

Rainfall Trends in Semi-Arid Cereal Regions of Algeria

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Received : 20/12/2020

Final Revision : 9/1/2021

Abstract. The study focuses on rainfall, number of rainy days and droughts, on an annual time step basis, over the period (1940-2019). Each parameter is analysed by the average behavior of 1,817 variables representative of 23 semi-arid wilayas. The approach helps to characterise the rainfall climate of cereal-growing regions, where production and yields per hectare are unstable for decades. The average rainfall, estimated at 423 mm, shows a cyclical evolution, reflected by a change in averages: 430, 405, 440 mm. These averages reproduce two relatively rainy cycles (1940-1970) and (2000-2019), separated by a dry cycle (1970-2000). The frequency of cyclical rains, however, shows that rains above 400 mm remain less dominant over 79 years. The averages of observations decrease progressively with the increase of the quantities of rains, that is to say, percentages that do not exceed 14, 13 and 9%. These characteristics underline interannual droughts, which fluctuate between 0.8 and -2.5, showing a progressively decreasing number of rainy days. The results obtained do not seem to explain all the variations in cereal production and yield. However, the correlation coefficients below 35% reflect the efficient use of rainfall during the crop growth cycle, which is subject to other production factors.

Keyword: Region, rainfall, rainy days, drought, production.

I. INTRODUCTION

Agriculture in Algeria remains the mainstay of the country's economy, providing nearly 60% of jobs, particularly in rural areas [1,2]. These regions, which belong for the most part to the territory classified as semi-arid, mark the eastern and western plains of the country, dominated by extensive rain-fed cereal cultivation. Cereal crops cover an average area of 2.5 million hectares (ha) according to the Agricultural Statistics Bulletin [3]. According to [2,4], only 30 to 40% of the usable agricultural area (UAA) receives more than 400 mm of rainfall per year. Cereal farming, which is largely dependent on this quantity, is very vulnerable to stable production. In its best year (2010), it produced only 44 million quintals (Mq), a yield per hectare equivalent to 17 q [3].

According to the [5], the weighted rainfall index for agricultural land is 241.5 mm for Algeria and 287.5 mm for Morocco, compared with 190.32 mm for Mauritania and 326.1 mm for Tunisia. Drought is thus reflected in the lack of rains or excessive rains posing a threat to cereal production in the country. In the Mediterranean region, the lack of rainfall causes between 10 to 80% of yield losses [6,7], attributes these variations to the water deficit, which can be estimated through the definitions of droughts. [8], also notes that the decline in wheat grain yield is variable depending on the variety, the intensity in addition to the duration of the water stress. These situations remind us that drought is a large-scale phenomenon, which varies from one climatic regime to another, even if its extent and intensity vary on a seasonal or annual time scale [8,9].

In spite of the various works, at the crop level, the drought remains poorly defined. [10] notes, however, that the water deficit common to all definitions can be used as a criterion for analysis. In Algeria, studies relating [11-13] to the evolution of rainfall, associated with water deficits or droughts in relation to cereal growing, are very rare. Their interests are all the more important in this context marked by climate change and the rise in the price of cereal products.

With this in mind, this research recommends an analysis of these parameters over a 79-year history, on the scale of the semi-arid regions of Algeria.

II. MATERIELS AND METHODS

• Study region

The study considers semi-arid regions, divided into 23 wilayas or departments. The wilayas, which represent the Tellian highlands from the east to the west of the country, are located between latitudes 34° and 37° North and longitudes -1° and 9° East. Their territorial surface area, equivalent to 228 877 km², or 22 887 700 ha, covers rain-fed cereal growing, equivalent to an average of 2.5 million hectares (Mha), or 11.3% of the total (Fig. 1).

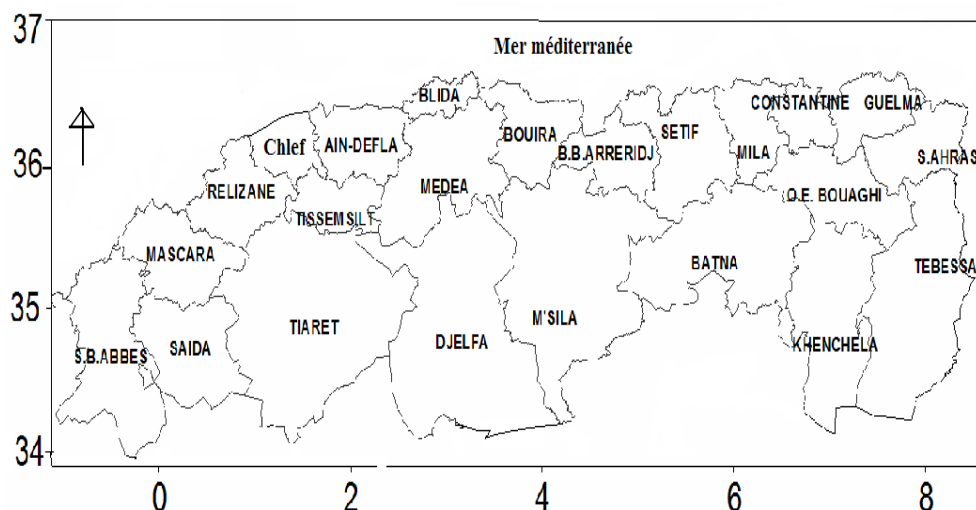


FIGURE 1. Geographical distribution of the semi-arid regions of Algeria.

• Rainfall data

The series of rainfall data considered over the period (1940-2019) belong to the stations of the National Meteorological Office (NMO). The stations, 23 in number, are represented by daily rainfall series, whose number of rainy days is greater than or equal to 0.1 mm ($R \geq 0.1\text{mm}$). The time step chosen attempts to highlight a rainfall database represented by the quantities of rainfall, the number of rainy days, in relation to drought indices, on an annual scale (September to June), in this context of climate variability and change in cereal-growing regions (79×23).

• Agricultural data

Each cereal-growing wilaya in the country is provided with data on areas sown, production and annual yields. The data collected from archive documents and Agricultural Statistics bulletins [3] have enabled the construction of databases over the period (1940-2019).

• Evaluation of rainfall and number of rainy days by statistical models

Rainfall in each wilaya over the period (1940-2019) is analysed, with reference to the stochastic model, based on the Markov chain of order 1 [14-17]. The starting hypothesis takes into account the annual count of rainy days (rd) from September to August. The rainy days considered refer to the rainfall threshold greater than or equal to 0.1 ($R \geq 0.1\text{mm}$). The choice of this threshold is related to the local climate and the first rains that occur in autumn, after three months of drought (June, July and August), referring to the definition of [9,18].

The principle of analysis, simulates a rainy state (all values of $R \geq 0.1\text{mm}$), by the number (1) and a dry state (all values of $R \leq 0.1\text{mm}$), by the number (0). The designed series matrices then have only values equal to one (1) and zero (0). This change contributes to the determination of annual droughts by recalling that for a Markov chain of order 1, the state of the variable (rain) at time (t) depends only on its state at time (t-1) [19]. The approach has enabled the construction in the laboratory, for each wilaya, of annual data series relating to rainfall amounts (R_i mm) and the number of rainy days per year (rd). The numerous results made it possible to synthesize for each parameter a number of variables (N), equivalent to 1817 cases (79×23).

The annual rainfall (mm) and the number of rainy days are then analyzed by: means (R_{AM}), minimums (min), maximums (max), standard deviations (SD), variances (V), coefficients of variation (CV), medians (R_{Med}) which remain references to compare rainfall between the 25% and 75% quartiles. And finally, by the frequencies characterized by an observation frequency (N) and a relative frequency (F) in %, calculated by dividing the frequency (N) by the number of years. According to [20,21], the statistical parameters used contribute to quantifying the

variability and changes that take place; as they help to choose the most appropriate rainfall trend model. The time step analyzed is interannual, periodic and decennial.

The statistical model chosen is a polynomial regression of order '3' (Eq. 1). It is a simple model that refers to two variables (R, Y), who's variable to be explained is high to increasing power.

$$Y = b_0 + b_1R_1 + b_2R_2 + b_3R_3 \quad (1)$$

The regression equation (Eq. 1), allows us to draw a curve which has as many inflection points as there are degrees in the polynomial. The tedious calculations required for the process: control, analysis, generation of new data and reliability on an annual scale, have been facilitated by the use of Instat version 3.1 software, used for agrometeorological purposes [22], Statistica (version 5.1) and Excel.

- **Assessment of the annual rainfall drought index (RDI)**

On this time scale, drought indices describing qualitatively and quantitatively droughts in relation to rainfall evolution are simulated, in the absence of data on soil moisture, runoff and evapotranspiration [23-25]. Supporting this theory, the drought in the study area is analyzed by the index of Nicolson et al., (1988) widely, used in West and Southern Africa, based primarily on fluctuating rainfall over large areas.

The index is based on the calculation of the mean to normal ratio and the standard deviation, for the period (1940-2019). It standardizes the data to transform them into reduced centered anomalies "ACR", giving each value the same weight. ACRs allow a clear distinction to be made between wet years (surplus) and less wet years (deficit or dry). The formula that summarized38 them is as follows:

$$RDI = (R_i - R_A)/S \quad (2)$$

With R_i : rainfall in year i ; R_A : average interannual rainfall over the period (1940-2019); S : standard deviation of the interannual rainfall over the same period. A year is considered surplus if this ratio is greater than 1 and deficit if it is less than 1.

- **Evaluation of drought indices, number of rainy days and cereal crops**

The results of the drought indices and the number of days of drought, over a series of years, are used as a benchmark to establish the dependency relationships between rainfall, production and cereal yield in the semi-arid regions of Algeria.

III. RESULTS AND DISCUSSIONS

- **Rainfall trend**

Descriptive statistics show an average rainfall, estimated at 423 mm, over the 79-year period (Table 1). This value ranges from a minimum of 74 mm to a maximum of 1429 mm. The median, which does not exceed 394 mm, fluctuates between 297 mm in the 1st quartile at 25% and 519 mm in the 3rd quartile at 75%. The interquartile range (IQ), 222 mm, denotes rainfall variability, the calculated standard deviation of which reflects the dispersion of values around the mean. According to [26], the standard deviation, calculated from the square root of the variance, is the indicator of climate variability par excellence. This variability is translated by a differentiation of the annual water input over the continuous period (1940-2019). According to the coefficient of variation, the variability in the study regions reaches 41%, which is higher than the figure defined (30%) by [27], Hoff and Rambal (2007), for the Mediterranean isoclimatic regions.

TABLE 1. Characteristics of the statistical parameters of annual rainfall (1940-2019).

Period	N mm	R _{AM} mm	R _{Med} mm	Min mm	Max mm	1 st quartile	3 rd quartile	E	IQ	V	SD	CV %
(1940-2019)	1817	423	394	74	1429	297	519	1355	222	30388	174	41

According to the polynomial regression model, which takes into account the results of the statistical parameters, the rainfall contributions (1940-2019) follow a trend curve whose variability is cyclical (Fig. 2) with reference to the mean (R_{AM}). The first cycle corresponds to the years (1940 and 1970). The second cycle coincides with the years (1970 and 2000). The third seems to start from the year 2000 until 2019 (19 years). The cyclic averages of 430 mm, 405 and 440 mm, deviate from the global average of +7, -18 and +17 mm, they reflect successive episodes: wet, then dry with the beginning of a new wet phase, starting in the years 2000.

The first two cycles, which determine series of year's equivalent to 30 years, coincide with the standards of climatological periods that make it possible to summarized38e a climate in the Mediterranean regions [28].

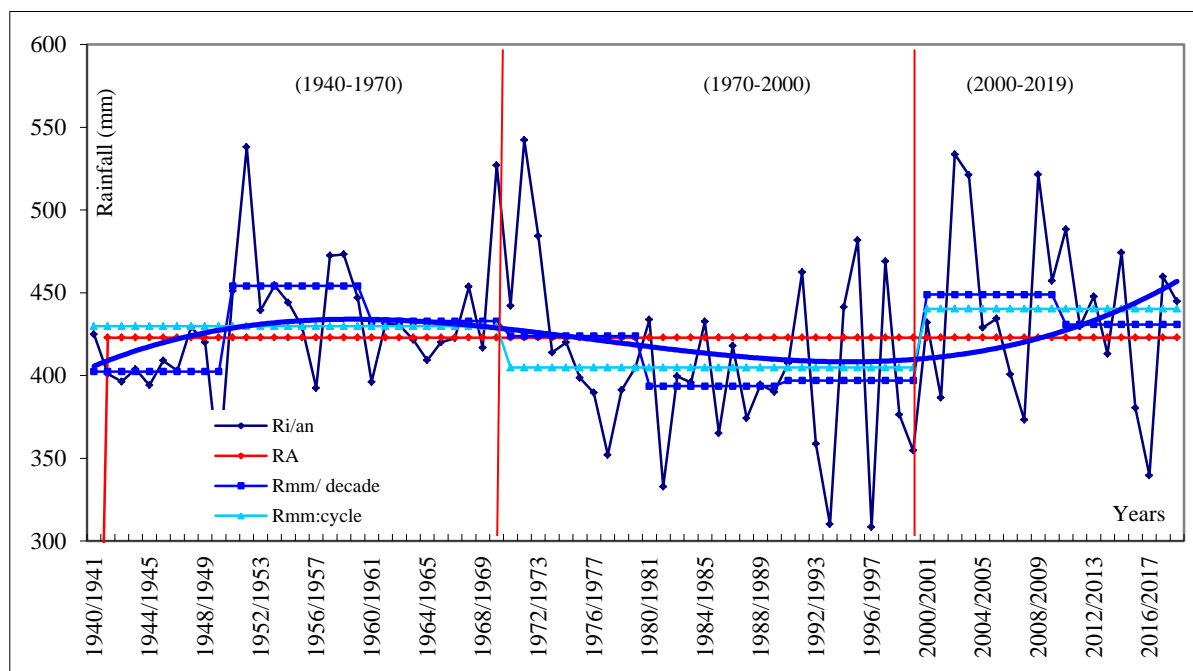


FIGURE 2. Evolution of rainfall (mm) in semi-arid cereal-growing regions.

Over successive decades, the rise and fall in average rainfall, even if the change is poorly formulated, is a sign of climate change. The graph underlines that during the first cycle, two (02) out of three decades recorded higher than average rainfall amounts, i.e. an increase of +31 (7%) and +10 mm (2%). This fact is marked by the rains received in the years 1951/1952 (538.1 mm), 1957/1958 (472.8 mm) and 1967/1968 (453.7 mm). On the other hand, during the second cycle, the three decades (3/4) show a decrease of -55 mm, i.e. a rain loss of 13%, particularly related to the years 1981/1982 (Ri, 333.0 mm), 1993/1994 (Ri, 310.2 mm) and 1996/1997 (Ri, 308.4 mm). As for the last cycle formed by two decades, it shows a gain of 34 mm (8%), linked essentially to the years 2002/2003 (Ri, 533.7 mm) and 2008/2009 (Ri, 521.4 mm). These fluctuations conceal the gains [1951/1952: Ri, +15.1 mm; 1958/1959: Ri, +50.3 mm] and losses of rainfall [1949/1950: Ri, -80 mm; 1981/1982: Ri, -90 mm; 2016/2017: Ri, -83.3 mm] that occur on an interannual scale.

The results which are in line with those reported by [29], [30], for the north of Algeria, show, however, that the study regions receive less rainfall. The loss of rainfall, accumulated during dry years, reaches nearly 70% over 79 years.

- **Drought rainfall trend**

The drought trend, expressed by the representation of annual rainfall drought indices (RDI), clearly shows the temporal evolution marked by wet and dry years (Fig. 3). The values of the RDI, for the years (1940-1970), are for the most part, positive, with an average of +0.03; as for those of the years (1970-2000), they remain, dominated by negative values; the average of the cycle of -0.16, is due to the years 1993/1994 (-0.93), 1996/1997 (-1.24) and 1981/1982 (-0.57). The last years with RDI dominated by values above the average +0.06, signal a return to rainy conditions. Fluctuations in RDI values highlight the succession of 'wet and dry' years, in the case of the years 2012/2013, 2013/2014 and 2014/2015, and contribute to estimating the ratio between extreme 'wet and dry' years (+0.57/-1.24). The results, summarized by the RDI curve, therefore highlight the intensity of interannual droughts in the cereal-growing regions.

- **Frequency trend of rainfall**

The annual series (Ri: 1817 = 79 × 23), classified according to increasing rainfall amounts, made it possible to estimate the dominant rainfall ranges in relation to the number of observations (N) and their weights, expressed in percentages (Fig. 4a). The average trend in the number of observations per rainfall range increases as rainfall amounts reach [400-500] mm, and then decrease steadily until it becomes negligible. It is thus noted that the most frequent rainfall is the one with the lowest amounts. In fact, the ranges below 400 mm alone concentrate nearly 945 cases, or 52% of the observations. The range [400-500] mm, which coincides with the average of the series, includes 226 cases,

or 12.6%. Finally, those above 500 and reaching 1050 mm, register between 126 and 1 case, i.e. 7% to 0.1% of the observations. By cycle, the averages obtained hide the frequency and distribution of the water waves. According to the same (Fig. 4: b, c, d) the histogram plot reflects a distribution in which the number of observations is progressively decreasing whatever the range considered. The more pronounced decline in recent years helps to explain the interannual droughts in cereal-growing regions.

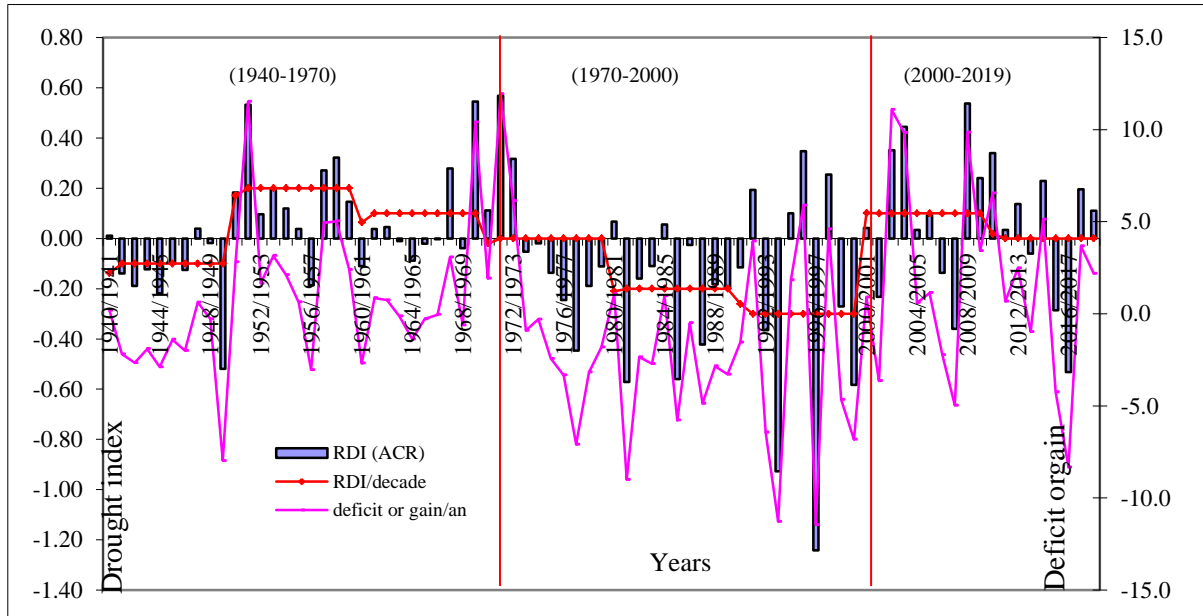


FIGURE 3. Characterization of rainfall change by rainfall drought indices or reduced centered anomalies (ACR).

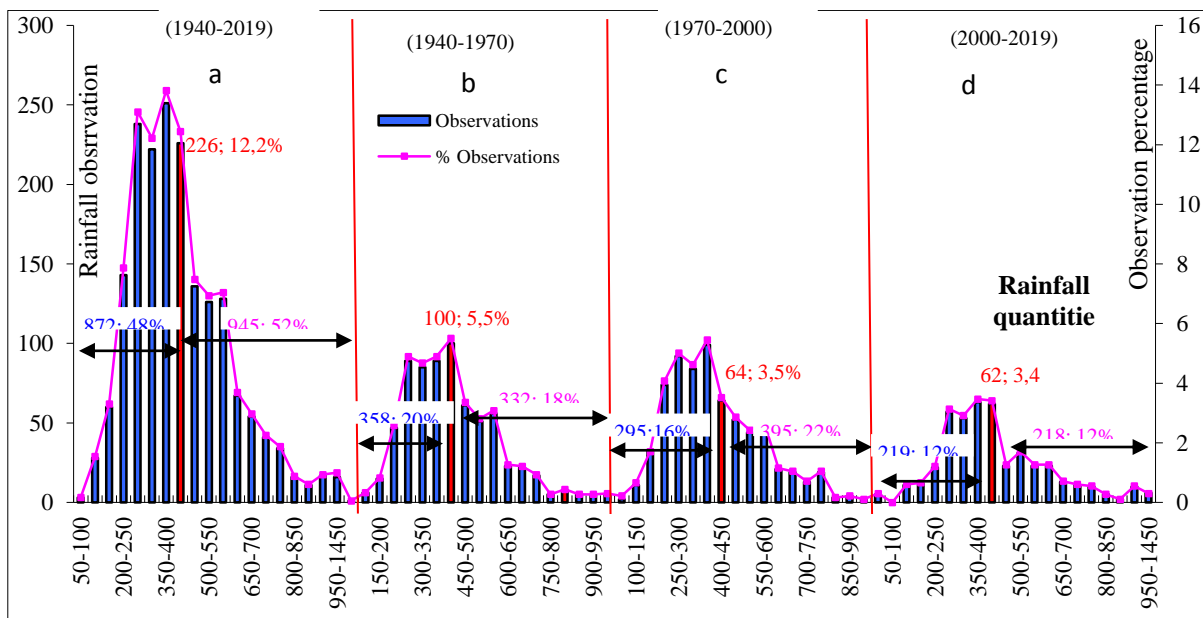


FIGURE 4. Evolution of the number of rainfall observations, evaluated by their percentages by range and by rainfall phase (1940-1970; 1940-2019 and 1970-2019).

• **Trend in rainfall and number of rainy days**

Regardless of the rainfall cycle, frequency analysis based on a number of observations equivalent to 1817 cases, estimates the average range of rainy days to be between 70-80 days, which represents only 12.2% of the series. According to Fig. 5, in detail, the plot of the histograms of representative rainy days, of the rainfall cycles, seems to

show an evolution that is inversely proportional to that of the evolution of rainfall quantities over the study period. The lowest rainfall ranges are represented by an above-average number of rainy days (16, 17, 13%), while the highest rainfall ranges are represented by a below-average number of days (14, 16 to 8%). The decrease in the frequency of rainy days has been marked since the 2000s, in line with the results of [31] in the Mediterranean region.

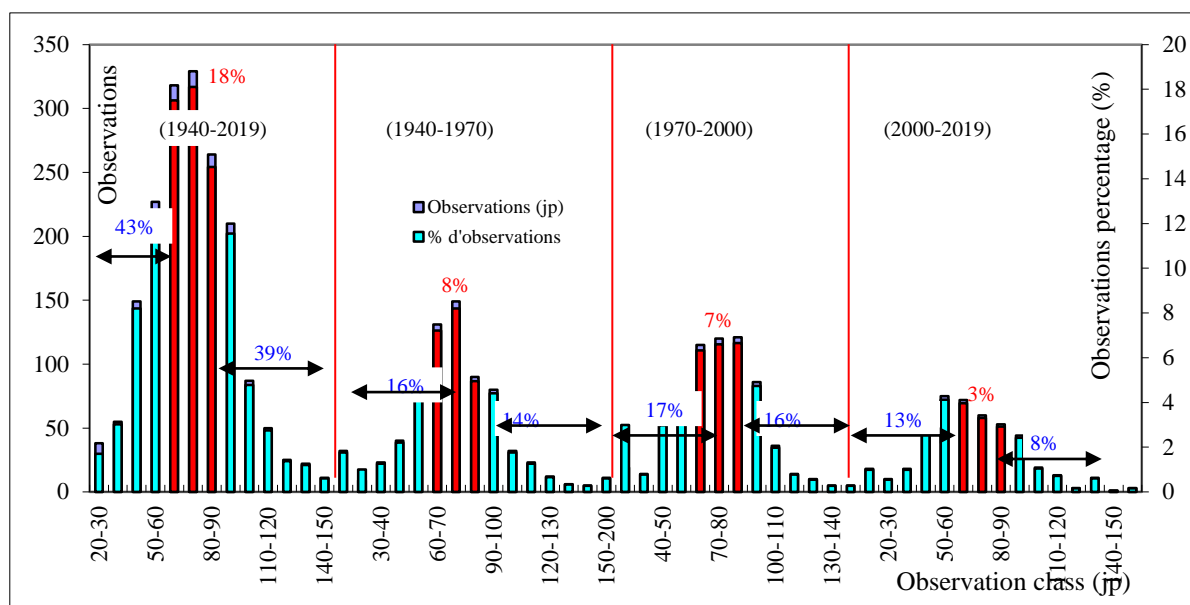


FIGURE 5. Evolution of the number of rainy days per range and per rainfall cycle.

- **Trends in drought indices, number of rainy days and cereal crop production**

Production over 79 years in the semi-arid cereal-growing regions is of the order of 19 Mq. This average varies from 15 Mq (1940-1970) to 17 Mq (1970-2000) to reach 28 Mq during rainy years (2000-2019). On a per hectare basis, this production evolves in the same direction (Fig. 6).

The average yield, estimated at 9 q ha⁻¹, evolves in stages from 8 to 9 to reach 13 q ha⁻¹. These trends, which seem to evolve in the direction of rainfall, especially during the first and third cycles, are however, very easily explained, correlated to the drought indices and the number of rainy days.

The correlation coefficients, below 35% (drought indices), or even below 10% (number of rainy days) (Table 2), curiously explain the wide dispersion of production and yield averages around the regression lines. On a time scale, these coefficients can be attributed to the efficient variability of rainfall across, the intensity of drought and the low frequency of rainy days during the crop growth cycle (September to June). These parameters are probably, moreover, combined with other production factors. These results corroborate those of [29], [12] in the northern region of Algeria. They contrast those of [32] in Morocco. [33] argue that the distribution of yields is also determined by the intensity of demand and the level of agricultural technology. As in the case of cereal growing in the country, despite the efforts made by the public authorities, yields remain highly variable, even if they represent the best indicators of the relationship between climatic factors and cultivation techniques.

For example, in a year considered wet (RDI = 0.54; rd = 84), the yield is 10.2 q ha⁻¹; in a year considered dry (RDI = -1.24; rd = 85), the yield is 7.5 q ha⁻¹.

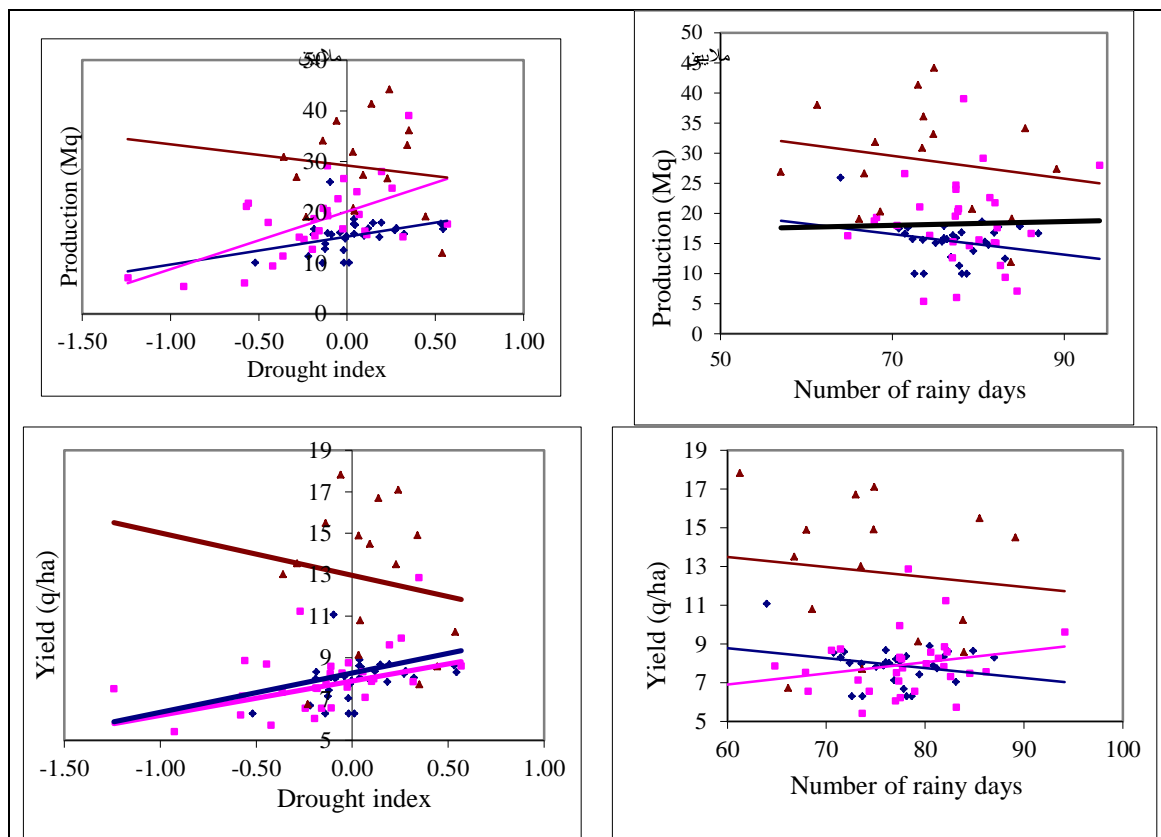


FIGURE 6. Evolution of cereal production and yield, in relation to the number of rainy days and rainfall droughts, period (1940-2019).

TABLE 2. Calculation results the correlation coefficient to assess the drought index and number of rainy days.

Production indicators		Drought index		Number of rainy days							
Statistical parameters		Correlation coefficient R ² (%)									
Cycles	(1940-1970)	Production	Yield	14	20	Production	Yield				
	(1970-2000)							14	6	6	5
	(2000-2019)							1.5	2.3	3.5	2

IV. CONCLUSION

The analysis of the annual rainfall, of the semi-arid cereal-growing regions, over 79 years, shows three rainfall cycles whose alternating averages (430 to 405 towards 440 mm), distinguishes an increase in interannual rainfall, over the last 20 years. Interannual droughts are however, detected, highlighting the intensity of wet and dry years. The decrease in the frequency of the number of rainy days per year, furthermore, affirms the deficit character of the regional rainfall. The interannual deficit, which represents on average 12%, corresponds to a water loss equivalent to 50 mm, or 500 m³ per hectare. This partially explains the weak correlation between production and cereal yields and the factors associated with rainfall. This result highlights the importance of considering that the lack of water acts in relation to the yield components that depend on the stage of the crop and the overall climatic conditions. In this context of climate variability and evolution, the yield of rainfed cereals, over a large area, must be studied not only with the rainfall (from September to June), but also, in association with other production factors (temperatures, sown varieties, agricultural

practices, lack of know-how), for solutions for improvement and sustainability of rainfed cereal farming in semi-arid regions of Algeria.

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