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PAPER

Characterization of the starting conditions of the rainy season in Senegal: highlighting the constraints of crop establishment

Mame Balla Ndiaye[1,2], Bassirou Sine[2], Diarietou Sambakhe[2], Amadou Oury Diallo[2], Bertrand Muller[3], Modou Sene[4] and Soussou Sambou[1]

[1] University Cheikh Anta Diop of Dakar, BP: 5505, Dakar-Fann, Senegal
[2] CERAAS/ISRA, BP: 3320-Thies Escale, Senegal
[3] CIRAD-BIOS-UMR AGAP, Madagascar
[4] Bureau d'Etudes et de Recherches sur la Gestion des Ress Nat pour le Développement Rural (BERGRN-DR), Thies, Senegal

E-mail: ndiayeballa@outlook.fr

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Abstract

The start of the rainy season in Senegal is characterized by critical variability, resulting in many crop failures after seed planting when a long dry spell occurs. The objective of this study is to characterize the starting conditions of the rainy season in different areas of Senegal in relation to crop success at the early stage. An analysis of four seasonal components determined from a daily rainfall database of 95 stations from 1950 to 2015. These seasonal components are the sowing date (Sowing), the Onset of the rainy season date (Onset), the length of the longest dry spell (DryMax), and the total rainfall (TotRain) during the 30 days after sowing. Statistical methods of time series homogeneity determination such as the Pettitt test, the Buishand test, the Von Newmann test, and the segmentation method have been applied to determine actual breakpoints and to obtain the most recent and homogeneous period to define the component in each site. The results indicate that these components have not exhibited statistically significant changes since 1950. Indeed, 3% of the stations show breakpoints for the Sowing, 4% for the TotRain, and 2% for the Onset. The start of the season follows a South East-North West gradient. It begins in the extreme South-East part of the country in the second decade of June while the first waves of sowing take place in the South-East center part from the second half of June. The north zone remains exposed to false start events with important seasonality. In the Northern and Central zones, the early or late character of the sowing passes more on the DryMax than the TotRain. It would be interesting to elucidate the effects of the rainfall regime at the early stage on the rainy season profile to gain better control of the pluvial crop yields.

1. Introduction

In the Sahel, and specifically in Senegal, rainfed agriculture is threatened by the recurrence of dry spells at the early and the end of the rainy season encountered in the previous few decades. The start of the rainy season is rarely sudden; it is usually preceded by a succession of isolated light, intermittent showers, followed by a sequence of long dry days [1]. Such a phenomenon called 'False start' contributes to drying out the topsoil and preventing the germination and emergence of seedlings [2]. In West Africa, the semi-arid zone is largely impacted by deficient and irregular rainfall, often leading to great intra-seasonal variability. The distribution of rainfall is concentrated at more than 80% between June and September [3]. This variable and unpredictable nature of rainfall at the start of the rainy season creates water stress, which is very detrimental to the survival of plants at the young stage. Yet the food security of a majority of the population depends on the rainfed agriculture of food crops such as millet and sorghum (according to FAO, 2007).

This situation is part of a difficult environment and climate: low soil fertility, and low and irregular rainfall with great Spatio-temporal variability [3]. One of the priorities of research institutions in West Africa is to strengthen the forecast on the optimal sowing date presenting less risk of crop failures and ensuring more stability in the yields of farmers' harvests. Crop failures after sowing have been reported in several studies due to long dry spell at the beginning of the rainy season. In Senegal, the agricultural sector employs more than 70% of the active population and contributes more than 20% to the country's growth rate [4]. It is an essential engine of the development of Senegal. Yet more than 90% of this agriculture depends on rain. Irrigated crops represent only 5% of national production. Many studies have been carried out to understand and characterize this variability and to quantify its effects on agricultural production in the Sudano-Sahelian zone [5, 6]. The studies carried out on the rainfall regime in Senegal have shown that the regime could be divided into three different periods. A wet period from the beginning of 1950 to the end of the 1960s was marked by excess rainfall accumulations, early starts, and long rainy season periods. It was followed by a dry period corresponding to the drought of the 1970s marked by cumulative deficits, late starts of the rainy season, and very short rainy season periods. This situation affected several areas, especially those located in the center of the well-known 'Groundnut Basin', an area of high groundnut, millet, sorghum, and cowpea productivity [7]. However, in recent years, there has been a trend to wetter conditions compared to the previous one [8, 9], with, however, increased rainfall variability and shorter rainy season lengths [10], also a recurrence of events of dry spells and extreme rains during the rainy season. Nevertheless this return is not homogeneous throughout the territory; some areas seem to always remain dryer due to drought. This return period observed in the West African Sahel coincides with the acceleration of global warming, which predicts a temperature increase of 1.5 °C by 2050 [11]. This increase of the temperature could affect the rainfall regime already characterized by high variability. These recent favorable conditions are often associated with intense and increasingly frequent rains causing runoff and flooding [12]. Many studies have been done on the characterization of the dry spells and the others seasonal components during the rainy season in the West African Sahelian zone to study their variability and their news trends [4, 13]. The most recent studies were carried out by [1, 9] in Senegal on the current characterization of the main seasonal components such as types of dry spells, the onset dates of the rainy season and the sowing date at the weather station scale, their spatio-temporal variability and their impact at the regional scale. But the consequences of the onset of rainy season on the sowing date was not be yet elucidated at the local scale and their impact on regional scale. As for millet the sowing method adopted by the farmers is different according the agroclimatic zones, which has a direct impact on the sowing date at the different areas. Millet is sown in dry conditions before the start of rainy season in the North and the Central parts of the country, but it is sown in moist conditions right after the first rain in the Southern part. The main questions we adress here are: what is the most homogeneous recent period of these seasonal components and their values on each station ? what is the impact of the rainy season onset on the sowing date in the different areas of Senegal ? and lastly what are their consequences on the success of millet at the early stage ?

The characterization of the starting conditions of the rainy season is therefore important for understanding the local and regional rainfall regime to optimize the choice of agronomic options in agricultural management and practices in rural areas. In fact since 1980, there has been an increase in the delay in the start of the season in the central and northern parts of the country[14].

It is, therefore, necessary to understand, based on the analysis of rainfall data from recent decades, the rainfall regime at the start of the cycle to optimize our choice of the optimal sowing date with less risk of crop failure. The objective of this work is to characterize the start conditions of the rainy season in the different agroclimatic zones of Senegal. Specifically, this will aim to: (i) develop a typology for the start of the rainy season in the different agroclimatic zones of Senegal (ii) link this typology to the constraints on the installation of a crop such as millet. This article is organized as follows: in the first part, we will present the physical and climatic characteristics of Senegal, then the data and methods used in this work. In the second part we will present our findings and results obtained and end with the discussion-conclusion followed by the perspectives.

2. Material and method

Senegal is located in the extreme west of West Africa between latitudes 12°5–16°5 N and longitudes 11°5–17°5 W. It covers an area of 196,712 km2. The climate is of the Sudano-Sahelian type characterized by an alternation of a dry season between November and May and a rainy season between June and October. The two determining factors of the climate in Senegal are the lack of significant relief and its geographical position: the territory is entirely located in the tropical zone [15]. The average annual rainfall follows an increasing North-South gradient, ranging from 200 mm in the semi-desert North to 1200 mm in the South, with variations from year to year. The main climatic zones of Senegal are a forest zone in the south, a wooded savannah in the center, and a semi-desert zone in the north. Rainfall is distributed at 75% between July-August-September in the south and more than 90% in the north [16]. Figure 1 shows the distribution of the main rainfall stations used in this study and the distribution of isohyets. We note in addition to the North-South gradient on the rainfall, there is a West-East gradient in the southern part coming from the coast, which is relatively linked to the coastal influence of the

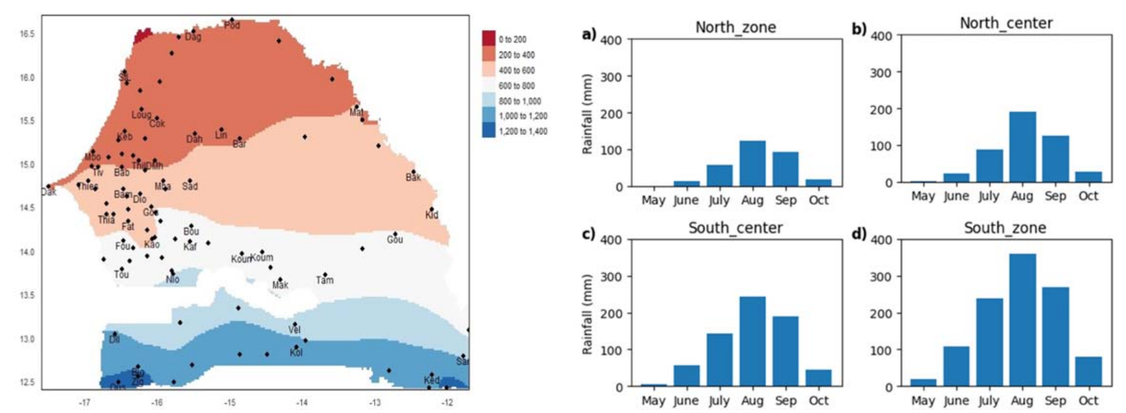

Figure 1. Map of Senegal with 95 stations taken in this study: The labeled stations have long series (1950–2015) and the others have short series (1987–2015). The distributions of isohyets on strips 200 mm thick (left). The distribution of monthly rainfall in the different agro-climatic areas (right).

cold current of the Canary Islands. The local atmospheric circulation is particularly influenced by the North Atlantic Ocean proximity. Senegal's ecological conditions are favourable for the farmers cropping of millet, sorghum, maize, groundnuts, cotton, and cowpeas [9]. Agriculture is much diversified following the north-south rainfall gradient. In the northern part, where the rainfall varies between 200–400 mm, rainfed agriculture is too difficult due to the recurrence of long dry spells. The central part of the country covering isohyets located between 400 and 800 mm presents a crop types diversity, it is commonly called 'the groundnut basin'. The southern part is the wettest zone located, between 800 and 1200 mm isohyets. In this part, agriculture is more secure.

The data used in this study are daily rainfall data taken from the database of the Regional Study Center for the Improvement of Adaptation to Drought (CERAAS) over the period 1950 to 2015. These are data on daily rain from a vast network of 95 rain gauge stations made up of rain gauges, synoptic stations managed by the National Agency for Civil Aviation and Meteorology in Senegal (ANACIM), and other stations managed by the Senegalese Institute of Agronomic Research (ISRA) for crop monitoring (figure 1). All stations received data quality control using the RClimDex package [17]. Quality control consists of detecting negative rainfall values and outliers due to input errors and correcting them using knowledge of the environment and experience with the climatology of the area. Among these 95 stations, 45 have long series, i.e. from (1950–2015) and 50 have short series (1987–2015).

2.1. Determination of seasonal components

For each site and each year, some seasonal components relevant to achieve the objectives are determined from the daily rainfall values. Four seasonal components have been retained: the Sowing date, the Onset date, the Drymax, and TotRain.

2.1.1. Sowing and onset dates

The date of sowing (Sowing) is determined based on the farmer's practice of sowing millet. Indeed, in the northern and central part (the area where rainfall is $\leqslant$ 600 mm), millet is sown before the first rains in dry soil conditions, so that the crops can emerge right from the first rain [18]. Farmers try to sow as early as possible in the season to reduce nitrogen losses in the soil through leaching or denitrification and to limit competition with weeds [5]. On sites located in this zone, the sowing date is taken as the first day after May 01 when it recorded a rain quantity of 15 mm over three days. In the southern part, sowing is practiced wet and corresponds to the first day after June 25 when it recorded a rain quantity of 25 mm over three days. If this criterion is not met, the date of sowing will be considered the first day after July 15 recording a rain quantity of 20 mm over three days. If this criterion is not met, the date of sowing will be considered the first day after July 25 recording a rain of 15 mm over three days. The start date of the season (Onset) corresponds to the installation date of the rainy season. It is taken as the date from which it cannot be followed by a long dry spell affecting the crops. Several authors have proposed definitions for Onset in the Sahel based on rainfall data or soil variables [3, 5, 9].

However, this study considers the one established from experimental studies on millet by the International Research Institute for Tropical Cultures in Semi-Arid Regions [13]. This approach considers the start of the rainy season in the Sahelian and Sudanese regions as the date from May 1st recording 20 mm of rain over 3 consecutive days, with no dry sequences of more than 7 days in the next 30 days. Choosing the 30-day control period protects against false starts that are a constraint to plant installation and development [19]. This approach

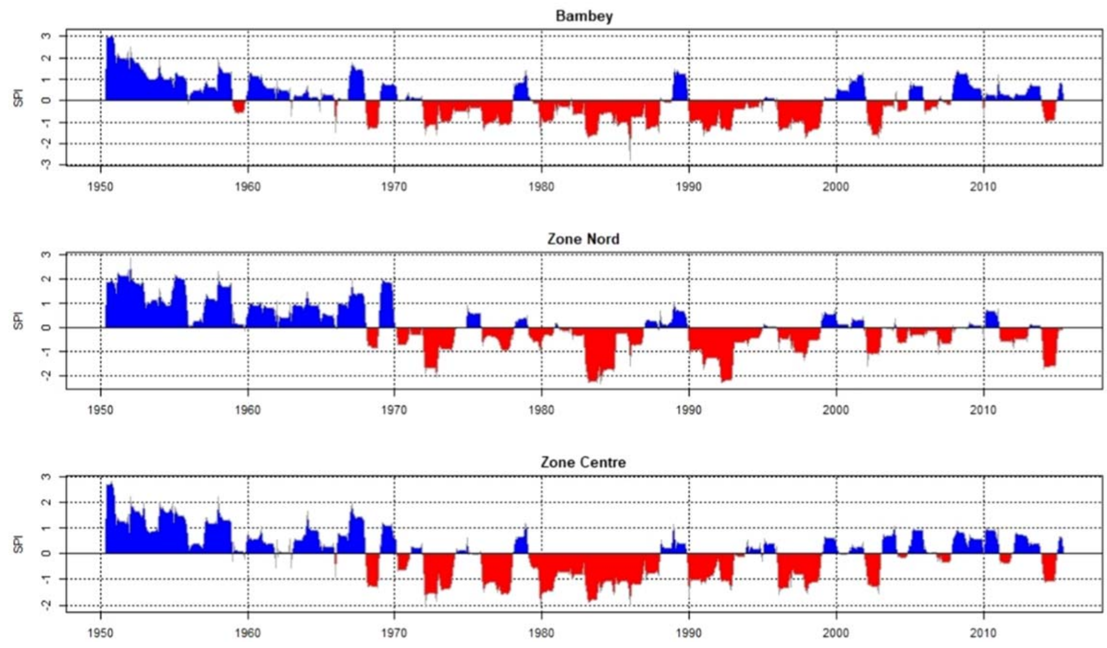

Figure 2. Standardized Precipitation Index (SPI) related by 1950–2015 for the local zone (Bambey) in the top and two regional zones (North and Center) in the middle and the bottom.

is known as the 'Sivakumar criterion' and helps to avoid the risk of false starts in the rainy season. A false start is characterized by the occurrence of a persistent dry sequence that depletes the soil water supply after more than 20 mm of rain. Consequently, the absence of a dry sequence of more than seven days during a 30-day control period eliminates the risk of false start and crop failure [20].

2.1.2. DryMax and TotRain

Intra-seasonal rainfall dry spells are the main factors affecting crop development and production when observed during the vegetation and before harvest phases. A day is considered dry at the station level when the daily rainfall is less than 1 mm [13]. The length of a dry spell is therefore defined by the period, in a number of days that separates two rainy events. To the constraints on the success of crops at the beginning of the cycle, we considered in this study the rainfall break component (DryMax) as the longest break within 30 days after the Sowing date. And the cumulative rainfall criterion (TotRain) is the cumulative rainfall recorded within 30 days after the sowing date.

2.2. Statistical analysis

From 1950 to the present, the precipitation regime in the Sahel, particularly in Senegal, is not homogeneous. This regime can be divided into three quasi-homogeneous periods. Figure 2 shows the evolution of the Standardized Precipitation Index (SPI) between 1950 and 2015 at the local level (Bambey) and the regional level (North and Center zones). The evolution of these bands shows the three phases of the rainfall regime in Senegal since 1950. The first period corresponds to the wet period (1950–1969), which remains rainy throughout the territory with positive SPI values (see figure 2). The second period corresponds to the years of drought, which started in 1970 and has affected the northern and central parts of the country. The third period gives an aspect of return to better rainfall conditions. This last phase is more observable at the level of the stations located in the central zone of the country compared to those in the northern zone which seem to always remain in the drought period. At the regional and local level, annual rainfall is not homogeneous over the analysis period, i.e. 1950 to 2015. What about the other seasonal components listed above? Therefore, determining the present value of a factor requires knowledge of the most homogeneous recent period of that factor at each site. A methodology developed by [21, 22] is used to analyze and determine potential breakpoints that might exist on the data of each seasonal component at each site to determine the most stable recent period and calculating the value taken by the component in that locality. The methodology consist to use 04 statistical tests or methods for the detection of breakpoints in temporal series. It has been modified for this study. In fact, the previous studies mentioned that the onset/cessation dates, successful sowing dates, rainy season length, cropping period, medium and extreme dry spell categories. Rather, some of these factors such as the successful sowing date and the cropping season length exhibit significant variability. The methodology is presented in detail and used by [1, 2]. The criteria used in study for decision for breakpoint existence are:

(a) No change point or homogeneous: A series may be considered as homogeneous, if no or one or two tests out of four tests rejected the null hypothesis at 5% significant level

(b) Change point or inhomogeneous: A series may has change point or be inhomogeneous, if more than two tests reject the null hypothesis at 5% significant level

2.2.1. Pettitt test

The Pettitt test for the detection of breakpoints developed by [23] is a non-parametric test, which is used to assess the occurrence of a sudden change in a climate series [24, 25]. Pettitt's test is the most widely used for the detection of breakpoints because of its sensitivity to changes in the middle of a series [22]. It is based on comparing averages in a series, where the start date of the changes is not known. According to this test, if $x_1, x_2, x_3, \ldots, x_n$ is a time series containing a breakpoint at the date t such that $x_1, x_2, x_3, \ldots, x_t$ has a distribution function $F_1(x)$ which is different from the distribution function $F_2(x)$ of the other series $x_{t+1}, x_{t+2}, \ldots, x_n$. The statistic value U_t for this test is equal to:

$$U_t = \sum_{i=1}^{t} \sum_{j=t+1}^{n} sign(x_i - x_j). \tag{1}$$

The confidence threshold for the test is given by:

$$\rho = \exp\left(\frac{-Max|U_t|}{n^2 + n^3}\right) \tag{2}$$

Where the value of the coefficient is below the specific confidence threshold, which is taken here to be equal to 5%, the null hypothesis is rejected. And an estimate of the break date is given by t corresponding to the date where $|U_t|$ is the maximum.

2.2.2. Buishand test

The Buishand test is based on a Bayesian procedure under the assumption that the series follows a normal distribution [26]. This test is used to determine a breakpoint that exists in a series. Buishand's U statistic is defined as

$$U = \frac{\sum_{k=1}^{N-1}\left(\frac{S_k}{\sigma_x}\right)^2}{N(N+1)} \tag{3}$$

with S_k and σ_x the partial sums and standard deviation of the series (x_i) . The null hypothesis H_0 of this test is the absence of breakpoint in the time series. In the case of the rejection of the hypothesis H_0, an estimate of the break date is proposed by the test [27]. The confidence interval which must contain the U value of the test when the null hypothesis is accepted is given by a control ellipse delimited by a function of the form [28]. In the case of a rejection of the null hypothesis, the value of the statistic U of the test is not included in the domain delimited by the control ellipse.

2.2.3. Von newman test

Van Neumann's ratio test is a powerful test for detecting the existence of a breakpoint in a time series, but it does not determine when changes begin. This test is defined by the ratio of the mean of the square, which is different from the variance. The test is described in various notable studies [21, 26, 29]. The statistical test for the detection of a breakpoint on a time series $x_1, x_2, x_3, \ldots.., x_n$ is given by:

$$N = \frac{\sum_{i=1}^{n-1}(Y_i - Y_{i+1})^2}{\sum_{i=1}^{n}(Y_i - \underline{Y})^2} \tag{4}$$

When the series is homogeneous, then the expected value is E(N) = 2. When the time series has a breakpoint, then the value taken by N is less than 2. The different values taken by N for confidence interval thresholds of 1 and 5% can be found in [30] for the identification of non-homogeneous series.

2.2.4. Segmentation method

The segmentation procedure can detect several breakpoints in a time-series. The algorithm that performs the calculation divides the time series into segments of homogeneous subsets such that the average between these

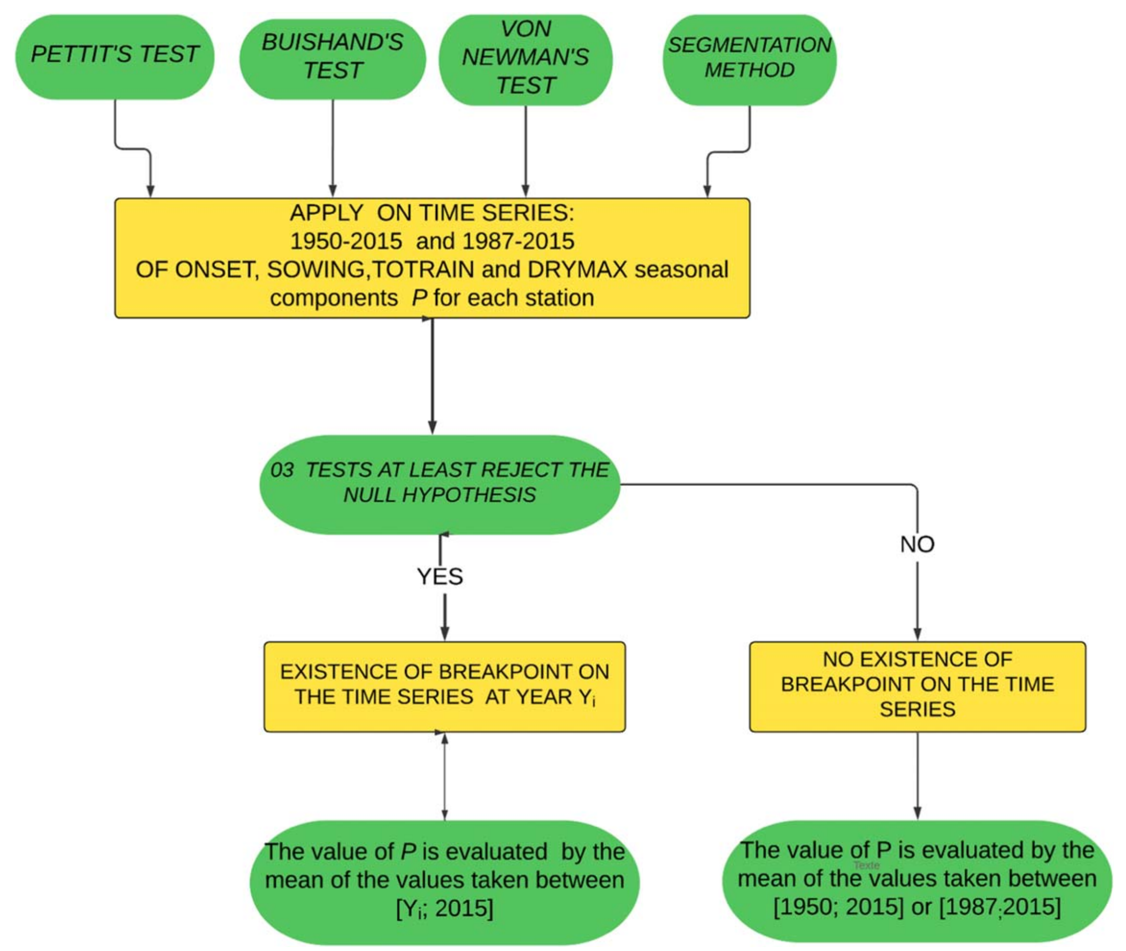

Figure 3. Statistical analysis scheme.

subseries is significantly different. The series segmentation is done with a dynamic programming algorithm that provides better splitting of the series into homogeneous segments. The algorithm is compiled under the 'segclust2d' package in R Statistical Computing Software [31]. Since the time series can be divided into homogeneous sub-periods, the Pettitt test, Buishand test, and Von Newmann test, which can only detect one breakpoint, were applied over the period (1950–2015) and the period (1970–2015). If the results return two breakpoints, then the most recent year is considered the year in which the changes begin. However, the segmentation method can detect several change points in a time series, it is applied only once. We consider a series to have a breakpoint when at least three of the methods detect the change point. In this case, the value taken by this component for a given station is the average of its values from the year of the break until 2015.

Otherwise, when no change point is detected, the component is evaluated by averaging its values from 1950 to 2015. This statistical analysis methodology is resumed as a scheme in the figure 3. This method used to determine the existence of breakpoints is presented in [22]. Table 1 is an example of the results of the four tests applied to seasonal components at the Bambey station.

3. Results

3.1. Homogeneity tests of the seasonal components

The results of these tests presented in table 2 give the stations and the years in which the changes began. Some stations on the large number used, have breakpoints for all components. The Onset component shows a breakpoint at Matam in 1967 and Tamba in 1989 only characterizing the lateness of the Onset in these two localities. The inter-annual variability of climatic components in the Sahel, marked by the contrast of wet and dry decades, did not change monsoon installation dates. The wet and dry periods give very similar installation dates [32]. For the Sowing, the stations that showed breakpoints in their series were the Matam stations in 1998 with 21 days early on the date of sowing, as well as the Thilmakha station in 1966 with 14 days of delay, relating to the beginning of the dry period from the 1970s. In the south, in Ziguinchor, a precocity on the date of sowing is

Table 1. Procedures of breakpoints detection (Results from the station of Bambey).

	Pettitt's test			Buishand's test			Von_newmann's test		Segmentation method		Final results	
Seasonal components	Statistic/p_value	Shift	Year	Statistic/p_value	Shift	Year	Statistic/p_value	Shift	Shift	Year	Décision	Year of break
Semis	474/0.01973	Yes	1964	1.6825/0.02445	Yes	1964	−1.3415/0.1798	No	Yes	1965	Yes	1964
Début	194/0.7872	No	—	1.099/0.4914	No	—	−0.089297/0.9288	No	Yes	1965	No	—
TotRain	316/0.2333	No	—	1.1578/0.4109	No	—	.27434/0.7838	No	Yes	1965	No	—
DryMax	429/0.03813	Yes	1972	1.4025/0/1442	No	—	−0.88045/0.3786	No	No	—	No	—

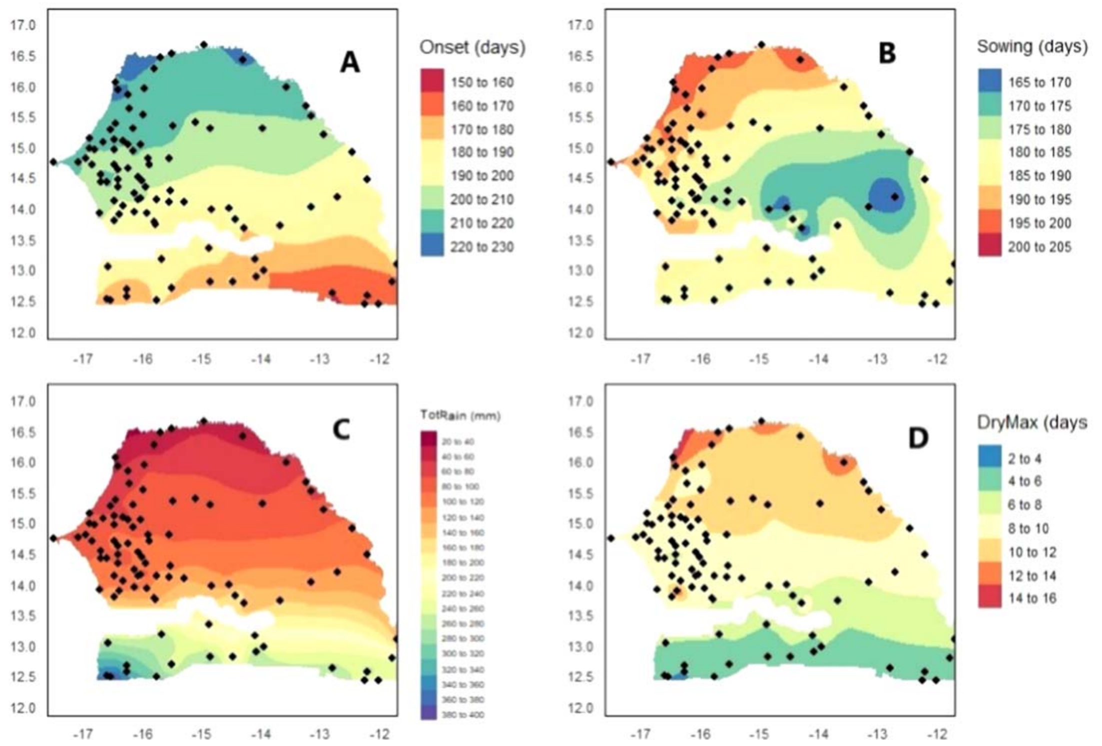

Figure 4. Spatial distribution of seasonal components throughout Senegal. (A) ONSET, (B) Sowing, (C) TotRain and (D) DryMax.

Table 2. Results of the Tests of Breakpoints detection.

Zones	Sowing (days)	Onset (days)	DryMax (days)	TotRain (mm)
Zone 1: ⩽ 600 mm	Matam (1998; −21)	Matam (1967; +18)	—	Matam (1993; +70)
Dry sowing practice	Thilmakha (1966; +14)			Toubacouta (1971; −92)
Zone 2: ˃ 600 mm	Ziguinchor (1994, +6)	Tamba (1989; +16)	—	Diouloulou (1975; −99)
Wet sowing practice				Tamba (1979; −77)

observed from 1994, with a magnitude of 6 days. The DryMax factor did not show any point of change at all stations, although episodes of long rainfall breaks at the beginning of the season are often observed at some localities in Senegal. Some features are noted in the Matam region on the important changes of the different seasonal components. A delay of 18 days since the beginning of the drought period is noted on the installation of the season compared to the wet period (1950–1969), a precocity on the sowing date of 21 days from 1998 compared to the previous drought period. There was also a significant 70 mm increase in rainfall in the same region from 1993 onwards within 30 days of sowing (table 2), which was characteristic of a return to wetter conditions after drought. At the stations of Diouloulou, Toubacouta, and Tamba, a decrease in rainfall within 30 days after sowing (TotRain factor: table 2) of 99, 92, and 77 mm respectively in 1975, 1971, and 1979, relating to the drought period of the 1970s.

3.2. Seasonal components features

The most relevant seasonal components to characterize the start of the season are the Start Date of the season (Onset), the sowing date (Sowing), the longest break length, and the rainfall accumulation (DryMax and TotRain) within 30 days after the sowing. Figure 4 shows the spatial distribution of these components over Senegal. For the Onset, the season starts earlier in the extreme south-eastern part of the country, between 9 and 19-June in the regions of Kedougou and Bandafassy, in case of delayed onset, with the installation of the Intertropical Convergence Zone (ITZ), which migrates to the Center. When Onset is early, the start of the season is observed in this same zone at the end of May (figure 4(a)). The frequencies of the Onset in this part during May and June are 30% and 70% respectively (figures 5(a) and (b)). It is very rare, if not impossible, for the season to start in other parts of the country during May. The Onset is observed in the southern part of the country precisely in Kolda, Ziguinchor, and Tamba between 20-June and 09-July (figure 4(a)), its frequency of

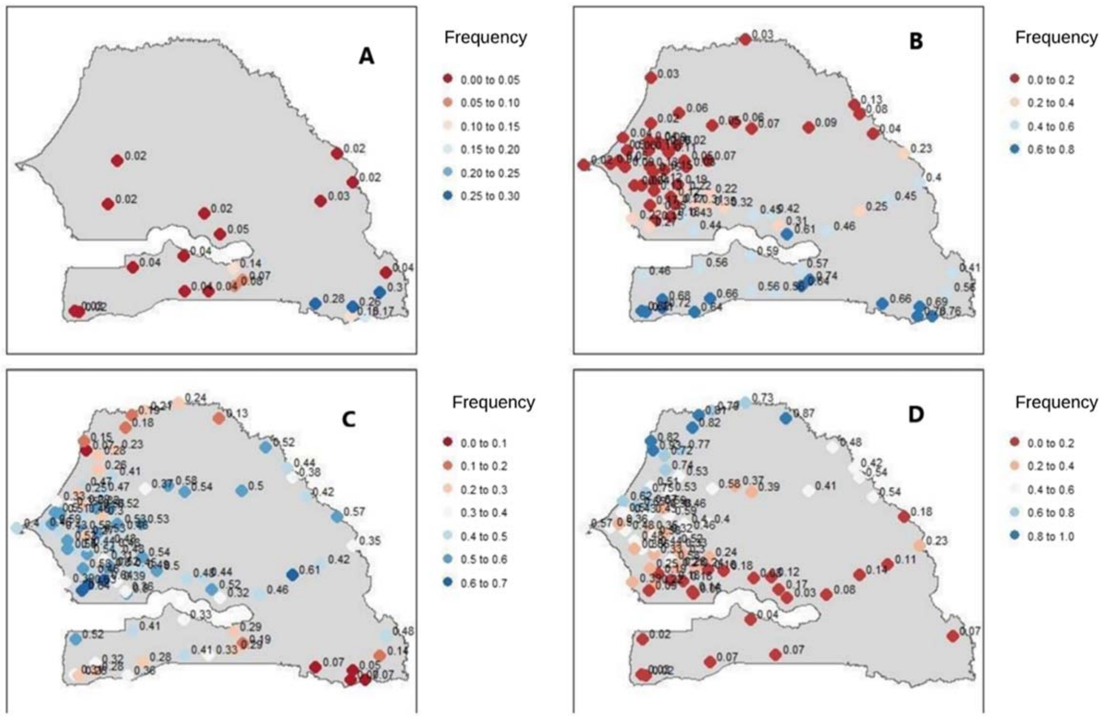

Figure 5. Spatial distribution of the ONSET frequency (A): MAY, (B): JUNE, (C): JULY and (D): AUGUST).

Table 3. Centile of Sowing and Onset components in the two zones.

	Sowing practices	25%	50%	75%	95%
ONSET	Dry sowing practice	19-july	26-july	31-july	06-Aug
	Wet sowing practice	20-june	27-june	1-july	12-july
SOWING	Dry sowing practice	1-july	7-july	11-july	15-july
	Wet sowing practice	30-june	1-july	2-july	5-july

installation during June is 60%. In the south-central part of Kaffrine extended in its eastern part, the rainy season installation is observed in the second decade of July for a frequency of 70% when the start is late. For an early start in this area, installation is done at the end of June with a frequency of 30%. Its total installation was 95% effective in the south-central part only during the second decade of July (table 3). For half of the years considered in this analysis, the installation of the rainy season is done during the third decade of July (figure 5(c)) in the central-north part covering a large part of the Groundnut basin corresponding to an early start of the season. In the same central-north region, the late start years represent a percentage of 45% and are most often realized in the first half of August. Rains are often seen during the end of June, corresponding to amounts of rain that would make believe the starting of the rainy season in this north-central part. But most of the time, these rains are followed by periods without rain of up to 30 days. it was the case in 2018 in almost the entire northern area of the peanut basin. In the northern part, the season starts from the beginning of August until the end of the second decade of that month for sites located in the extreme north, which is observed over one-third of the years. In contrast to the North-South gradient for the Onset of the rainy season observed on the Sahel, a SE-NW gradient is rather observed for Senegal.

The start of the season is effective at 75% and covers 95% overall territory respectively from July 31 and from August 06 (table 3). This result is confirmed by [9] which shows that the start is effective at 75% in the northern part of Senegal from July 27. On the other hand, the Sowing date of the millet precedes the start of the season in most of Senegal, particularly in areas where it is practiced in dry conditions and often coincides with the first rains [33] which generally occur one month before the installation of the monsoon (Onset)[34]. The first waves of sowing are recorded in the central-eastern part (Goudiry, Tamba, Koumpentoum) at the beginning of the second half of June and spread towards the south and towards the center (figure 4(b)). The frequency of sowing in this part during this period is more than 75% (figure 6(b)). For a frequency of 20%, the sowing is carried out at the beginning of July in this same part and corresponds to late sowing. Throughout the southern and central-

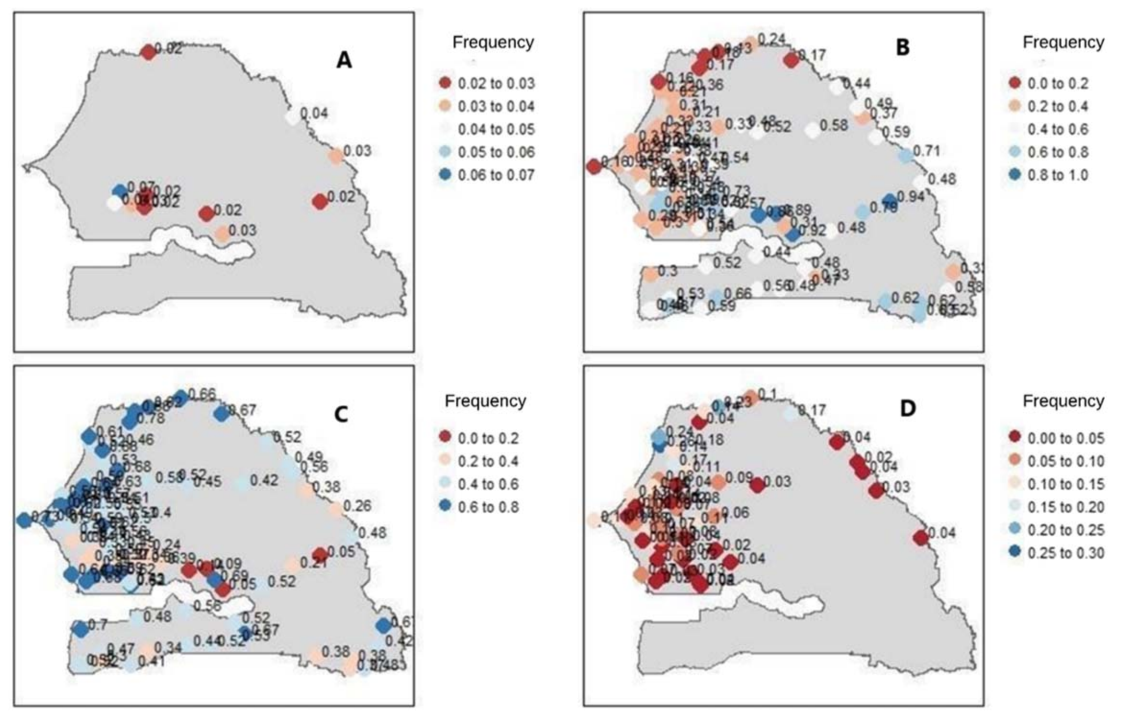

Figure 6. Spatial distribution of the SOWING frequency (A): MAY, (B): JUNE, (C): JULY and (D): AUGUST).

northern parts, the sowing is done at the same time between June 24 and July 05, even though the difference in days between the Onset and the Sowing dates is about 40 days. In fact, in the southern part, the sowing is done in humid conditions, and this sowing period is very close to the period of the installation of the season in this zone. Therefore, it will be very difficult to observe pockets of rainfall breaks after sowing. Table 3 shows that sowing is 95% effective before July 05 in the whole southern part corresponding to the zone where it is practiced in moist conditions, which is followed by the full start of the season in no more than one week thereafter. In the north-central part, sowing is practiced in dry conditions. The difference between the date of sowing and the start of the season in this part is on average 20 days, which can reach 30 days in some areas and for some years.

In zone 1 (where the sowing is practiced in dry conditions), the sowing is only done at the beginning of July, i.e. rain able to germinate the millet only occurs during this period and for 25% of the sites (entirely composed of sites located in the east-central part of the country).

The period after sowing is crucial for the farmers because the success of the crops depends heavily on it. The DryMax and TotRain factors show a North-South gradient figures 4(c), (d) in their distribution across Senegal. They represent the maximum length of the dry spell and the amount of rain recorded, within 30 days after sowing. In this critical phase for the young plant, it is observed in the south and center-south zones that the values of TotRain vary between 140–400 mm, sufficient to make any crops succeed. In this same part, the average values of DryMax observed during this phase varies between 4 and 8 days, although some extreme values of DryMax on a few stations and for a few years, which can be detrimental to crops are observed. For example, 22 days in Djilor in 2012; 20 days in Foundiougne in 2006; 21 days in Guinguineo in 2008, and 26 days in Koumpentoum in 2013 exclusively on stations located in the Center-South zone. In the central part of the country, the TotRain is around 80–120 mm and the maximum average DryMax is around 8–12 days. It is in this part of Senegal that extreme breaks are often encountered, which can lead to situations of false starts during the rainy season. However, these situations are not frequent in this zone compared to the northern zone where there is a more extreme dry spells. Some extreme values after sowing are listed at the sites of Bambey 30j in 2006; Semme 24 days in 2014; Thiadiaye 21 days in 2007, Diourbel 19 days in 2014. In the northern zone, the maximum average value of DryMax observed is 16 days with an average rainfall of about 20 to 60 mm within 30 days after sowing. There are many more extreme Dry spells after sowing in this northern area; for example, in AereLao 21 days in 2011; Podor (30 and 20 days respectively in 2006 and 2010). In the same area on a few stations, there is also a strong return of extreme values over intervals of two to three years. For example, in Dahra station there are extreme values of 15,21,15,16, and 24 days respectively in 2006, 2007; 2011; 2013, and 2014 and at other stations in the same area. Stations in the extreme north, such as Podor, have the highest DryMax values. The rainfall values recorded in the central and northern parts of the country may be sufficient in certain situ ations if they are well distributed during the post-emergence phase. This finding indicates that post-sowing Dry

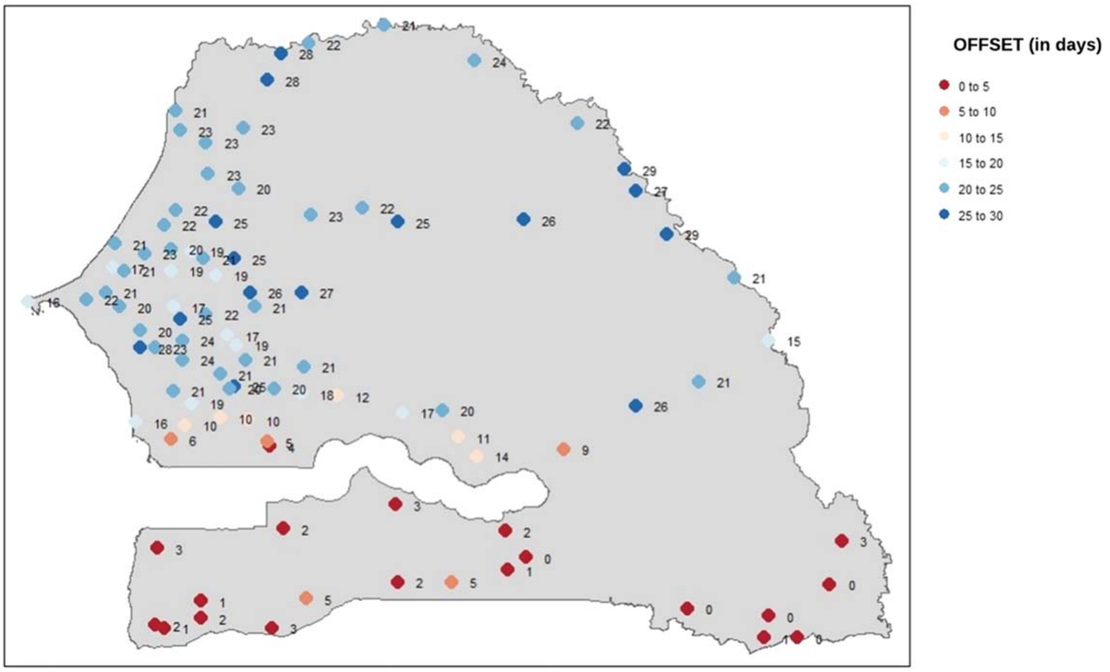

Figure 7. Distribution of the Offset between Onset and Sowing over Senegal (in a number of days).

spells characterizing false-start events that may be harmful to crops are most prevalent in the northern and central parts of the country.

3.3. Starting conditions and constraints on crop establishment

The start of the season has a strong impact on the traditional farming practices in Senegal. The structure of the rainy season in terms of rainfall events and its distribution is often more critical than the simple annual cumulative rainfall [35]. Several authors have shown that some changes are observed in seasonal components such as Onset and season length in the early 1990s compared to the previous drought period. However, these changes are not statistically significant. Rather, they are involved in significant Spatio-temporal variability in the northern and central parts of Senegal [9].

Figure 7 shows the offset in the number of days between Onset and Sowing at the local scale determined at each station and represents the time average over the stable period common to both components. The offset is expressed in a number of days and its value is obtained by doing the difference between the start date and the sowing date. It can be seen that the distribution of the offset follows a certain distribution according to the zone. The offset value remains very low or zero for the stations in the south of the country, the largest offset values observed there hardly exceed 5 days. Moving up towards the center and north, we see that the offset values are becoming more and more significant . At the south-central zone towards Koungheul and Koumpentoum, a sharp break is observed for the values observed in the south zone. The values obtained in this zone are very large and vary around 21 and 26 days. Offset values substantially equal to those observed in the south are obtained at the stations located on the northern border with the Gambia, particularly at Nioro and Toubacouta stations. The values observed in the central-western part of the country are lower and range from 19 to 20 days. The highest offset values are observed at stations in the eastern part of the country and can be reached at 28 or 29 days.

Figure 8 shows scatter plots giving the relationships between Sowing and TotRain and between Sowing and DryMax. These Seasonal components are standardized to the zero mean and unit of variance at the station level. The error bars in figure 8 are an estimate of the variance between sites in the same agro-climatic zone. It is observed that at the stations located in the North and North-Central zone of Senegal, the correlation coefficients between Drymax and Sowing and TotRain and Sowing are negative and low. In addition, the correlation between Sowing and TotRain in the northern zone is smaller in absolute terms than the one between DryMax; they are −0.048 and −0.39, respectively. The Pearson correlation test between the two correlation coefficients showed a significant difference (p-value = 0.0263), which suggests that early or late seeding in the northern zone has more effect on the length of break (DryMax) after seeding than on the amount of rain recorded within 30 days after seeding (TotRain). In the North Central Zone, although correlations between TotRain-Sowing and DryMax-Sowing are low, the values found are close in absolute terms and equal to 0.38 and −0.44, respectively. The Pearson test between these two correlation coefficients gives a significant difference (p-value = 0.0001).

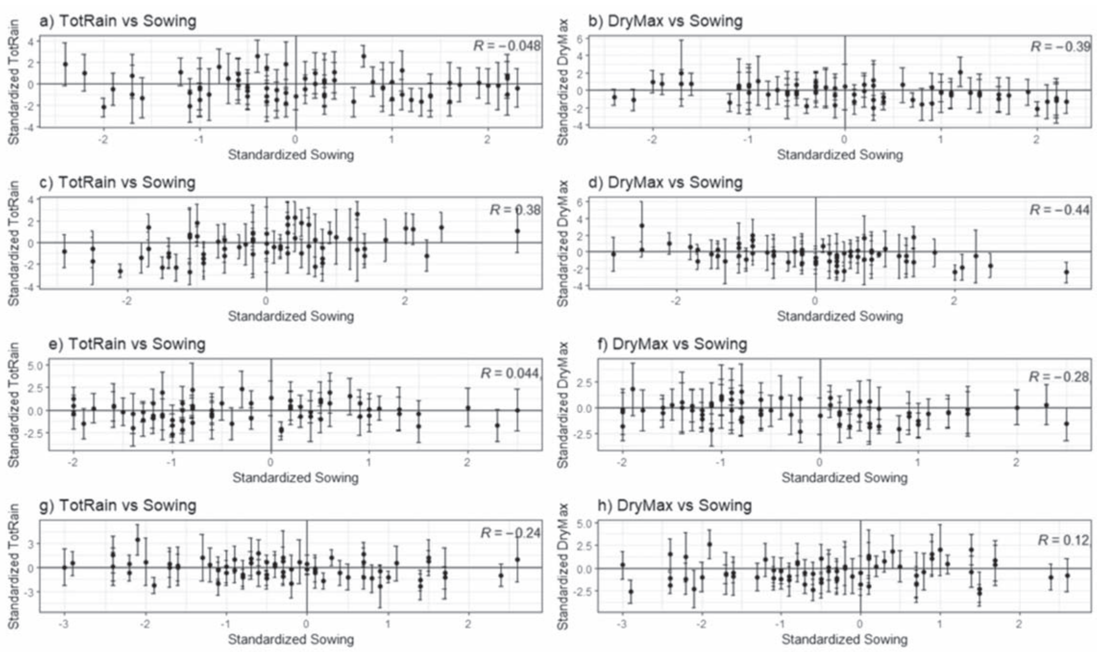

Figure 8. Correlation of the anomalies between Sowing-TotRain and Sowing-DryMax [1st line north zone (isohyètes: 200–400 mm), 2nd line: Central north zone (isohyètes:400–600 mm), 3rd line: Central south zone (isohyètes: 600–800 mm), 4th line: South zone (isohyètes: 800–1200 mm].

Thus, in the same way, as in the northern zone, late or early seedlings have a greater impact on DryMax than in TotRain, but with a smaller weight than in the northern zone. A similar result to that observed in the North zone is observed in the Center-South zone, except that the correlation between DryMax and Sowing is −0.28 and therefore weaker than the one found in the North zone. (See figure 8). However, the Pearson correlation test carried out on the correlation coefficients shows that the null hypothesis is accepted at the threshold of a probability of 5% (p-value = 0.1367). The same result is obtained in the southern zone of the country, where the isohyets are below 800 mm. The values of correlation coefficients found always remain low. Although the correlation coefficient obtaining between TotRain and Sowing is greater than the coefficient between Dry-Max and Sowing. The null hypothesis is rejected by the Pearson correlation test (p-value = 0.0910) between the two correlation coefficients. So for the South-Central and South-Central zones, we can't say that the seedling has more impact on the DryMax than on the TotRain.

4. Discussion and conclusion

In this study, the most relevant seasonal components to characterize the start of the season were studied at several sites and locations across the country. The density of stations used is fairly representative to draw conclusions about the seasonal characteristics of the entire region. The seasonal components studied showed very little change. In the study done by [9], the Onset, the Sowing dates, and the rainy season length are the most statistically stable seasonal components since 1950, and an inter-seasonal temporal variability is observed for these factors in the northern and central parts of the country. Our results support these findings; indeed the new trends of return to wet situations are observed in the northern and central areas of the country, but they are marked by considerable inter-annual variability. Very few stations have shown statistically significant change points. The particularity of Matam station that, Onset, Sowing, and TotRain components gave breakpoints can be explained by the fact that Matam is located between the North and North-Center zones. So the region is characterized over time by two different climatic situations. Stations between two agro-climatic zones have shown much more breakpoints, due to the 200 km southward isohyets shift of during the droughty time period [18], which has been reflected in zonation changes and consequently changes in climatic characteristics.

In contrast to what is observed and reported throughout the Sahel region by several researchers on the start of the rainy season. In Senegal the start follows a SE-NW gradient; the season starts in the extreme south-east part of the country between the end of May and the beginning of June. However, the sowing starts in the east-central part of the country. Although the methods adopted by the farmers on the sowing differ from the central and southern parts, they are implemented at the same time in these two parts. When the season starts in the extreme southeast, the farmers of this zone sow their seeds. During this time the first rains of at least 10 mm that can motivate the sowing are observed in the central-east parts. In the southern part, farmers often sow after the start of the season or wait for certainty of a high season. In the central and northern parts of the country, the millet is sown before the arrival of the rains, or after a rain of at least 10 mm. Extreme dry spells or crop failure situations are observed only in the northern and central parts of the country. Indeed, in the southern part, farmers sow in most cases after the rainy season has been set up, which cannot be followed by breaks damaging crops. The phenomenon of false starts of the season, which could have harmful repercussions on the crops, is observed only in the areas above the 800 mm isohyet. Indeed, even if the mean Drymax values found in the central part of Senegal may create a situation of water deficit to crops, it would not be fatal given the amount of rain observed within 30 days after sowing. So the phenomenon of false starts is not a real danger for crops in these areas, notwithstanding extreme dry spells of above-average duration fatal to crops –i.e., greater than 15 days– observed throughout the area. On the other hand, in the north-central and northern areas, DryMax is longer and has a strong seasonality further north. In the north of the Groundnut basin, where agricultural activities are more intense, compared to the northern zone of Senegal, episodes of extreme dry spells are observed and as they have become more and more frequent.

Furthermore, the lag in the number of days between Onset and Sowing dates remains very low or equal to zero in the southern part of the country but tends to increases when moving further north. The offset values obtained in the South are similar to the values obtained on the stations located on the northern border with the Gambia (Nioro and Toubacouta). This is due to fact that in these zones in most cases the sowing is done in moist soil conditions similar to those in the Central-South-East part of the country. The Onset is close to the start at the stations in the South zone. According to [19], the Intertropical Front (FIT) approaches Senegal in its southeastern part and evolves progressively towards the north. Ndong [36] used six stations to characterize the start of the rainy season in the central region of the country. The results from his study showed that the stations in the central-western region (Nioro and Kaolack locations) had earlier start date. However, the large offset values obtained at the center-south-east zone are due to the precocity of the sowing operation. The TotRain and DryMax factors show a North-South gradient. The TotRain values are greater in the South zone and decreases as you go further North you go, while the DryMax values change in the opposite direction, they are low in the southern zone and increases as one moves further North. Extreme dry spells ($>$ 15 days) are often observed in the Center (Center-North and Center-South) and North zones but remain more frequent in the Northern zone of the country where they are much more observed between May-June-July [32].

Late or early Sowing behavior is more apparent in the DryMax than in the TotRain at the North and North-Central sites. Therefore, early sowing in these areas has more effect on DryMax than TotRain. But that effect decreases as you move south. Studies have shown, that annual rainfall above or equal-to-normal rainfall totals, is strongly linked to events of false starts of the season [32, 37] noted for Senegal on an intra-seasonal scale that when the start of the season is early (late), rainfall totals in northern Senegal in July-August-September are higher (low) than average. Similarly, [38] reveal similarities between Senegal and Niger in that, at a local scale and above 800 mm isohyet, the occurrence of extreme breaks during the months of May and June is linked to the starting date of the season. However, no such relationship has been observed in the South.

Finally, the development of the starting typology of the rainy season in Senegal is necessary because the rainfall dry spells at the beginning of the season are recurrent in recent decades. Their direct effects on crop success have been studied for different agro-climatic zones of the country. We can say that the parts of Senegal above the 800 mm isohyet are exposed to extreme breaks at the beginning of the cycle. However, the offset values between the start and sowing dates show that the Mid-Southeast zone remains highly exposed to extreme dry spells at the start of the rainy season because sowing is done very early in this zone and Onset does not follow automatically. The Central-West area towards Nioro du rip, which is the heart of the groundnut basin could escape the episodes of false starts (low offset values). Researchers have always been concerned about the success of the crops at the early stage in Sahelian countries. The recurrence of crop failure after sowing has always been a problem for farmers. This work reinforces our knowledge on the prediction of rainy season breaks, and could provide additional support for early warning systems that help farmers to better cope with false starts of the rainy season. The impact of this starting typology on the season profile and on yields deserves to be studied in order to better mitigate the effects of long and recurrent rainy season breaks throughout the crop cycle. The results of this study show also the vulnerability of the west-Sahelian zone to the consequences of climate changes such as the recurrence of floods and periods of drought during the rainy season. The recurrence of floods and drought negatively affects food security [39]. In addition to socio-economic factors, most Sahelian households have very low incomes so any decrease in incomes will cause food insecurity for these individuals. Climate change is affecting agricultural productivity and 80% of the Sahelian agricultural population [40] is at risk of being food insecure, following an increase in the occurrence of drought or flooding.

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Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

ORCID iDs

Mame Balla Ndiaye https://orcid.org/0000-0003-0757-2215

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