,880 hectares, i.e., 68.7% below the average for the 2000–2001 decade, to 1,845.7 hectares, i.e., 56.58% below the average for the 2019–2020 decade. Bean yields fell, as did the area under cultivation in the Zaër region, from 11.2 tons per hectare, i.e., 20.36% below the average for the 2000–2001 decade, to 1.71 tons per hectare, i.e., 31.47% below the average for

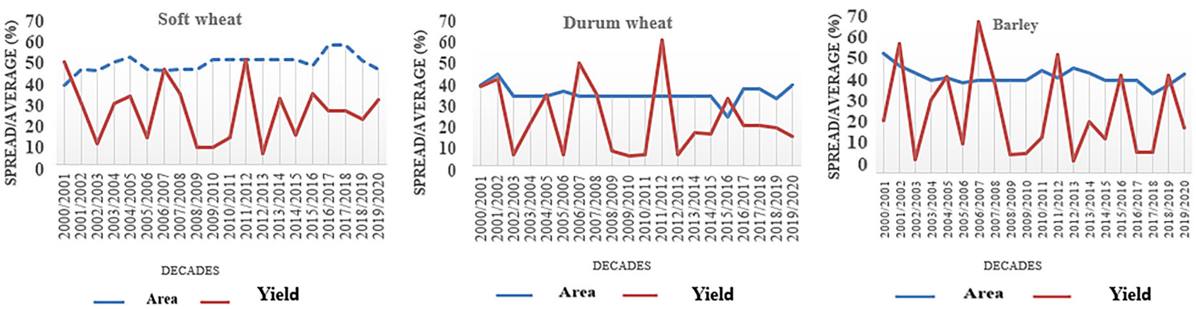

Figure 10. Areas sown and cereal yields in the Zaër region (2000–2020)

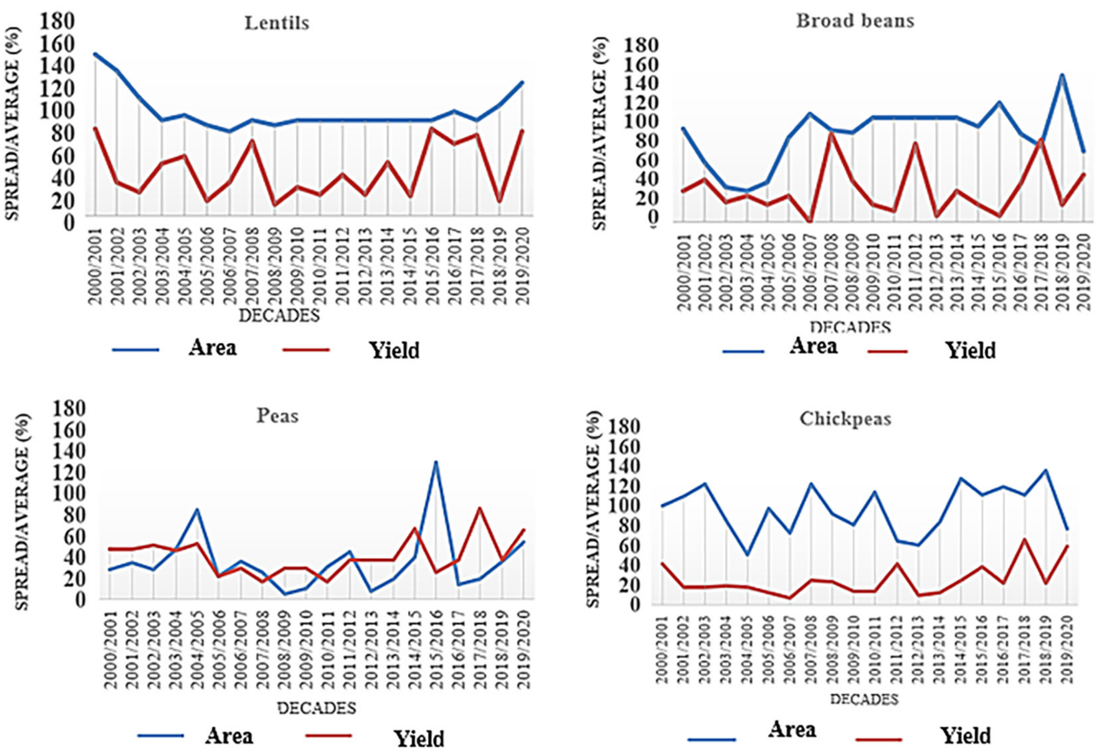

Figure 11. Areas sown and yields of legumes in the Zaër region (2000–2020)

the 2019-2020 period. The highest yield recorded in the region for the 2017–2018 decade was 14.5 tons per hectare, i.e., 54% below the average. The area under cultivation fell from 500 hectares, or 61.64% below the average for the 2000–2001 decade, to 64 hectares, or 46.81% below the average for the 2019–2020 decade (Fig. 11). Pea yields fell, as did the area sown to the crop in the Zaër region. Yields fell from 7.9 tons per hectare, i.e., 38.19% below the average for the 2000-2001 decade, to 1.04 tons per hectare, i.e., 71.69% below the average for the 2019–2020 decade. Between 2009–2010, a high value of 13.68 tons per hectare was recorded, i.e., 7.53% below the average. The area under cultivation fell from 320 hectares, or 64% below the average, in 2000–2001 to 95.65 hectares, or 87.19% below the average, in 2019–2020 (Fig. 11). More recently, yields of chickpeas have fallen, as has the area under cultivation. Yields have fallen from 3.2 tons per hectare, or 26.14% below the average for the 2000–2001 decade, to 2.07 tons per hectare, or 36.79% below the average for the 2019–2020 decade. The area under cultivation fell from 460 hectares, or 62.62% below the average for the 2000–2001 decade, to 369.49 hectares, or 48.03% below the average for the 2019–2020 decade (Fig. 11). Since legumes' crop cycle occurs between late winter and spring, they will be significantly more impacted such as chickpeas (François et al., 2016).

Impacts of rainfall and temperature variability on agricultural yields

Agricultural production in the rainfed region of Zaër is subject to strong inter-annual fluctuations in rainfall. An analysis of yields shows the irregularity of average soft wheat yields over the aforementioned crop years [Ouharba et al., 2015]. Agricultural forecasting methods used mainly meteorological variables, based essentially on two variables, temperature and rainfall, because these two variables are closely related to crop needs and can be easily obtained from weather stations The average yields of cereals and pulses in relation to rainfall and temperature in the Zaër region between 2000 and 2020 are shown in the graph (Fig. 12).

Figure 12 shows that yields will systematically fall as a result of the scarcity of rainfall resources and the rise in temperatures from 18°C in 2014/2015 to 22°C in 2019/2020, with increasing differences between yields and climatic factors. poor weather conditions, which cause suffering and exhaustion linked to the formation and filling of grains before they flower. The only negative impact on simulated yields observed was a 2°C increase in temperature.

The moderate correlations between rainfall and crop yields are confirmed by the values of the coefficient of variation (R^2). In fact, the coefficients of variation are closer to 1 than to 0, and they are moderate and almost equal in value in all the agricultural zones of the region and for all the cereal crops. On the other hand, negative correlations are recorded for temperature, which corresponds to temperature values increasing as yields decrease. The moderate values of the coefficients of variation show that there is virtually no correlation between cumulative annual rainfall and the yields obtained in the five agricultural zones of Zaër. In other words, in our study area, the influence of rain on agricultural yields, although it exists, is moderate to weak. Good yields require good production factors, the case of chemical or organic fertilizers, agricultural equipment, the absence of quality seeds, and so on, prevent and limit agricultural yields in the study area. Not forgetting that soil fertility plays a vital role in production capacity (Table 6).

Strong correlations between rainfall and crop yields are confirmed by the coefficient of variation (R^2) values. Indeed, the coefficients of variation are closer to 1 in all the agricultural zones of the region and for all the leguminous crops. On the other hand, negative correlations are recorded for temperature, which corresponds to temperature values that increase as yields decrease the high coefficients of variation for beans and peas show a correlation between cumulative annual rainfall and yields in the five agricultural zones of Zaër. In other words, in our study area, the influence of rain on agricultural yields, although it exists, is medium to strong. The mean values of the coefficients of variation were found for lentils and chickpeas (Table 7).

Statistical analysis

Statistical analysis has enabled a summary to be drawn up of cereal and pulse yields between the main producing communes in the region studied.

Table 8 shows that the highest average cereal yield in the Zaër region is that of common wheat, with the highest coefficient of variation (43.21%), and the highest average legume yield is that of lentils, with the highest coefficient of variation

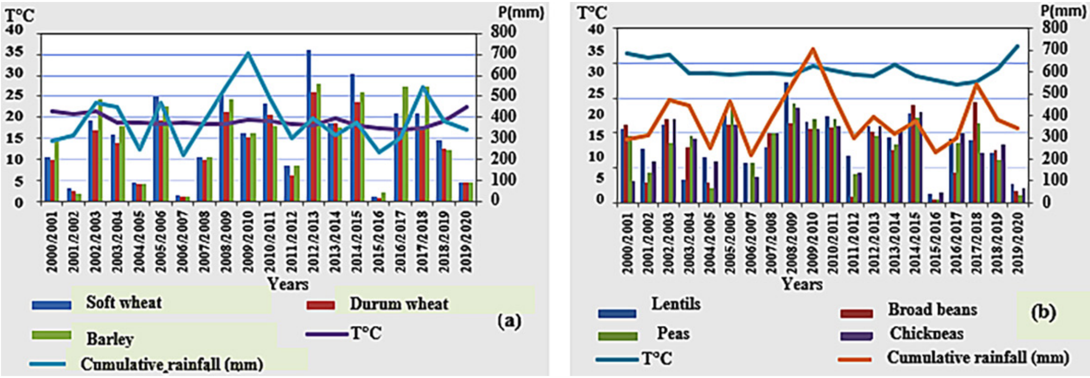

Figure 12. Evolution of yields (QT/HA) of the three cereal varieties (a) and the four leguminousvarieties (b) in relation to average rainfall and temperatures in the Zaër region (between 2000 and 2001)

Table 6. Comparison of correlation coefficients of cereals (the five main agricultural zones of the Zaër region)

Parameter	Soft wheat	Durum wheat	Barley	T°C	Cumulative rainfall (mm)
Soft wheat	1.00				
Durum wheat	0.99	1.00			
Barley	0.95	0.96	1.00		
T°C	-0.31	-0.30	-0.34	1.00	
Cumulative rainfall (mm)	0.66	0.57	0.51	-0.03	1.00

Table 7. Comparison of correlation coefficients of pulses (the five main agricultural zones of the Zaër region)

Parameter	Lentils	Broad beans	Peas	Chickpeas	T°C	Cumulative rainfall (mm)
Lentils	1.00					
Broad beans	0.74	1.00				
Peas	0.81	0.86	1.00			
Chickpeas	0.77	0.72	0.80	1.00		
T°C	-0.07	-0.05	-0.30	-0.25	1.00	
Cumulative rainfall (mm)	0.56	0.70	0.72	0.61	-0.03	1,00

(13.20%). The study confirms the direct links between rainfall and agricultural production in the Zaër region.

DISCUSSIONS

The rainfall study reveals that annual rainfall is low and irregular. The annual average is 385 mm, with very significant inter-annual fluctuations, alternating between relatively long periods of deficit and fairly short periods of surplus. Exceptional rainfall was recorded in the 1995/96 and 2009/2010 agricultural years, with 655 and 707.2 mm respectively, while the lowest total rainfall was recorded in 1999/2000, at 210.5 mm. According to the Musset indicator, the seasonal rainfall pattern is of the HAPE type (winter, autumn, spring, summer), with an excess of rainfall in winter (44.1%) and an aggravated deficit in summer (4.4%). Average monthly rainfall is irregular from one month to the next, with the highest level recorded in January (61.9 mm) and the lowest in July (0.1 mm). The rainy period extends from October to April, and accounts for almost 90% of the year's rainfall [Moussadek et al., 2011]. Temperature monitoring during the series of observations reveals a temporal irregularity in this climatic factor. With alternating cool and hot periods, the average maximum temperature is a clear indication of this. The average annual temperature at the Rommani station is around 19.4°C, with a peak of 22.5°C recorded in 2019/20, while a minimum of 17.8°C was measured in 1991/92. Average monthly temperatures show that January is the coldest month (4.5°C), while July is the hottest (38.2°C).

Table 8. Descriptive statistics of yields and pulses in the Zaër region

Commune	Average yield (QT/HA)				Average pulses (QT/HA)		
	Soft wheat	Durum wheat	Barley	Lentils	Broad beans	peas	Chickpeas
Had Brachoua	19	15	18	10	7	9	9
Aïn Sbit	16	14	16	9	9	8	8
Merchouch	17	14	16	9	8	9	9
Jamaa Moullablad	12	10	13	7	7	7	7
Moulay Driss Aghbal	14	12	14	8	7	8	8
Standard deviation	6.72	5.58	6.51	1.16	0.73	0.75	0.68
Average	16	13	15	9	8	8	8
Coefficient of variation	0.43	0.42	0.42	0.13	0.09	0.09	0.08
Coefficient of variation en%	43.21	42.67	42.18	13.20	9.59	9.22	8.34

By combining the various climatological parameters, the umbrothermal diagram shows that the dry period extends over seven months, between April and October. From a bioclimatic point of view, the study region lies at the boundary between the semi-arid and arid bioclimatic stages with temperate winters. Whereas the De Martonne and UNEP aridity indices show that the climate is semi-arid. Calculation of the Standardised Rainfall Index (SPI) has made it possible to determine the intensity and frequency of the dry periods that have affected the region during the 1986/87–2020/21 sequence. The results show a slight upward trend in this indicator. Normal years dominated in terms of intensity, with a frequency of 66%; dry periods were qualified as moderately severe, with a frequency of 17%, the most notable being 1998/99 and 1999/20; while wet to extremely wet years, also with a percentage of 17%, were spread over the years 1995 to 1997 and 2008 to 2011, with a remarkable peak in humidity in 2009/2010. The succession in time and space of dry and wet years certainly influences agriculture and crop yields. But despite all these fluctuations, the climate in the study region remains favorable to agricultural development for the time being [Bahir et al., 2016]. The five communes show the same variations in yields as a function of rainfall. In the analysis of climatic variability and its influences on agricultural yields in the Zaër region [Mekkaoui et al., 2021], the results showed that climatic variability manifests itself through a standardized spatio-temporal dynamic of annual rainfall, and that the correlations between yields and rainfall are not all as high as expected. Indeed, [Barakat, Handoufe., 1998] confirm the effect of accumulated rainfall deficit on yield decline. This study shows that rainfall is highly variable in space and time. During the periods from 2000 to 2007 and from 2016 to 2020, an increase in rainfall led to a systematic increase in biomass yields, while a decrease in rainfall led to a decrease in yields.

As far as the climate-yield relationship for cereals is concerned, higher temperatures and, above all, lower rainfall have led to production shortfalls since the 2000s. [Elkriti, 1976] and Papy (1979) demonstrated the correlation between rainfall and straw cereal productivity. If we regress the yield of the various cereal species (soft wheat, durum wheat and barley) on cumulative rainfall, we see that there is a linear and positive relationship, up to a rainfall level of around 540.3 mm. Rainy companions, where rainfall exceeds 540 mm, are rare, with the exception of 2009/10 with an average of 707 mm and 2017/18 with an average of 544.5 mm. Added to these results is the effect of temperature on evapotranspiration, which can increase water consumption and accelerate drought. Cumulative rainfall shows more frequent steps, indicating drought years with poor yields recorded as in the case of the agricultural years: 2001/02, 2004/05, 2006/07, 2011/12, 2015/16 and 2019/20, and rainy years with optimum yields during the agricultural years: 2002/03, 2005/06 and in 2017/18. The 2008-2011 crop years are special in that rainfall reached its maximum (707.4 mm), but yields are estimated to be lower than expected. This is essentially due to the rise in temperature to 1°C, which will reduce the length of crop cycles and increase water stress through increased evaporation, leading to drought. In fact, it is during the phase of rapid biomass accumulation that the demand for water per crop is high, and this phase also corresponds to the rise in temperature mentioned above, which will result in an increased demand for water. During this phase, drought has consequences for yields in the study region [Moussadek et al., 2011]. The 20012/13 and 2014/15 crop years had the highest yields, despite average rainfall and temperatures equivalent to those of previous years. This was due to rainfall in November and January, February and March. This highlighted the importance of rainfall in these months for plant growth and development. In fact, this can be explained by the ease of access to high-yielding varieties, the presence of quality seeds, farming equipment, chemical or organic fertilisers, and so on, all of which boost yields. In addition, agricultural yields are also determined by the action of insects and parasites, which are abundant in these agricultural years. Soft wheat and barley are the main crops grown in the Zaër region between 2000 and 2020 [Moussadek et al., 2011]. As for legume varieties, we can see that they are closely linked to variations in rainfall, and broadly follow the same trend. Yields fell dramatically during the 2006/07, 2011/12, 2015/16 and 2019/20 crop years, which coincided with periods of drought for cereals. The crop years with the highest yields were 2005/06, 2008/09 and 2014/15, due to the heavy rainfall during these periods, while the highest yields were recorded for lentils and chickpeas during the period from 2000 to 2020.

The robustness of the rainfall results classifies the yields of cereals and legumes in Zaër as vulnerable to climate change over the coming decades. We learn that for cereal varieties and pulses, warming (+1.5°C) will inevitably have negative effects on yields, while increased rainfall can mitigate these effects [GIEC, 2001]. Yield and rainfall trend analyses for the Zaër region between 2000 and 2020 are presented in Table 11. It is clear that there is a significant variation in temperature over the period, with a coefficient of variation of around 7%. With a coefficient of variation of around 31% for rainfall, the variation is very high. For cereals, the coefficient of variation is around 59%. The World Bank's study on Morocco produced the WB/FAO/INRA/DMN report, which contains these findings [Gommes et al. 2009]. For legumes, the coefficient of variation is around 50%. It is important to note that various studies have shown that yield variability is not only explained by temperature and rainfall, but can also be explained by technology, the seed varieties used and biological activity in the soil [Belaid et al., 2012]. The results of our study show that the semi-arid region of Zaër should be taken into consideration when targeting government agricultural development measures in Morocco, due to the low rainfall and high temperatures, which have a negative impact on cereal and pulse yields [Ja et al., 2019].

CONCLUSIONS

Climate change in the region points to a temperature rise of 1 to 2°C and an increase in aridity. Consequently, in order to mitigate this impact, particularly for rain-fed crops, adaptation options have been selected to enable farmers to understand these measures and limit the impact of climate change on their crops. Faced with the water stress experienced for decades, it is time for farmers to think in two directions: either resist climate change and adapt their cropping systems (bour), in particular by overhauling the traditional agricultural calendar and optimizing sowing dates in line with climate change. It is time for Morocco to focus on innovating varieties that are adapted to drought, have regular yields and are disease-tolerant, such as: barley or wheat varieties with an emergence-flowering cycle of less than 100 days ($\Sigma\theta°J < 900°C$), such as Amalou, Arrehane and Rumax [Sonacos, 2016] because e the length of the emergence-flowering or emergence-maturity cycle would be reduced by global warming, as some simulations on Morocco have already shown [Benaouda, Balaghi, 2009].

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