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Impacts of Intra-Seasonal Rainfall Variability and Cropping Practices on Cereal Yields in Sub-Saharan Africa

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Abstract: West African Sahel is one of the most exposed areas to the adverse effects of climate variability. All the agricultural production systems are affected, exposing local populations to food insecurity and poverty. This study aimed to assess the impacts of intra-seasonal rainfall variability and cropping practices on cereal yields in the North Central region of Burkina Faso. Daily rainfall data covering the 1984-2015 period were collected from eleven stations across the region. The agro-climatic parameters such as the onset and the end of the rainy season, its length, seasonal rainfall amount, rainy days and long dry spells in the rainy months were determined. Annual cereal yields statistics (sorghum, millet and maize) (1984-2015) were used. Data on cropping practices were taken into account in this study. The statistical methods for trends and breaks were applied to data series. Simple correlation tests were used to assess the impacts of agro-climatic parameters on cereal yields. The results showed that the North Central region of Burkina Faso experienced extreme rainfall events such as "false starts" of rainy seasons, long dry spells and early rainfall cessation. The onset of the rainy season and the long dry spells in July (duration ≥ 8 days) and August (≥ 6 days) months had negative impacts on cereal yields in the region. The results also highlighted an increase in rainfall since the 1990s and 2000s. Increased rainfall and the positive effects of changes in cropping practices affected cereal yields, which increased significantly (44 to 72%) since that period. Dissemination of climate information, adoption of improved cropping technics and supplemental irrigation are innovating practices that could increase cereal yields in North Central Burkina Faso.

Keywords: Cereal Cropping, Agricultural Vulnerability, Rainfall Extremes, Semi-Arid Area, Cereal Yields

1. Introduction

West African Sahel is one of the most exposed areas to the adverse effects of climate change, and as such its agricultural sector is highly vulnerable [1, 2]. The most significant effect has been the long-term reduction in rainfall in the semi-arid regions of Africa [3]. During the 1968-1995 period, the Sahel experienced the largest rainfall deficit of the 20th century, in terms of duration, intensity and geographical extension [4, 5]. The length of the rainy season has been significantly reduced since the 2000s, compared to the 1980s in southern Gourma (Mali) [6]. Highly variable and late onset of rainy seasons, in contrast to the ends which were relatively constant, have been observed between 1960 and 2018 in Zinder region (Niger) [7]. Seasonal rainfall amount, rainy days and average daily rainfall decreased significantly during the dry period 1971-2000 in the cotton basin of Ivory Coast [8]. According to these authors, the decline in this area was intensified from

2011 to 2016.

In Burkina Faso, a shortening of the rainy season between 1998 and 2008 has been reported by [9]. In the southwestern part of the country, rainy seasons were characterized by low annual rainfall amount, late onset, early cessation and longer dry spells (duration > 7 days) during the dry years of 1970-2013 period [10]. Local populations in Burkina Faso perceive a late start and early cessation of rainy seasons and a higher frequency of dry spells [11-13].

The disruption of the rainy season is the result of the adverse effects of climate variability and change. Rural communities and agricultural production systems are exposed to rainfall extremes, the most recurrent of which in the Sahelian zone are "false starts of rainy seasons", long dry spells, heavy rains and early rainfall cessation, which increase the risks of food insecurity [14] and poverty. Yet agriculture is the primary source of livelihood for agro-pastoral communities in the Sahelian zone of Burkina Faso [15].

In the North Central region of Burkina Faso, agriculture accounts for more than 80% of household income. The dominant crops are sorghum, millet and maize, which are the basis of the population's diet, especially in rural areas of the country [16]. However, cereal production remains insufficient to meet the food needs of local populations, due to rainfall irregularities [17, 18], rising average temperatures [12] and declining soil fertility [19]. This region is food-dependent and needs food. In this context, it is necessary to analyze rainy season parameters and assess their impacts on cereal yields in this area. The interest of such a study is to contribute to guiding the resilience strategies of local populations in this region in the context of climate and security crisis. The study aimed to assess the effects of intra-seasonal rainfall variability and cropping practices on cereal yields in the North Central region from 1984 to 2015. Specifically, the study sought to: (i) identify cropping risks in the facing of intra-seasonal rainfall variability; and (ii) assess the impacts of variability and cropping practices on cereal yields. The study is based on the following assumptions: (i) seasonal rainfall parameters have experienced variability in the Nord Central between 1984 and 2015; (ii) the intra-seasonal distribution of rainfall affects cereal yields in the region; (iii) the "rainfall recorded" observed in recent decades had positive effects on rainfed agriculture, resulting in an increase in cereal yields; (iv) cropping practices adapting to climatic variability have contributed to an increase in cereal yields in the region.

2. Materials and Methods

2.1. Presentation of the Study Site

The North Central region of Burkina Faso covers three administrative districts: Bam, Namentenga and Sanmatenga. This region is located between the Sahelian and the Sudano-Sahelian climatic zones of Burkina Faso (Figure 1). The Sahelian zone is characterized by average annual rainfall ranging from 300 to 600 mm, and the Sudano-Sahelian zone, by average rainfall ranging from 600 to 900 mm. Rainfall increases from north to south [16]. The climate is characterized by a long dry season from November to May, and a short rainy season from June to October. According to the National Meteorological Agency (NMA), the rainy season starts on average on June 4 in the south and June 19 in the north (1981-2010 period). In 80% of cases, the rains stop after October 6 in the south and after September 18 in the north. The length of the rainy season varies on average from 110 to 120 days in the south and 75 to 85 days in the north of this zone.

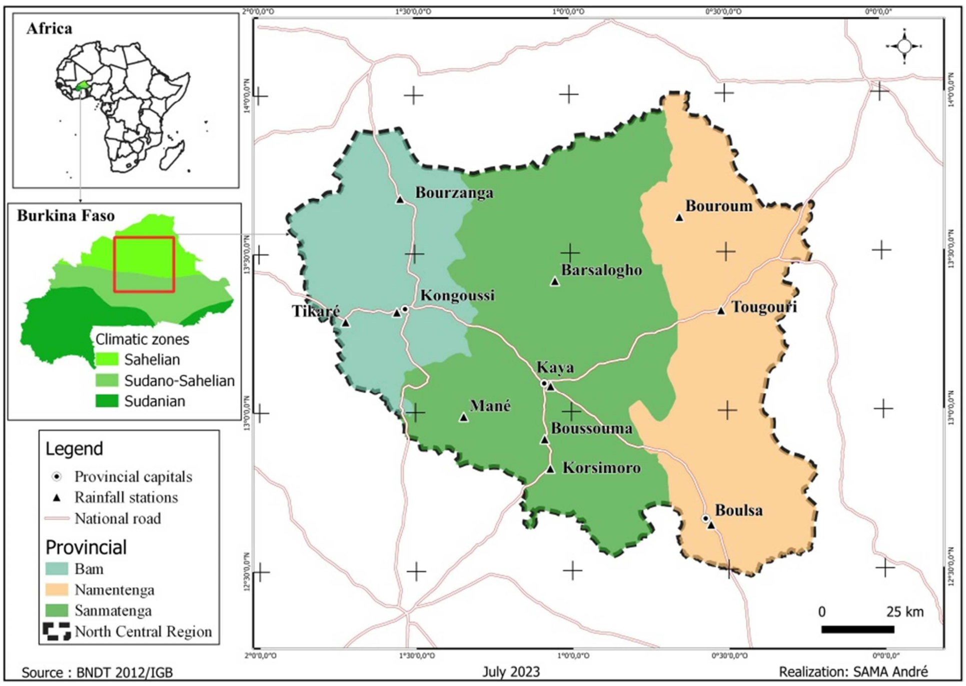


Figure 1. Localization of the North Central region of Burkina Faso.

Agriculture is the main economic activity of rural households. This agriculture is mainly rainfed, extensive, uses very few inputs, and is poorly mechanized. Main cereals grown include white sorghum, red sorghum, millet, maize, rice and fonio [20]. The average pure crop yields of millet, maize and white sorghum in 2015 were 747, 859 and 820 kg/ha, respectively. Soils are poor in organic matter, phosphorus and nitrogen [16, 18].

Farmers' main adaptation strategies to climate change are the adoption of Water and Soil Conservation (WSC) techniques, the construction of manure pits, the adoption of off-season irrigation and the change of crop varieties coupled with the use of good quality seeds. The most common practices are stone cordons, manual *zaï* and half-moons [20]. We also note the presence of *Andropogon gayanus* or *Euphorbia balsamifera* strips and mulching [21]. These techniques are fairly widespread in this region (26.5% compared to 17.5% for the national average). There is also a significant use of phosphate (easily soluble) (20.8%) in composting. The quantities of mineral and organic fertilizers distributed in 2008 to farmers were 210 258 tons of phosphate, 975 595 tons of NPK, 121 739 tons of urea and 17 184 443 tons of organic manure [22].

2.2. Theoretical Framework

This study based on the relationships between intra-seasonal rainfall variability and variations in cereal yields on the one hand, and increased rainfall and changes in these yields, on the other. It also investigated the positive effects of adaptation practices to climate variability on yields increases. The "rainfall effect" and the "adaptation effect" in increasing yields have been analyzed separately and complementarily. The intra-seasonal distribution of rainfall has adverse effects on rainfed agriculture. As a result, dry spells strongly affect cereal crop yields [23, 24, 10]. Several studies also showed that the use of WSC techniques combined with organic manure and improved varieties significantly increase cereal yields in this zone [25, 21, 26]. The causal relationships between the intra-seasonal distribution of rainfall and the variation in yields have been put into perspective by means of simple correlation tests. The analysis of the impacts of increased rainfall on cereal yields increase was based on information on the break-up period of both parameters. The analysis of the positive effects of cropping practices on cereal yields increase was based on the results of simple correlation tests and on the scientific literature on the subject in the study area.

2.3. Data Collected

Climatic data have been collected from the NMA of Burkina Faso and cover the 1984-2015 period. The data consisted of daily rainfall series from eleven stations in the North Central region (Figure 1). The agricultural data concerned only rainfed agriculture. They come from General Direction for Sectoral Studies and Statistics (GDSSS) of the Ministry of Agriculture, and also cover the same period. These were annual data on sorghum, millet and maize yields by province. They have been collected annually by the GDSSS as part of its Permanent Agricultural Surveys (PAS). The PAS methodology used to acquire agricultural data is as follows: cultivated areas have been first estimated by measuring all the sown plots in a sample on August 15 of each year. On this date, the forecast crop yields were estimated from satellite-measured vegetation data and final yields from the previous season. The estimated area is repeated on September 15. The final yields have been obtained by placing yield squares on all plots in all sampled households. These are simple average yields obtained from 25 m^2 squares placed randomly in the crop plots [27]. Household size varies annually in each of the three provinces, primarily due to budget constraints. Table 1 shows for example the size of households sampled during the 2008-2015 period. Weighing was done at the end of the harvest. Pure crop yields have been considered in this study. An area-weighted average yield has been calculated for the three provinces using the following formula:

$$WAY = \sum Yi \times Ai / \sum Ai$$

Where WAY is the weighted average yield (kg/ha); i is the province; Y is the yield (kg/ha) and A is the cultivated area (ha).

Table 1. *Size of households sampled during the 2008-2015 period in the North Central region.*

Years / Province	2008	2009	2010	2011	2012	2013	2014	2015
Bam	112	63	131	51	62	63	55	73
Namentenga	175	97	157	85	86	98	60	76
Sanmatenga	134	71	156	67	70	66	54	89
Total region	421	231	444	203	218	227	169	238

Sources: General Direction for Sectoral Studies and Statistics (GDSSS) of the Ministry of Agriculture

2.4. Data Analysis

A quality control of the daily data has been carried out before any use. This involved detecting and correcting any outliers in the data. These are mainly missing values, rain traces and erroneous rainfall values (negative rainfall). The gaps correction has been made for a given station by using a multiple regression between the existing values of that station and those of two to three closest stations in the same climatic zone. The data for the cereal yields have been also subjected to a rigorous quality control before any use.

A rainy season is characterized by a set of agro-meteorological events. These events are key characteristics or factors in the success or failure of the agricultural season. These parameters are the onset (Start) and cessation (End) dates of the rainy season, the length of the rainy season (Length), the seasonal rainfall amount (SeaAm), the number of rainy days (Raiday) and the longest dry spells (DS) in a given period [28]. Table 2 lists six agro-climatic parameters used in this study. According to [29], the rainy season begins when, from April 1st of the current year, rainfall of at least 20 mm is recorded for one or two consecutive days, with no dry spell of more than 7 days in the following 30 days. The criterion for the end of the rainy season is based on the water balance. It is sought from September 1st, when the useful water reserve of the soil is depleted and remains less than or equal to 0.05 mm, following daily evapotranspiration of 5 mm [29]. The maximum usable water reserve (UR) corresponding to the soils of different stations has been used. Calculating season length is based on the difference (in Julian days) between season start and end dates. The seasonal cumulative rainfall was determined by the amount of rainfall collected between these dates. The maximum dry spells of the four rainy months (June, July, August and September) have been determined on the basis of the 1 mm/day threshold. Indeed, it is during this period that the critical phases of the plant take place (tillering, flowering, seed formation and filling). Several consecutive days without rain ≥ 1 mm constitute a dry spell. The maximum dry spell of a rainy month is defined as the maximum number of consecutive dry days without rain recorded during that month. For example, the maximum dry spell in June is calculated as follows: if this dry spell starts at the end of May, the number of consecutive days without rain in May is counted for the month of June. If it does not rain from 25 may to 6 June, the duration of the dry spell in June is 12 days (i.e., 6 days in May and 6 days in June [28]. The frequency of rainfall ≥ 5 mm/day has been determined (period from April 1st to 31 October of each year) and counted. It is assumed that a daily rainfall of at least 5 mm has more impacts on crop phenology if daily water losses through evapotranspiration are taken into account. These losses are fixed at 5 mm/day for soils in the Sudano-Sahelian zone [30]. They correspond to the maximum daily evapotranspiration during the maize development cycle [31].

Table 2. *List of the agro-climatic parameters used.*

Acronyms	Definition of the agro-climatic parameters	Units
Start	Start date of the rainy season	Julian days
End	Cessation date of the rainy season	Julian days
Length	Length of the rainy season	Days
SeaCum	Seasonal cumulative rainfall recorded between the start and cessation of the rainy season	Mm
Rainday	Number of rainy days ≥ 5 mm	Days
DSJune	Longest dry spell in June	Days
DSJuly	Longest dry spell in July	Days
DSAugust	Longest dry spell in August	Days
DSSeptember	Longest dry spell in September	Days

Statistical methods for trends and breaks were applied to the series of agro-climatic parameters and cereal yields. These methods are: the rank correlation test [32, 33] which has been applied here to test whether these series are random or not. Pettitt A. N. test [34] allows the detection of the presence of a break in the series studied. A "break" can be defined as a change in the probability distribution of the random variables whose successive realizations define the time series studied [35]. The results of this test are based on three significance levels: 90%, 95% and 99%. Lee and Heghinian test [36] test give the posterior probability density of the breakpoint position. The segmentation method [37] makes it possible to detect several changes in the mean within the same series. These methods are integrated in the Khronostat 1.01 software [38]. Simple correlation tests have been performed to highlight the impacts of agro-climatic parameters on cereal yields from 1984 to 2015. In this study, no factor is controlled. INSTAT+ 3.036 software has been used to determine seasonal parameters. Frequency analyses have been performed probability levels of 20%, 50% and 80%. These probability levels correspond respectively to the start and end dates of the early, normal and late rainy seasons. For the length, these probabilities correspond respectively to short, normal and long seasons. SPSS 22 software has been used to perform simple correlation tests between the agro-climatic parameters and the yields of each of the three cereals.

3. Results

3.1. Evolution of Annual Rainfall

According to the mean annual rainfall observed at five of the eleven stations in the region (1984 to 2015), a break in the rainfall increase has been detected, covering the period 1987-2008 (Table 3). This period is more likely to occur between 1987 and 1990 for the three stations in the Sahelian zone. The years 2007-2008 correspond to a period of increased rainfall for two localities in the Sudano-Sahelian zone. The increase seems to have first affected the Sahelian zone between the late 1980s and early 1990s, and the Sudano-Sahelian zone during the 2000s. This increase appears to be greater in the Sahelian zone than in the Sudano-Sahelian zone.

Table 3. *Average rainfall increases observed with respect to the break-up date during the 1984-2015 period in five of eleven localities in the North Central region.*

Statistical methods					
Rainfall stations	**Segmentation of Hubert and Carbonnel**	**Lee and Heghinian test**	**Mean before breakage (mm)**	**Mean after breakage (mm)**	**Increased rainfall (%)**
Sahelian zone					
Barsalogho	1990	1990	429	608	+41.72
Bouroum	1987	1987	346	577	+66.76
Bourzanga	1987	1987	389	529	+35.98
Mean					+48.15
Sudano-Sahelian zone					
Boulsa	-	2008	619	767	+19.29
Boussouma	2008	2007	603	796	+32.00
Mean					+25.64

Data source: National Meteorological Agency (NMA) of Burkina Faso

3.2. Evolution of the Daily Rainfall Regime

The annual number of rainy days (Rainfall ≥ 0.1 mm) increased between 1984 and 2015 in five of the eleven North Central localities. This trend has been confirmed in three localities by the correlation test on rank at confidence levels ranging from 90 to 99%. An upward break has been observed between 1988 and 2008 in four localities. This period corresponds to the period of increased rainfall. In contrast, rainy days showed a slight decreasing trend (not confirmed at 99% threshold) in five localities of the region. The frequency of rainfall ≥ 5 mm averaged 14 days in both climate zones. Analysis of the monthly distribution of these rainy days showed a greater frequency during August, September, and October. The frequency of rainfall ≥ 5 mm indicated an increasing trend (confirmed at 90% threshold) between 1984 and 2015 in both climate zones. The increase in rainfall amounts is partly related to the increase in rainy days.

3.3. Evolution of the Start and Cessation Dates and Length of the Rainy Season

The rainy season starts on average on June 21 in the Sudano-Sahelian zone and on June 29 in the Sahelian zone (Table 4). The rainy season starts from the south to the north part of the region. The early, normal, and late starts of the season respectively occur from June 15, June 30, and July 11, in the Sahelian zone. In the Sudano-Sahelian zone, the early, normal, and late starts to the season were observed from June 12, June 21 and July 5, respectively. The 1984-2015 period showed a trend towards an earlier rainy season in the Sahelian zone. In the Sudano-Sahelian zone, the trend towards an early start to the season has been confirmed by the rank correlation test in two localities (95% threshold for Mané and 99% for Kaya), but not confirmed in two other localities. There is also a trend towards a late start to the rainy season in three localities in the region (Kongoussi, Korsimoro and Tikaré).

The rains stopped on September 19 in the Sahelian zone and on September 25 in the Sudano-Sahelian zone. This cessation follows the opposite direction of the rains. The early, normal and late cessation of the seasons respectively occurs on September 9, September 19 and September 27, in the Sahelian zone. In the Sudano-Sahelian zone, the cessation of the season respectively occurred on September 19, September 27 and October 6. A trend towards a late cessation to the rains (confirmed at 99% threshold) has been observed in the Sahelian zone, with a significant break (95% threshold according to Pettitt A. N. test) in 2006. The Sudano-Sahelian zone showed a trend towards an early cessation of rains in two localities, and a trend towards a late cessation in four localities (Boulsa, Boussouma, Mané and Kaya) in the North Central.

The length of the rainy season averaged 88 days in the Sahelian zone and 107 days in the Sudano-Sahelian zone. The short, normal and long of seasons last 74, 87 and 103 days, respectively in the Sahelian zone. In the Sudano-Sahelian zone, these types of seasons lasted 90, 106 and 123 days, respectively. A trend towards a longer rainy season (confirmed at 99% threshold by the rank correlation test) has been observed in the Sahelian zone, with an average increase of 25 days between 2009 and 2015. The Sudano-Sahelian zone also experienced an increase in the length of the rainy season, with an average increase of 26 days from 2008 to 2015. The end of the 2000s was saw by a trend towards longer seasons in the region.

Table 4. *Average start and cessation dates and the length of the rainy season calculated at ten rainfall stations in the North Central region between 1984 and 2015.*

Rainfall stations	**Parameters of the rainy season**		
	Starting dates of the rainy season	**Cessation dates of the rainy season**	**Length of the rainy season (days)**
Sahelian zone			
Barsalogho	2 July	16 September	80
Bouroum	3 July	15 September	83
Bourzanga	21 Jun	17 September	90
Tougouri	26 Jun	26 September	100

Rainfall stations	Parameters of the rainy season		
	Starting dates of the rainy season	Cessation dates of the rainy season	Length of the rainy season (days)
Mean	29 Jun	19 September	88
Sudano-Sahelian zone			
Boulsa	17 Jun	30 September	114
Boussouma	28 Jun	26 September	106
Kaya	24 Jun	2 October	113
Kongoussi	23 Jun	26 September	101
Korsimoro	26 Jun	18 September	95
Mané	22 Jun	3 October	113
Mean	21 Jun	25 September	107

Data source: National Meteorological Agency (NMA) of Burkina Faso

3.4. Monthly Distribution of Maximum Dry Spells

During the 1984-2015 period, the maximum dry spells of the four rainy months averaged 14, 8, 6, and 9 days, in June, July, August, and September, respectively (Table 5). The long dry spells in June with a mean duration ≥ 15 days could reflect "false starts" of rainy seasons. The localities of Barsalogho and Bouroum (Sahelian zone), Kongoussi and Tikaré (Sudano-Sahelian zone) appear to have experienced “false starts of seasons”. The maximum dry periods are shorter in August and September. Those in September (duration ≥ 8 days) could reflect early season cessation observed in both climate zones. Overall, there is an upward trend in the duration of long dry spells in June over the 1991-2015 period. Other rainy months showed a downward trend in the duration of long dry spells (1984 to 2015).

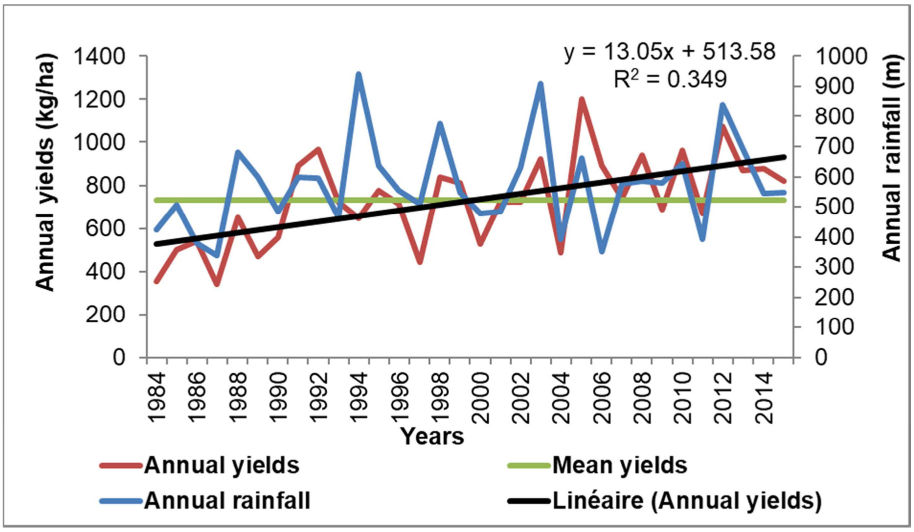
Table 5. *Average distribution of maximum dry spells during the months of June, July, August and September for the period 1984-2015 in the North Central region.*

Rainfall stations	Rainy season months			
	June dry spells (days)	July dry spells (days)	August dry spells (days)	September dry spells (days)
Sahelian zone				
Barsalogho	17	9	6	9
Bouroum	17	9	6	10
Bourzanga	14	7	6	9
Tougouri	13	9	6	9
Mean	15	8	6	9
Sudano-Sahelian zone				
Boulsa	11	7	5	8
Boussouma	14	8	6	9
Kaya	14	9	5	8
Kongoussi	15	8	6	8
Korsimoro	14	9	6	8
Mané	13	7	5	9
Tikaré	16	9	7	10
Mean	14	8	6	9

Source: National Meteorological Agency (NMA) of Burkina Faso

3.5. Evolution of Cereal Yields (1984-2015)

Average cereal yields were 729 kg/ha for sorghum, 648 kg/ha for millet and 755 kg/ha for maize from 1984 to 2015. Figure 2 shows this upward trend, which is confirmed by the rank correlation test at the 99% confidence level for sorghum and millet, and 90% for maize. Three periods could be observed in the evolution of sorghum yields: the 1984-1990 period, when yields are below the interannual average; the 1991-2004 period, when yields fluctuated around this average; and the 2005-2015 period, when yields are above the interannual average. The evolution of millet yields has been marked by two periods: the 1984-2004 period, when millet yields fluctuated around the interannual average; and the 2005-2015 period, when yields were above this average. Maize yields have also evolved over two periods; the 1984-1992 period marked by low yields, and the 1993-2015 period where yields fluctuated around the 1984-2015 average. The upward break in yields for all three cereals occurred between 1990 and 2004 (Table 6). We note that this period appears similar to the period of increased rainfall. There would be a causal relationship between the increase in annual rainfall and that of cereal yields. Annual maize yields increased significantly (90% threshold) by +72% between 1992 and 2015. Annual sorghum yields increased by +63% between 1990 and 2015. Annual millet yields increased significantly (90% threshold) by +44% from 2004 to 2015.



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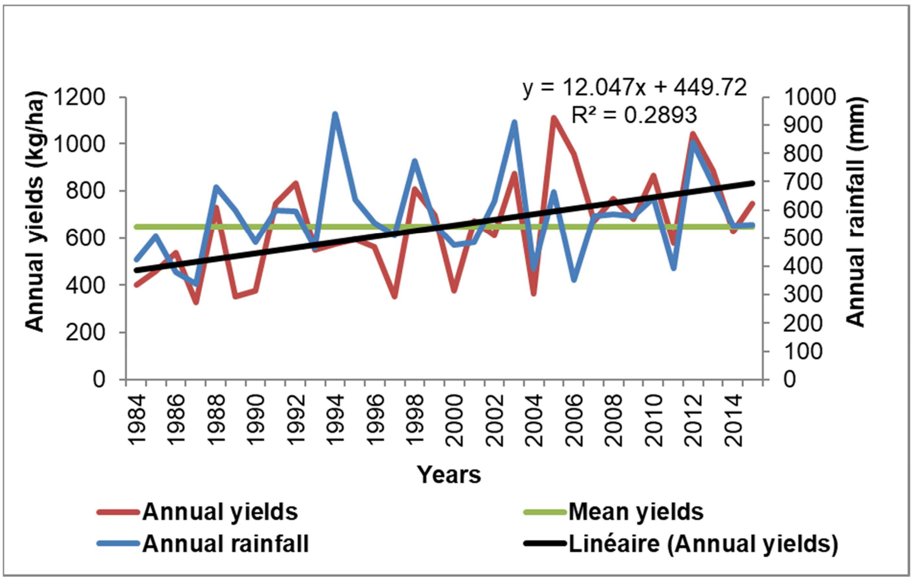

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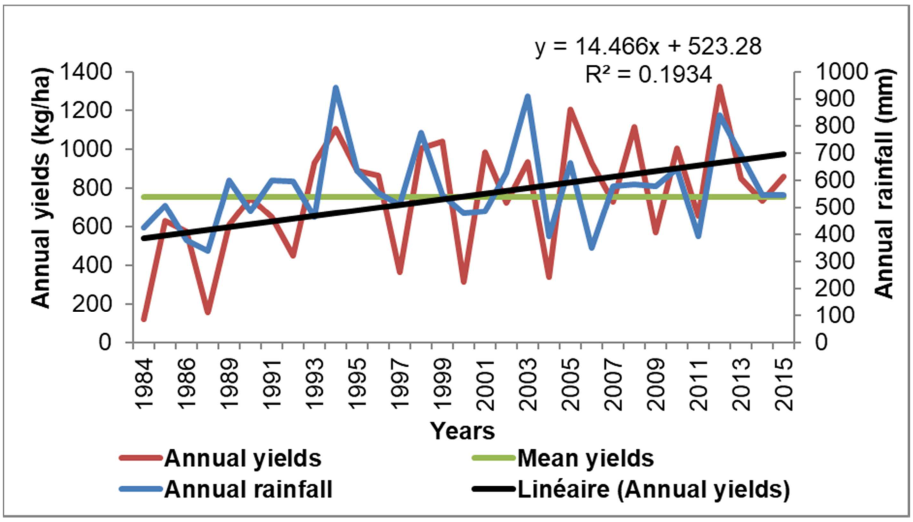

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Figure 2. *Evolutionary trend of annual sorghum (A), millet (B) and maize (C) yields between 1984 and 2015 in the North Central region.*

Table 6. *Results of break detection tests applied to sorghum, millet and maize yields (kg/ha) during the period 1984-2015.*

	Statistical methods					
Cereal yields	**Pettitt**	**Lee and Heghinian**	**Hubert and Carbonnel**	**Mean before breakage**	**Mean after breakage**	**Increase (%)**
Yields sorghum	2004**	1990	1990	487	796	+63
Yields millet	2004**	2004	2004	562	812	+44
Yields maize	1992*	1992	1991	492	846	+72

Legend: The signs ***, ** and * mean that the break is significant at the 99, 95 and 90% threshold respectively according to the result of Pettitt A. N. test.
Sources: General Direction for Sectoral Studies and Statistics (GDSSS) of the Ministry of Agriculture

3.6. Impacts of Intra-Seasonal Rainfall Variability on Cereal Yields

The results of simple correlation tests between agro-climatic parameters and cereal yields are reported in Tables 7, 8 and 9 for maize, sorghum and millet, respectively. The responses of cereal yields to rainfall variability appear to differ from one cereal to another. Indeed, Table 7 indicates that 71% of interannual variations in maize yields are significantly explained by seasonal cumulative rainfall and 58% by the season's break period (1% threshold), and 45% by the number of rainy days (5% threshold). Maize yields are highly dependent on water requirements. There was also a positive (R = +38) but significant (5% threshold) correlation between maize yields and season length. Long dry spells in June do not appear to affect rainfed maize yields. In contrast, long dry spells in August had a significant (1% threshold) negative impact on maize yields (R = -0.64).

Table 7. *Pearson correlation matrix between agro-climatic parameters and annual maize yields for the 1984-2015 period in the North Central region.*

Variables	Start	End	Length	SeaAm	Raiday	DSJun	DSJuly	DSAug	DSSept	Yieldsmaize
Start	1									
End	-0.14	1								
Length	-0.47**	0.70**	1							
SeaAm	-0.49**	0.78**	0.62**	1						
Raiday	-0.57**	0.19	0.37*	0.58**	1					
DSJun	0.52**	0.00	-0.26	-0.15	-0.58**	1				
DSJuly	0.40*	-0.43*	-0.41*	-0.50**	-0.19	-0.04	1			
DSAug	-0.11	-0.55**	-0.20	-0.49**	-0.12	-0.29	0.30	1		
DSSept	0.05	-0.28	-0.17	-0.17	0.14	-0.10	0.21	-0.04	1	
Yieldsmaize	-0.22	0.58**	0.38*	0.71**	0.45*	0.009	-0.30	-0.64**	-0.12	1

** Significant at the 1% threshold; * significant à the 5% threshold.

Table 8 shows that 56% of interannual variations in sorghum yields are explained by seasonal cumulative rainfall and 54% by the occurrence of rainy days at the 1% significance level. Variations in these yields are explained significantly and to a lesser extent at 39% by the length of the rainy season and 38% by the cessation period at the 1% threshold. The long dry spells in July and August had significantly (5% threshold) affected sorghum yields at 39% and 41% annual change, respectively. There was a negative (R = -0.41) but significant (1% threshold) correlation between rainy season onset and sorghum yields.

Table 8. *Pearson correlation matrix between agro-climatic parameters and annual sorghum yields for the period 1984 to 2015 in the North Central region.*

Variables	Start	End	Length	SeaAm	Raiday	DSJun	DSjuly	DSaug	DSSept	Yields Sorghum
Start	1									
End	-0.14	1								
Length	-0.47**	0.70**	1							
SeaAm	-0.49**	0.78**	0.62**	1						
Raiday	-0.57**	0.19	0.37*	0.58**	1					
DSJun	0.52**	0.00	-0.26	-0.15	-0.58**	1				
DSJuly	0.40*	-0.43*	-0.41*	-0.50**	-0.19	-0.04	1			
DSAug	-0.11	-0.55**	-0.20	-0.49**	-0.12	-0.29	0.30	1		
DSSept	0.05	-0.28	-0.17	-0.17	0.14	-0.10	0.21	-0.04	1	
Yields Sorghum	-0.41*	0.38*	0.39*	0.56**	0.54**	-0.23	-0.39*	-0.41*	0.22	1

** Significant at the 1% threshold; * significant at the 5% threshold.

Table 9 indicates that the annual variations in millet yields are significantly explained by cumulative seasonal rainfall at 57% and by the frequency of rainy days at 51% (1% threshold), and at 40% by the season's cessation period (5% threshold). The long dry spells in July and August account for the low annual millet yield variations of 38% and 42%, respectively. In contrast, the short rainfall breaks in September seem to have positively affected millet yields, as was the case for sorghum (Tables 7 and 8). There was also a slight negative (R = -0.37) but significant (1% threshold) correlation between season onset and millet yields.

Table 9. *Pearson correlation matrix between agro-climatic parameters and annual millet yields for the period 1984-2015 in the North Central region.*

Variables	Start	End	Length	SeaAm	Raiday	DSJun	DSJuly	DSAug	DSSept	Yields millet
Start	1									
End	-0.14	1								
Lenght	-0.47**	0.70**	1							
SeaAm	-0.49**	0.78**	0.62**	1						
Raiday	-0.57**	0.19	0.37*	0,58**	1					
DSJun	0,52**	0,00	-0,26	-0.15	-0.58**	1				
DSJuly	0.40*	-0.43*	-0.41*	-0.50**	-0.19	-0.04	1			
DSAug	-0.11	-0.55**	-0.20	-0.49**	-0.12	-0.29	0.30	1		
DSSept	0.05	-0.28	-0.17	-0.17	0.14	-0.10	0.21	-0.04	1	
Yields millet	-0.37*	0.40*	0.34	0.57**	0.51**	-0.15	-0.38*	-0.42*	0.15	1

** Significant at the 1% threshold; * significant at the 5% threshold

4. Discussion

4.1. Rainfall Pattern Dynamic in the North Central Region

The North Central region of Burkina Faso has been adversely affected by climate variability since several decades. The most significant effect is the decrease in annual precipitation since the late 1960s [17]. However, the situation has improved during recent decades. Indeed, this study highlights an increase in annual rainfall since the 1990s and 2000s in the region. Increased rainfall has already been confirmed in the West African Sahel by several studies. For example, the years 1991-2014 have been a period of "rainfall recovery" for Burkina Faso [39]. Similarly, a return to rainy periods has been observed since 1998 in Niger [40]. This study shows that "rainfall recovery" is more marked in the Sahelian zone than in the Sudano-Sahelian zone. In Benin, a greater increase in rainfall in the dry tropical zone than in the sub-humid zone over the 1976-2015 period has been observed by [41].

The installation of the rainy season progresses gradually from south to north in the North Central region. Its cessation follows the opposite direction. In Burkina Faso, the onset of the rainy season reaches the central zone in May-June, and the north in June or early July [29]. The start of the rainy season is linked to the early or late penetration of the West African monsoon, which moves from southwest to northeast in the country.

"Rainfall recovery" is followed by a trend towards an improvement in the quality of rainy seasons in two climate zones. Significant late and early starts of rainy seasons have been observed in the west and east (by 1.5° west longitude), respectively, in Ghana between 1981 and 2019 [42]. Similarly, significant late cessations and longer rainy seasons were noted in the north of this country. Since 2008, particularly early rainy seasons starts have been observed by rural populations in Bambey, Sénégal [43]. Other studies reported deterioration in the quality of rainy seasons in Burkina Faso. Indeed, a significant increase in the frequency of late seasons starts between 1986 and 2013 in southwestern of the country was evoked by [10]. A shortening of the length of rainy seasons has been observed between 1998 and 2008 in Burkina Faso [9].

The phenomena of false starts and early ends of rainy seasons are common in the North Central region. "False starts" of rainy seasons are manifested by dry spells whose duration exceeds 15 days during May, June or July. The early cessation is characterized by dry spells of 8 to 14 days observed between August and September [44, 45]. A significant increase in the duration of June and July maximum dry spells between 1960 and 2018 in Zinder region has been reported by [7]. The occurrences of false starts of rainy seasons, long rainfall breaks, and early season cessation constitute rainfall extremes, which are more recurrent in the Sahelian zone of West Africa [13].

4.2. Impacts of Intra-Seasonal Rainfall Variability on Cereal Yields

Our study shows that the pattern of the onset of the rainy season had significant negative impacts on sorghum and millet yields. The onset of the season (May-June-July) is prone to false starts, which are sometimes responsible for seedling losses in farming areas [44, 47]. Major rainfall breaks at the onset of the season affect cereal crops germination [10]. Those observed during the 30 days after planting determine the potential risks of reseeding [45]. Cereal crops grown in the Sahel are weakened when faced with water stress during their juvenile phase. The water deficit affects the photosynthetic activity of crop plants with the consequences of reduced projected yields [48]. The long dry spells observed during the start of the rainy season explains the loss of 30 to 50% of millet yields in Niger [47]. The onset of the rainy season is a major climatic risk for both cereal in the North Central region.

The maximum dry spell in June did not have a significant negative impact on maize yields. This could be related to the planting period of this crop in the region, which coincides with a reduction in the duration of rainfall breaks. Indeed, because of the high sensitivity of maize to water stress, farmers in the Bonam locality (Namentenga) generally wait until after 10 to 12 days of dry period in June before planting this crop. This period generally occurs between mid-June and early July and coincides with the visible phase of the 8th lunar cycle of the year [49]. The season onset period does not seem to constitute a major climatic risk for maize cultivation in the Sudano-Sahelian zone of Burkina Faso [24]. However, long dry spells in August particularly affect maize yields in the region.

The long dry spells in July and August significantly and negatively affect sorghum and millet yields. For 90-day cereal crops sown between mid-June and early July, July corresponds to the growing period (first 30 days after sowing), while August month corresponds to the critical period (40 to 75 days after sowing). This critical period corresponds to the flowering or maturation phase. Consequently, yield of a crop is greatly affected if the dry spell occurs during this period, reducing grain filling [23]. Similarly, dry spells occurring during the period from 15 to 25 July resulted in maize yield losses in the order of 20 to 91% compared to a situation where water requirements were met [50].

Seasonal rainfall amount, cessation period of the rainy season and the occurrence of rainy days strongly influence cereal yields. It is the cumulative rainfall in the third month after planting and the application of nitrogen fertilization that explain more of the variability in maize yields in the southern Sudanian zone of Burkina Faso [51]. Maize yields are 51.8% dependent on variations in rainfall in this zone [15]. The length of the rainy season positively and significantly influenced maize and sorghum yields in North Central Burkina Faso. However, a study showed that there are no explicit linear correlations between maize yields and the length of the rainy season after the breaks (1966, 1970, 1980, and 1982) of the 1950-2000 period in the central and northern zones of Ivory Coast [52].

This study shows that intra-seasonal variations in rainfall affect negatively cereal yields. Despite these impacts, yields have increased over two last decades. Indeed, the 1990s and 2000s exhibited an exceptional increase in cereal yields (in the order of 44 to 72%). However, these results could be moderated, given the quality of the data used. In Africa as elsewhere, agricultural statistics are often "questionable". Agricultural production data do not take into account soil parameters, the use of varieties input, optimal sowing dates, or even crop coefficients (kc) that reflect the level of water needs of crops [52].

Previous studies reported that cereal yields (sorghum, maize, millet, paddy rice) increased by 51% between 1980 and 2006 in ECOWAS countries [53]. An increase in cereal yields from the 2000s in the "New Lands" region of eastern Senegal has been reported by [54]. In the Zinder region, millet yields increased between 1991 and 2017 [7]. The increase of cereal yields in the North Central region is partly attributable to the increase in annual rainfall amount and rainy days, observed since the 1990s and 2000s. Indeed, the 1994-2015 period was marked by related a "rainfall recovery" in this region [17]. It is obvious that the increase in annual rainfall during this period will induce an increase in cereal yields.

However, it is clear that the "rain factor" alone cannot explain the inter-annual fluctuations of cereal yields. Other factors, such as cropping practices, are also involved. Indeed, a study showed that under wetter-than-normal rainfall conditions, 25% of the variations in maize yield in Ghana are attributable to non-climatic conditions or cropping practices [55].

In response to the adverse effects of climate change, African farmers have adopted adaptation strategies, the most common of which in Burkina Faso are the use of seeds of improved crops varieties, SWC techniques, organic fertilizer and modified planting dates [11]. Consequently, yields increases are likely related to the use of more drought-resistant varieties and SWC/SDR practices. These practices have been shown to be effective in improving runoff collection and maintaining soil fertility [21]. In the Central Plateau of the country, farmers have adopted short-cycle (50-70 days) and drought-resistant cereal varieties [56]. Improved varieties of millet, sorghum, and maize have been introduced in the North Central since 2001 through several agricultural programs [57]. By associating livestock farming with agriculture, animal manure and household waste are used in composting. In Burkina Faso, a study showed that 76.74% of farmers in four provinces, including Namentenga, have at least one manure pit [58].

These improved cropping practices have been implemented by farmers with the support of rural development programs and government technical services. For example, the activities of Phase II of the Special Program for Soil and Water Conservation and Agro-forestry (PS/CES-AGF) allowed for the construction of 2202 manure pits and 747 filter dikes, the development of 3224 ha of *zaï* and of 311 ha of half-moons, and the production of thousands of tree seedlings between 1995 and 2002 in seven provinces of the country, including Bam, Namentenga, and Sanmatenga [21]. The FAO has involved in the North Central region through inputs distribution in support to the government subsidy program. In fact, according to the FAO, 79360 kg of seeds (40000 kg of sorghum and 39360 kg of maize) have been distributed in 2012 to 4000 beneficiaries in the provinces of Sanmatenga and Namentenga. All of these technical supports have allowed for some agricultural intensification, which could justify this increase in cereal yields in the region.

5. Conclusion

The 1990s and 2000s were reference periods of increased rainfall in the North Central region of Burkina Faso. This increase, combined with the positive effects of changes in cropping practices, has affected cereal yields, which have increased significantly since this period. The study showed that cereal crops face climatic constraints. The main agro-climatic risks are the false starts of rainy seasons, the long dry spells observed in July and August, and the early cessation of rains. These agro-climatic risks reduce strongly cereal yields.

In addition, the northern part of North Central Burkina Faso has been subjected to numerous attacks by armed terrorist groups over the past six years. These attacks have displaced thousands of local people who had to abandon their fields, their herds and lost their economies. These abandonments will lead to a decrease in agricultural production, particularly cereal production in this region, with the risk of increased food insecurity and poverty. Facing the adverse effects of the climate and security crisis, the weak resilience capacities of local populations of this region need to be strengthened through a program or response plan. In order to strengthen cereal production in the North Central region so that it can cover the food needs of the population to a considerable extent, it is therefore necessary to promote intensive agriculture. To do this, it will be necessary to mitigate most of the constraints and difficulties related to the access climatic information, agricultural inputs, equipment and financing. The communication of seasonal climate forecasts and agro-meteorological advice are essential to help farmers better plan their agricultural activities facing climate risks. In addition, farmers must be trained to agricultural technologies and best practices. The adoption of supplemental irrigation from small individual runoff collection basins could be an innovative strategy for reducing climate risks in agriculture, as it enables crops to cover their water needs during extreme rainfall breaks. The implementation of such a resilience program will require major investment efforts by the Burkina Faso government and an amount of political will.

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