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Climate Variability in the Sudanian Zone of Côte d'Ivoire: Weather Observations, Perceptions, and Adaptation Strategies of Farmers

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Abstract: Located in the extreme north of Côte d'Ivoire, the Sudanian zone is an area where 95% of the population depends on agricultural activities, particularly rain-fed agriculture. Given the serious threats that climate variability poses to food security and household incomes, it is important to understand the evolution of climate variables and their impacts on crops, perceptions, and adaptation measures taken by farmers. To do this, various statistical analyses were conducted using rainfall and temperature data from 1987 to 2018. These analyses were coupled with a survey of 287 farmers. The results showed a strong variability of precipitation marked by the succession of deficit and surplus periods with a return to wetter conditions since 2008. At the same time, an increase in temperature was observed. These phenomena have been perceived by farmers. Thus, to cope with the adverse effects of climate variability, farmers have developed numerous adaptation strategies that include the use of organic manure, agroforestry, changing planting dates, and introducing new crops, notably cashews.

Keywords: rainfall; temperature; adaptations; family farms; Sudanian zone

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1. Introduction

Climate change and variability are increasingly the focus of global scientists and policymakers because of their myriad impacts on the natural environment and on humans. Many authors have shown that climate change and variability represent enormous challenges to humans and their socio-economic activities, health, livelihoods, and food security [1–4]. According to the Intergovernmental Panel on Climate Change [5], the consequences for countries' economies are already considerable, and the situation can worsen as the frequency of extreme events is predicted to increase with global warming [6]. The studies carried out by Folefake et al. [7] and Faye et al. [8] showed that agriculture in particular is one of the main economic sectors where climate change will have a significant impacts. Moreover, of all the continents, Africa is considered to be the most vulnerable to the effects of climate change because of the strong dependence of its economies on rain-fed agriculture, which accounts for 95% of production, and because of the difficulties of the populations to adapt [9–12]. Major phenomena such as the frequency of heavy rainfall [13], the increase in temperatures [14], the shortening of the agricultural season and prolonged dry spells will increasingly affect [15] crop growth and productivity in large areas of Africa [5,16]. Côte d'Ivoire, an emerging country in West Africa, is not immune to the threats posed by climate variability [17–19]; similar to most African countries, agriculture is one of the driving forces of the economy. However, this agriculture remains exposed to climatic hazards because of the still limited use of modern irrigation techniques and the extensive, rather than intensive, use of land [20]. For nearly four decades, climate change has had an exceptional impact on the northern and central regions of the country [21]. The changes in Côte d'Ivoire are expressed by the decrease in rainfall; the increase in temperatures; the persistence and severity of dry seasons; and the frequent floods and bush fires [22–24]. The direct consequences on agriculture are a shortening of the average duration of vegetative growth periods (shifting of the beginning of the cropping season), a low growth of biomass, and a reduction in the productive potential of ecosystems (reduction in arable land due to its degradation, increased exposure of plants to water stress, and reduction in the volume of surface water in most regions) [25]. These changes affect farmers' incomes and their ability to invest in the assets needed to expand their businesses. According to World Bank forecasts [20], by 2050, the country is likely to face the combined effect of rising temperatures (+2 degrees Celsius), and variations in rainfall (−9% in May and +9% in October) from north to south. All these phenomena are already affecting and will continue to affect rain-fed agricultural production, which covers 90% of the country's production. Without adaptation measures, yield reductions in cereal crops such as millet, maize, and sorghum are predicted by 2050, with the possibility of reaching critical thresholds [26]. In response to the adverse consequences of climate change, farmers are adopting adaptation strategies [27]. For example, in east-central Côte d'Ivoire, farmers opt for local modification of the cropping calendar, and there is a growing trend towards diversification of income sources and new food habits [28]. In the Sudanian zones of Burkina Faso and Senegal, faced with the impacts of climate variability, farmers have changed crop varieties and even speculations. They are using water and soil conservation techniques (SWC), organic fertilizer, and changing sowing dates [8,29]. In Niger, we are witnessing the expansion of irrigation systems, the adjustment of crop sowing times according to localized climate forecasts, and the selection of plants and the establishment of crops that are more tolerant to climatic stresses associated with agroforestry [30,31].

The present research was conducted in a region of Côte d'Ivoire where agriculture is strongly confronted with the reality of climate change, namely the Sudanian zone located in the extreme north of the country. As well as belonging to a dry tropical climate, this zone is marked by a unimodal rainfall (six months of the year) and it is subject to high temperatures with low humidity (60% to 70%) [32]. Furthermore, the Sudanian zone of Côte d'Ivoire remains vulnerable insofar as maize, the staple food of local populations, is one of the crops predicted to be most affected by future climate conditions. Results from the RCP2.6 and RCP6.0 climate models [33] indicate a negative trend in yields for maize, millet, and sorghum in Côte d'Ivoire, with a greater decline for RCP6.0. Compared with the year 2000, yields are expected to decline by 9% for maize and 10% for millet and sorghum by 2080 under RCP6.0 [33]. Under RCP2.6, maize, millet, and sorghum yields would decline by 5% [33]. In addition, the World Bank 2018 group [20] predicted maize yield losses in excess of 25% in the northern regions of the country. Faced with this situation, there is an urgent need to understand the current manifestations of climate change in the Sudanian zone of Côte d'Ivoire, the perceptions of farmers, and the solutions provided. Addressing this issue is in the interest of rural farmers in the current context of economic globalization. The literature indicates that many studies related to climate change have been conducted in Côte d'Ivoire [23–25,28]. However, those studies were essentially directed to forest and pre-forest zones. The Sudanian zone has long been marginalized in terms of climate change studies. The originality of this study lies in the fact that it focuses on the perceptions and feedbacks of farmers living in the Sudanian zone of northern Côte d'Ivoire to climate change. Indeed, farmers' knowledge of climate change is important for integrating climate adaptation into agricultural development strategies and plans.

The methodology applied in this study is mainly based on the analysis and interpretation of climatic variables and the adaptive reactions of farmers to this situation. Indeed, climate modification leads to social changes as it has an impact on agricultural activities and farmers' well-being [34]. The present study is based on the hypothesis that in the face of climate variability and change, which is becoming increasingly perceptible, farmers in the Sudanian zone of Côte d'Ivoire are implementing new adaptation strategies to ensure their production and the income generated by agricultural activities. For the purpose of understanding the impact of climate variability on agriculture and farmers' daily lives, this study analyzed the interannual evolution of climate variables, rainfall, and temperature over a period of 32 consecutive years from 1987 to 2018. In addition, farmers' reactions were investigated in order to better understand the adaptations induced by their perception of this climate change. Rainfall and temperature were investigated as they are recognized as the most important variables in climate science and hydrology and are frequently used to determine the extent and magnitude of climate change and variability [34]. In addition, their trends and variability are frequently mentioned as factors explaining various socio-economic problems such as food insecurity in countries where the economy is highly dependent on rain-fed agriculture [35,36]. Therefore, the analysis of changes in these meteorological variables coupled with the reactions of farmers is very crucial in order to provide policymakers and practitioners with information that would help in making accurate decisions beneficial for the sustainability of the environment and the welfare of farmers.

2. Materials and Methods

2.1. Description of the Study Sites

Côte d'Ivoire is located in West Africa and is part of the Gulf of Guinea countries. It covers an area of 322,462 km^2, about 1% of the African continent. The present study was conducted in the Sudanian zone of Côte d'Ivoire, which is located in the extreme north between 8 and 10° N, and 3 and 6° W and belongs to the dry tropical zone. Indeed, the Sudanian zone covers about 11% of the total area of Côte d'Ivoire [35]. It is dominated by savannah vegetation with a Sudanian-type climate that, while extending south of Mali and Burkina Faso, constitutes the northern limit of the Sahelian climate. The choice of this specific area of Côte d'Ivoire is based on the fact that climate forecasts indicate that it is very vulnerable to climate variability, particularly because of some of its biophysical and socio-economic characteristics. First, rainfall in this unimodal area, ranging from 400 mm to 1200 mm per year, is a limiting factor for agriculture [36] more exacerbated than elsewhere in the country. Secondly, it is subject to the continental influence of the harmattan (hot and dry wind) [37] and is marked by a water deficit greater than 500 mm due to a higher evapotranspiration (ETP) [25]. In addition, the study area is subject to temperatures ranging from 14 to 33 °C with low humidity (60% to 70%) [32]. Considering the main activity of the populations, the crops grown and the heterogeneity of the ethnic groups, three localities were chosen in the Sudanian zone to conduct the study (Figure 1). These were Tengréla, Ouangolodougou, and Tienko. In general, the economy of these different localities is essentially agricultural, with a large share provided to food crops such as maize, sorghum, rice, millet and fonio, oilseeds dominated by groundnuts and sesame, and recently cash crops led by cashew nuts and cotton. Tengréla is home to approximately 69,000 inhabitants with an average of 40.3 inhabitants/km^2 [38]. The population is predominated by the Senufo people. These populations are mostly (70%) rural and live on rain-fed agriculture. Maize, the staple food of the population, is the main cereal crop. In addition to maize, sorghum and fonio are highly prized by the people of Tengréla [39]. Ouangolodougou is home to approximately 49,000 inhabitants with 20.7 inhabitants/km^2 [38]. Besides the Senufo people, there are also the Gbin people who, as with the Senufo, depend primarily on rain-fed agriculture. Crops are dominated by corn, millet, sesame, and rice [40]. The population of Tienko is approximately 10,000 inhabitants with an average of 152 inhabitants/km^2 [38,41]. The dominant ethnic group is the Malinke, who live on rain-fed agriculture. The most common crops are rice, corn, peanuts, and fonio. In addition to agriculture, the people of Tienko are involved in trade. In view of the above, the various manifestations of climate variability are likely to compromise agricultural development and thus make family farms in the Sudanian zone of Côte d'Ivoire more vulnerable.

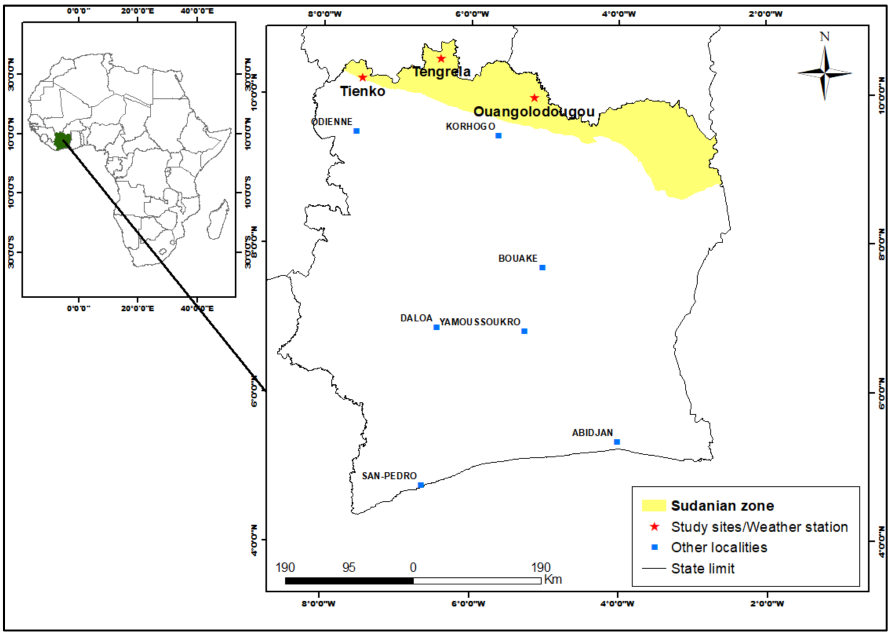


Figure 1. Map of Côte d'Ivoire showing the study locations located in the Sudanian zone at the northern part of the country. Source: Map of Côte d'Ivoire.

2.2. Methodology

2.2.1. Analysis of Climatic Variables

Temperature and rainfall are recognized as the most critical parameters for rain-fed agriculture in the intertropical region [8]. Thus, the climatic data included daily rainfall and temperature data observed over the period 1987 to 2018 at the Ouangolodougou, Tienko, and Tengréla stations (see Figure 1). Following the recommendations of the World Meteorological Organization (WMO), the series covering more than 30 years are long enough to identify possible trends. The climate data used in this study were obtained from the Société d'Exploitation et de Développement Aéroportuaire, Aéronautique et Météorologique (SODEXAM), the official agency of the meteorology of Côte d'Ivoire.

- Analysis of interannual variability of precipitation and temperature

The analysis of interannual variability of rainfall in the Sudanian zone of Côte d'Ivoire over the period 1987–2018, required the use of indices [42,43]. The Lamb rainfall index [44,45] was used to determine the number of deficit and surplus years. This index defined as reduced centered variables play an important role in determining seasonal variations. It is computed using Equation (1):

$$I_i = \frac{X_i - \overline{X}}{\sigma} \quad (1)$$

where I_i is the rainfall index, X_i is the rainfall in year I (in mm), $\overline{X}$ is the average rainfall over the study period (in mm), and σ is the standard deviation of rainfall over the study period. According to the values, I_i greater than 0.5 denotes excess rainfall, I_i between 0.5 and -0.5 shows normal rainfall, while I_i less than -0.5 indicates a deficit rainfall.

A better observation of interannual fluctuations in precipitation and runoff is achieved by highlighting seasonal variations from the second-order Hanning non-recursive low-pass filter. The calculation of filter-weighted runoff totals is performed using the equations recommended by Tyson et al. [46]. Thus, each term in the rainfall series is calculated according to Equation (2):

$$X_t = 0.06X_{t-2} + 0.25X_{t-1} + 0.38X_t + 0.25X_{t+1} + 0.06X_{t+2} \quad \text{For } 3 \le t \le n-2 \quad (2)$$

where X_t = the weighted rainfall total of term t. X_{t-2} and X_{t-1} are the observed rainfall totals of two terms immediately preceding the t term. The weighted rainfall totals of the first two (X_{n-1} and X_n) and last two terms of the series are calculated using the following expressions (n being the size of the series):

$$X_1 = 0.54X_1 + 0.46X_2$$

$$X_2 = 0.25X_1 + 0.50X_2 + 0.25X_3$$

$$X_{n-1} = 0.25X_{n-2} + 0.50X_{n-1} + 0.25X_n$$

$$X_n = 0.4X_n + 0.46X_{n-1}$$

The interannual evolution of the minimum and maximum temperature over the period 1987–2018 was determined using the graphical method. It consists of a representation of temperatures as a function of time (year over the selected period) and allows to detect the trend considering the totality N of the observations. The analysis of the chronological trends of the temperature was carried out using the software R-instat 0.7.2 [47].

- Analysis of the interannual evolution of the duration of the rainy season, the number of rainy days and drought episodes

The interannual evolution of these parameters was determined over 32 years for the different stations. The duration of the rainy season is defined as the difference in days between the end and beginning dates of the rains. For our study area, the start date of the rainy season is the date of May 1 during which a cumulative rainfall of 25 mm is recorded over a period of 10 consecutive days without a dry sequence of more than 7 consecutive days during the following 30-day period [48,49]. The end of the rainy season is defined as the date from September 1 during which the useful soil water reserve is zero. The useful soil reserve is set at 100 mm and the daily evapotranspiration at 5 mm [50–52]. Finally, the frequency of dry spells was determined by the evolution of the greatest differences (expressed in number of days) between two consecutive rains during the cropping season [52–54] over the reference period. In this study, a day is considered dry if the cumulative daily rainfall received is less than the threshold of 1 mm. Thus, a dry spell is the consecutive days without rain in a long sequence. The R-instat software 0.7.2 was used to calculate the different parameters [47].

2.2.2. Analysis of the Perceptions and Adaptation Strategies of Farmers to Climate Variability

Information on farmers' perceptions of climate variability was collected by conducting surveys with group surveys and individual interviews with farm managers from December 2018 to July 2019. Perception refers to the process in which people receive information and stimuli from their environment and transform them into conscious psychological actions [55]. The targets included adult (at least 30 years old) male and female farm managers randomly selected in the three localities of the Sudanian zone of Côte d'Ivoire (Tengréla, Ouangolodougou, and Tienko). The interviews were conducted either at their homes or on their farms depending on their availability. Before administering the questionnaire, a detailed description of the survey was presented to these participants. As a result, all farm managers interviewed consented. However, for confidentiality purposes, details such as the names of the participants in the survey were not disclosed. In this study, no laboratory studies or samples were performed on the respondents. Thus, a total of 287 male and female farm managers, aged 30 years and older, were interviewed. The surveyed farmers were randomly selected and subjected to a questionnaire covering the following elements: (1) identification of the farm manager: name, sex, age, marital status, level of education, and number of years of experience in agriculture; (2) characteristics of the farm: main crops grown, area sown, and whether or not they own draft animals; (3) the exercise of other non-agricultural activities; (4) the perception of climate variability; (5) the manifestations of climate variability observed in the locality; (6) the main impacts generated; and (7) the strategies adopted to adapt to climate variability. Subsequently, descriptive and percentage analyses were used, and the descriptive analyses were then used to represent farmers' responses to these different variables.

Also, an ANOVA test was performed at the 5% probability level to determine if any differences existed between the means of the three localities. For this study, all descriptive and statistical analyses were performed using the R 3.5.2 software.

3. Results

3.1. Interannual Variability of Precipitation and Temperature over the Period 1987–2018 in the Sudanian Zone

The reduced centered index with raw and filter weighted data of annual precipitation over 32 years showed a high variability in precipitation with successive periods of deficit and surplus (Figure 2). The annual precipitation trends show a general upward trend in all three locations starting in 2008. Examination of the evolution of the duration of the rainy season in the three localities showed a high variability of the rainy season between 1987 and 2018. However, there is a trend back to relatively longer rainy seasons from 2010 onwards (Figure 3). At the same time, the rainy season is affected by the high variability in the number of rainy days over the 32 years (Figure 4). In addition, the graphical representation of the interannual evolution of dry spells of more than 5 days during the rainy season highlighted an ascending slope of the linear regression line in the three localities (Figure 5). This reflects a tendency of increasing amounts of dry spells between rainy days during the rainy season. For all variables, the significance test showed no significant difference ($p > 0.05$) between the different values from 1987 to 2018.

Trends in annual maximum and minimum temperature from 1987 to 2018 are shown in the figures (Figures 6 and 7). As with rainfall, there was an increase in maximum and minimum temperatures in all three locations. However, statistical analysis showed that the increase in temperature was not significant ($p > 0.05$).

3.2. Farmers' Perceptions and Adaptation Strategies to Climate Variability

3.2.1. Profile of the Operation

The profile of farm managers in the Sudanian zone (Table 1) shows that most of them (84.89%) are men, with 88.5% in Ouangolodougou, 91.2% in Tengréla, and 68% in Tienko. Farmers in the three localities have a relatively low level of education. However, they have many years of experience in agriculture, with an average of 30.41 years in Ouangolodougou, 26.62 years in Tengréla, and 26.40 years in Tienko (Table 2). Almost all these people (99.60%) have observed climate variability in their locality and were even able to clearly mention the different manifestations as well as the impacts on crops. The one-factor ANOVA test applied did not show any significant difference between localities in terms of the average number of people present on the farms. However, a highly significant difference was observed in the average area planted, which was 14 ha for Ouangolodougou, 17 ha for Tengréla, and 11 ha for Tienko. The main crops grown in the three localities are cashew nuts, cotton, maize, rice, peanuts, and sorghum.

Table 1. Profile of farm managers.

Profile of Farm Managers		**Proportion of Citations (%)**			
		Sudanian Zone (n = 287)	**Ouangolodougou (n = 85)**	**Tengréla (n = 102)**	**Tienko (n = 100)**
Average age		49.33	50.64	48.38	49.04
Sex	Female	15.11	11.50	8.80	32.00
	Male	84.89	88.50	91.20	68.00
Level of education	Without education	67.97	73,10	76.50	55.00
	Educated	32.03	26.90	23.50	45.00

Table 1. *Cont.*

Profile of Farm Managers		**Proportion of Citations (%)**			
		Sudanian Zone (n = 287)	**Ouangolodougou (n = 85)**	**Tengréla (n = 102)**	**Tienko (n = 100)**
Possession of livestock	Yes	76.79	87.20	86.30	59.00
	No	23.21	12.80	13.70	41.00

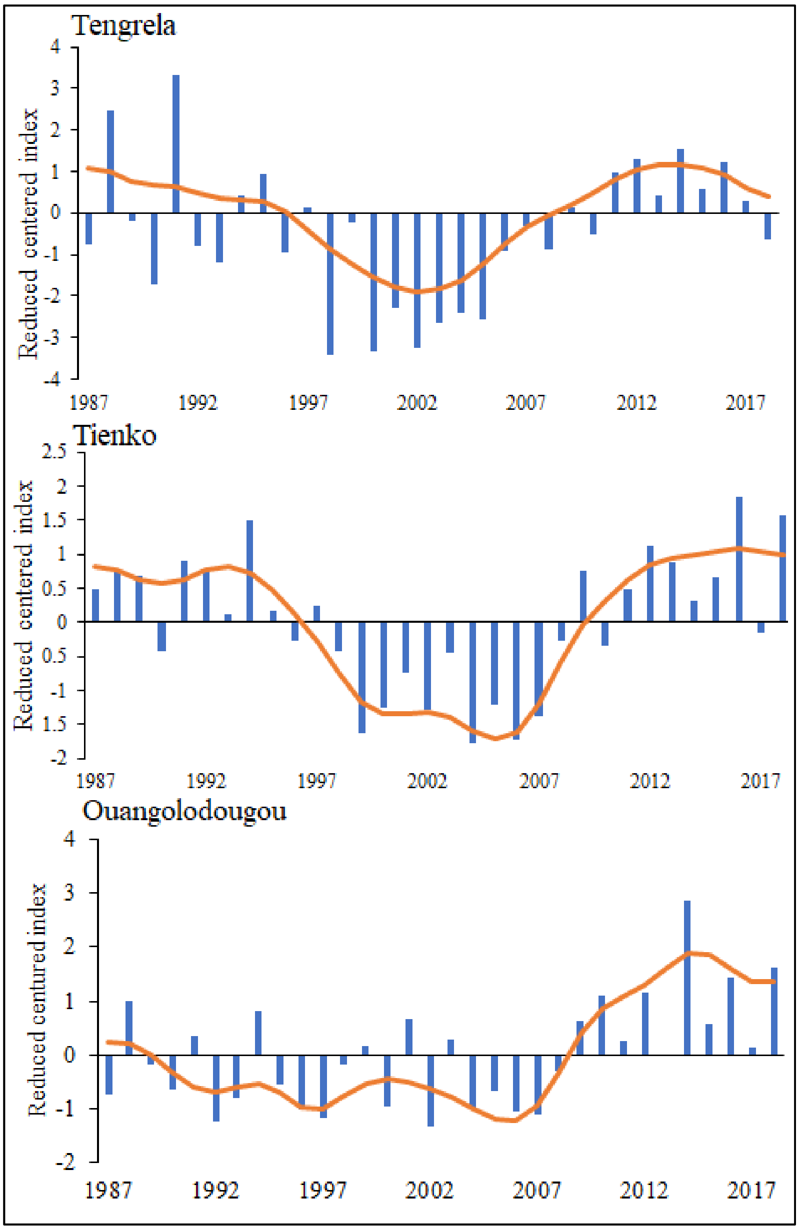


Figure 2. Interannual rainfall variability from 1987 to 2018 in the Sudanian zone of Côte d'Ivoire. Blue represents the rainfall index; Orange represents second-order Hanning non-recursive low-pass filter curve.

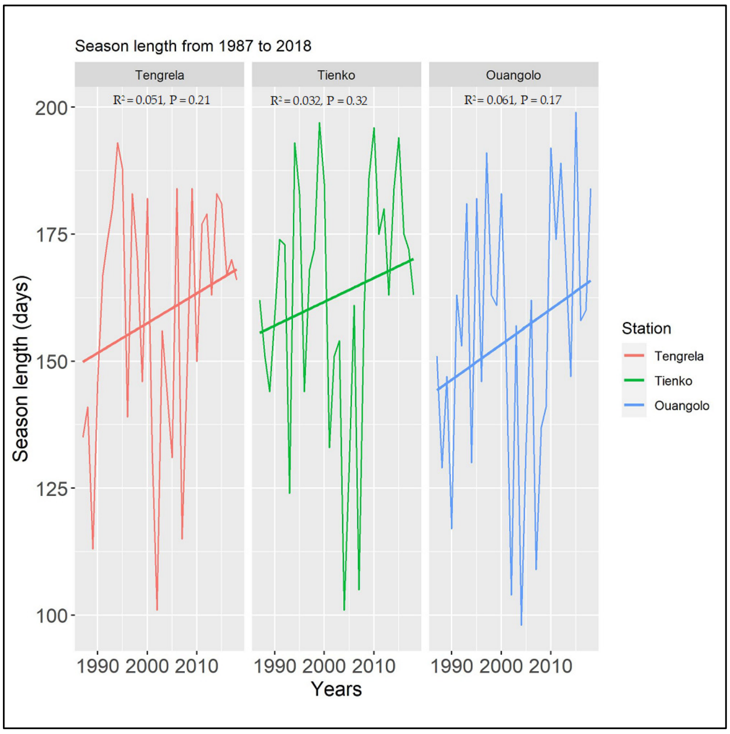


Figure 3. Interannual variability in rainy season duration from 1987 to 2018 in the Sudanian zone of Côte d'Ivoire. R^2 is the coefficient of determination, p is the significance at the 5% level. The red, green and blue curves represent the trend in the season length from 1987 to 2018 respectively for Tengréla, Tienko and Ouangolodougou.

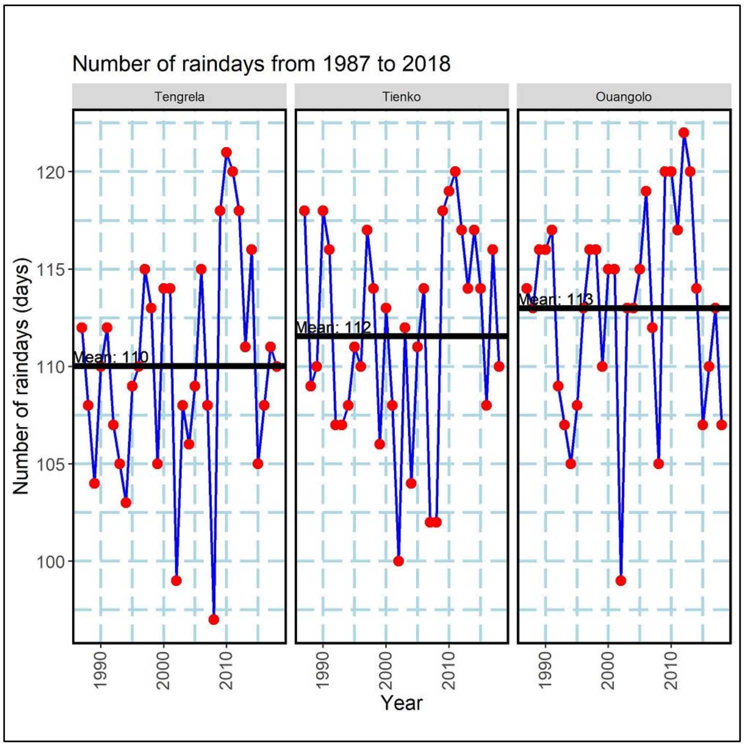


Figure 4. Interannual variability of the number of rainy days during the rainy season in the Sudanian zone of Côte d'Ivoire between 1987 and 2018. The blue curve represents the evolution of the number of rainy days over the 32 years. The red points represent the number of rainy days in a given year and the black line represents the average number of rainy days from 1987 to 2018.

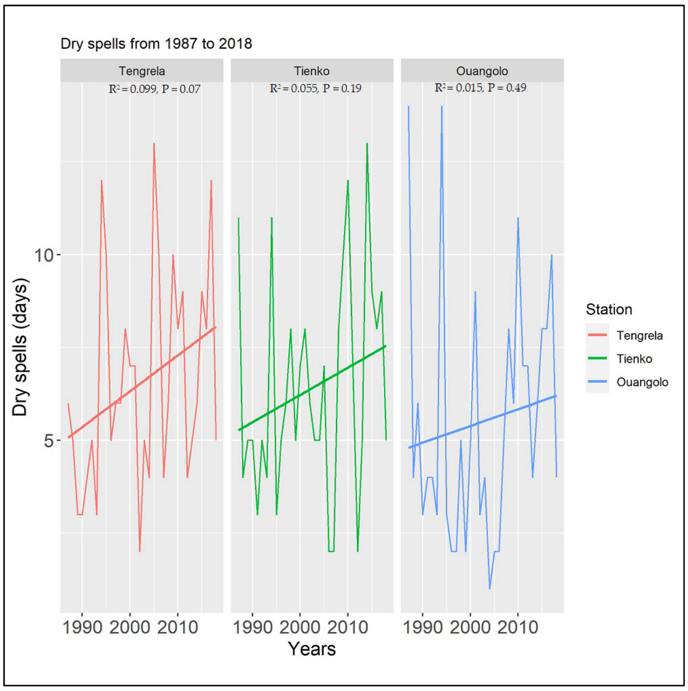


Figure 5. Changes in dry spells during the rainy season in the Sudanian zone of Côte d'Ivoire between 1987 and 2018. R^2 is the coefficient of determination, p is the significance at the 5% level. The red, green and blue curves represent the trend in the dry spells from 1987 to 2018 respectively for Tengréla, Tienko and Ouangolodougou.

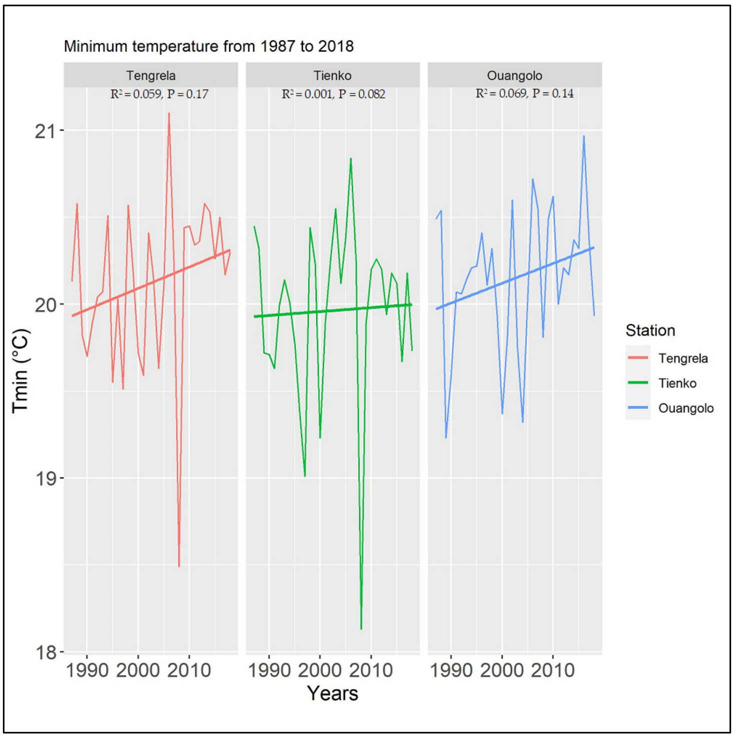


Figure 6. Evolution of annual minimum temperature in the Sudanian zone of Côte d'Ivoire between 1987 and 2018. R^2 is the coefficient of determination, p is the significance at the 5% level. The red, green and blue curves represent the trend in the minimum temperature from 1987 to 2018 respectively for Tengréla, Tienko and Ouangolodougou.

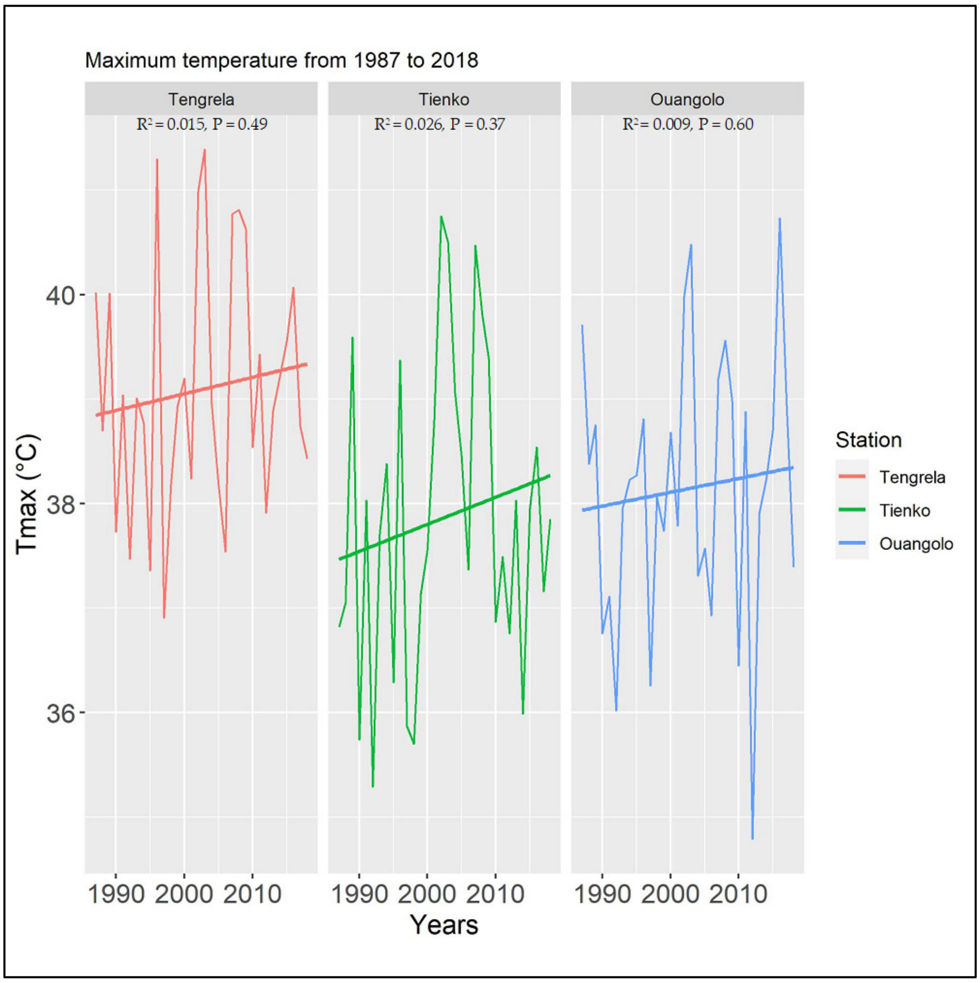


Figure 7. Changes in annual maximum temperature in the Sudanian zone of Côte d'Ivoire between 1987 and 2018. R^2 is the coefficient of determination, p is the significance at the 5% level. The red, green and blue curves represent the trend in the maximum temperature from 1987 to 2018 respectively for Tengréla, Tienko and Ouangolodougou.

Table 2. Characteristics of the farms.

Profile of the Operation	Proportion of Farmers (%)				Pr (>F)
	Sudanian Zone (n = 287)	Ouangolodougou (n = 85)	Tengréla (n = 102)	Tienko (n = 100)	
Average number of animals	8.00	5.00 ^{a}	11.00 ^{b}	9.00 ^{ab}	***
Average number of people	17.00	16.00 ^{a}	17.00 ^{a}	15.00 ^{a}	NS
Average farming experience (years)	27.90	30.41 ^{b}	26.62 ^{a}	26.40 ^{a}	NS
Average area planted (ha)	15.00	14.00 ^{ab}	17.00 ^{b}	11.00 ^{a}	***
Main crops					
Cashew	93.72	93.59	93.14	100.00	
Cotton	59.58	78.20	76.47	28.00	
Corn	89.19	87.18	96.08	88.00	
Rice	70.73	73.08	60.78	77.00	
Peanut	40.76	61.54	22.55	41.00	

Table 2. *Cont.*

Profile of the Operation	Proportion of Farmers (%)				Pr (>F)
	Sudanian Zone (n = 287)	Ouangolodougou (n = 85)	Tengréla (n = 102)	Tienko (n = 100)	
Sorghum	17.07	11.54	38.23	0.00	
Perception of climate variability	99.60	100.00	99.00	100.00	

*** = significant difference, NS: not significant; locations with the same letter are not significantly different.

3.2.2. Manifestation and Impacts of Climate Variability in the Sudanian Zone of Côte d'Ivoire

All farmers clearly mentioned the manifestations of climate variability in their locality, with significant differences. The most recurrent manifestations are illustrated in Table 3. Thus, the main manifestation of climate variability concerns rainfall. Indeed, regardless of the locality, the shortening of the rainy season (75.95%) and the irregularity of rainfall (84.67%) during the rainy season are the manifestations of variability most mentioned by the farmers. However, depending on the locality, other manifestations were more frequently mentioned, such as the increase in temperature observed mainly in Tienko and Tengréla, and the prolongation of the drought and the increase in rainfall intensity observed in Ouangolodougou. All these different manifestations of climate variability have had enormous impacts on crops (Figure 8), particularly food crops such as maize, rice, sorghum, and especially millet. The most notable impacts are the decrease in crop yields, particularly in Tengréla (92.16%) and Tienko (96%). However, farmers in Tienko also reported an increase in insect attacks on crops (35%) and early crop drying (86%). On the other hand, 97.43% and 51.28% of Ouangolodougou farmers respectively cited disruption of the cropping calendar and crop flooding as the main impacts of climate variability in their locality.

Table 3. Manifestations of climate variability as perceived by farmers.

Signs of Climate Variability Evoked	Proportion of Citations (%)				Pr (>F)
	Sudanian Zone (n = 287)	Ouangolodougou (n = 85)	Tengréla (n = 102)	Tienko (n = 100)	
Increase in temperature	13.60	7.06 [a]	15.68 [a]	17.00 [a]	NS
Increase in precipitation intensity	12.20	37.65 [b]	2.94 [a]	0.00 [a]	***
Dense fog	0.35	1.18 [a]	0.00 [a]	0.00 [a]	NS
Irregularity of precipitation	84.67	58.82 [a]	91.18 [ab]	100.00 [b]	***
Prolonged drought	23.70	44.70 [c]	28.43 [b]	1.00 [a]	***
Shortening of the rainy season	75.95	67.06 [a]	83.33 [ab]	85.00 [b]	***
Drying up of rivers	9.06	8.23 [ab]	16.67 [b]	2.00 [a]	***

***: significant difference, NS: not significant; locations with the same letter are not significantly different.

3.2.3. Strategies for Adapting to Climate Variability

In response to the various manifestations of climate variability in the different localities, farmers have adopted numerous strategies to limit the negative effects on the farms. A total of 16 adaptation strategies were reported in the three locations (Table 4). Adaptation of the cropping calendar is the main strategy common to all three localities, as it is used by more than three quarters (86.41%) of the farmers in the Sudanian zone of Côte d'Ivoire. In addition to this strategy, 87.14% of farmers in the Sudanian zone opt for cashew nut cultivation. For these two most adopted strategies, the ANOVA test indicates that there is no significant difference at the 5% level between the different localities. Beyond these two strategies common to the different localities, the adoption of certain adaptation strategies varies from one locality to another. In Ouangolodougou, the majority of farmers use improved seeds and diversify crops on their plots. In Tengréla, farmers are more likely to use organic manure based on ox dung, chemical fertilizers for soil improvement, and to adopt agroforestry practices. Moreover, farmers in this locality are increasingly using animal traction to plow their plots, burning cotton stalks on the farm plot, and adopting crop rotation. Finally, in Tienko, farmers prefer to expand the agricultural area and diversify crops on the farm plot.

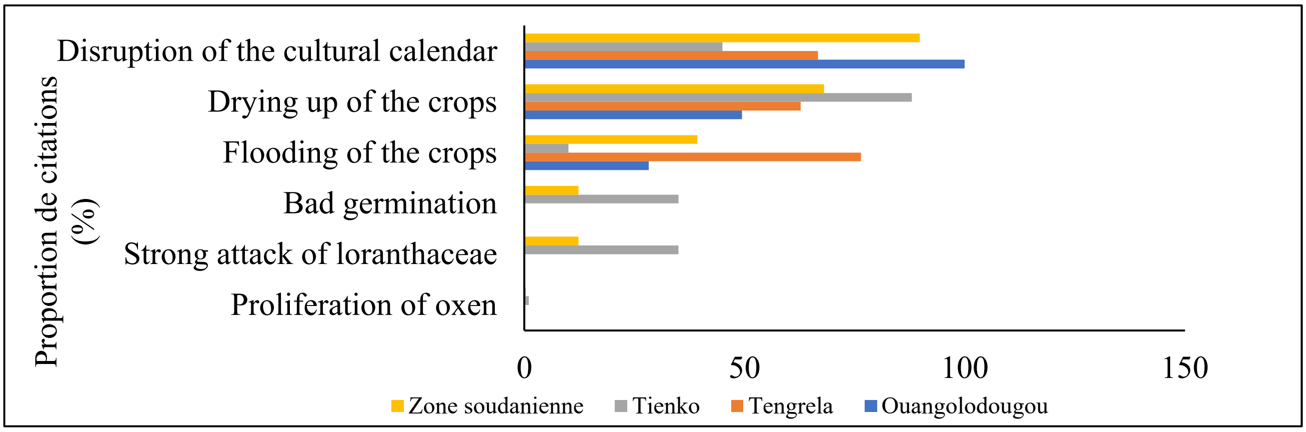


Figure 8. Impacts of climate variability mentioned by farmers.

Table 4. Main coping strategies adopted by farmers.

Line Labels	**Proportion of Citations (%)**				**Pr (>F)**
	Sudanian Zone (n = 287)	**Ouangolodougou (n = 85)**	**Tengréla (n = 102)**	**Tienko (n = 100)**	
Abandonment of certain drought-sensitive crops	6.96	3.53 [a]	5.88 [a]	11.00 [a]	NS
Adaptation of the crop calendar	86.41	90.59 [a]	88.23 [a]	81.00 [a]	NS
Practice of agroforestry	5.57	0.00 [a]	11.76 [b]	4.00 [ab]	***
Increase in the size of the ridges	2.78	4.70 [a]	3.92 [a]	0.00 [a]	NS
Increase in the surface of the crops	11.14	3.53 [a]	8.82 [a]	20.00 [b]	***
Change in activity	0.34	0.00 [a]	0.00 [a]	1.00 [a]	NS
Crop diversification	16.37	27.06 [b]	0.98 [a]	23.00 [b]	***
Cashew nut cultivation	87.14	85.89 [a]	88.23 [a]	87.00 [a]	NS
Use of improved varieties	49.12	91.76 [b]	25.49 [a]	39.00 [a]	***
Replanting	0.34	0.00 [a]	0.00 [a]	1.00 [a]	NS
Crop rotation	5.57	2.35 [a]	11.76 [b]	2.00 [a]	***
Animal traction	9.05	0.00 [a]	13.72 [b]	12.00 [b]	***
Use of cotton stalk ash	4.52	0.00 [a]	10.78 [b]	2.00 [a]	***
Use of organic manure	22.64	11.76 [a]	45.10 [b]	9.00 [a]	***
Use of chemical fertilizers	21.25	1.18 [a]	45.10 [b]	14.00 [a]	***
Use of pesticides	12.89	11.76 [a]	12.74 [a]	14.00 [a]	NS

***: highly significant difference, NS: not significant. Locations with the same letter values are not significantly different.

4. Discussion

4.1. Rainfall and Thermal Variability in the Sudanian Zone of Côte d'Ivoire

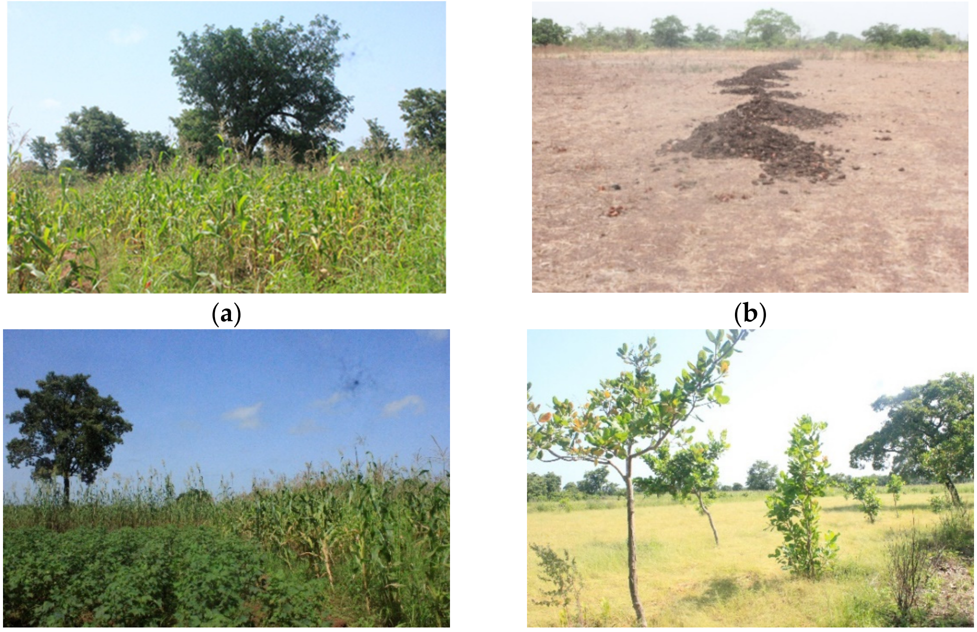
The Sudanian zone of Côte d'Ivoire is subject to significant interannual variations marked by a succession of deficit and surplus periods in the rainfall series with a return to better rainfall conditions in the zone since 2008. Indeed, a return to an increase in rainfall has been reported by many studies conducted in several sub-Saharan African countries including that of Nouaceur et al. [56] in Burkina Faso, Senegal, Mauritania, and Bodian [57] in the southern and northern Sudanian zone of Senegal. This return to more humid conditions can be explained in the Sudanian zone by the rehabilitation of degraded land following the numerous soil recovery and restoration works carried out [52,58]. More and more farmers in the Sudanian zone of Côte d'Ivoire are interested in cashew cultivation, which is a perennial woody crop that, when mature, can develop into a real forest. However, the increase in rainfall in the Sudanian zone is negatively correlated with the evolution of the number of rainy days. The decrease in the number of rainy days observed in the Sudanian zone of Côte d'Ivoire is generally in line with the heavy trend in the evolution of rainy days observed throughout the African continent [59–61]. According to authors [59–61], the number of rainy days seems to have decreased since the 1970s in these different regions of Africa. In parallel with the rainfall amounts, the maximum and minimum temperatures show an increasing trend. The increase in temperature can generate in the Sudanian zone of Côte d'Ivoire a strong variability in rainfall amounts and number of rainy days. In general, our results are consistent with temperature trends in Côte d'Ivoire and Africa. Indeed, linear regression applied to temperature data in many regions of Côte d'Ivoire from 1961 to 2010 yields a steady increase with an absolute rate of 1.6 °C over the last 50 years. Over the last century, the evolution of temperatures in Africa has shown a trend faster than global warming. This increase has varied from 0.2 to 0.8 °C since the late 1970s with a slightly greater warming between June and November [60,62]. Between 1980 and 2080, the IPCC [5] predicts temperature increases of about 0.30 °C per decade in the West African area.

4.2. Farmers' Characteristics and Perceptions of Climate Variability

Analysis of the characteristics of the farmers revealed that nearly 68% of these people have not attended school and there is also a low representation of women as farm managers. This finding may be attributable to the cultural realities of the study area, where Malinke and Senufo are the dominant peoples. These two peoples have a culture that is particularly based on agriculture, leaving schooling in second place. The low rate of women's access to land is mainly the result of customary rules. In general, in most African societies, land is owned by men and women have only use rights [63,64]. In these African societies, women play an important role in post-harvest activities (threshing, shelling, and agro-processing) as well as in the commercial activities that follow. In the Sudanian zone of Côte d'Ivoire, the 15% of women who own farms are for the most part owners following the death of their husbands. Thus, men are in the majority as farm managers. However, regardless of sex and education level, all farmers perceived climate variability through such manifestations as irregular rainfall, shortening of the rainy season, appearance of dry spells during the rainy season, and increased heat. The identification of these different climatic parameters demonstrates that farmers are aware of climate change in their locality. These manifestations were more visible and memorable by the farmers because they are the main parameters that impact the crops the most and thus determine the good or bad agricultural season [29,52,65]. Dedjan [65] found that these parameters were the recent climate changes mostly felt by farmers in the Sudanian zone of Benin. The perception of climate variability by farmers in the Sudanian zone of Côte d'Ivoire corroborates perfectly the trends observed with the analysis of climate data for the last 32 years, except for the duration of the rainy season. Indeed, unlike the majority of farmers who mentioned irregularity or even a decrease in rainfall, the analyses showed an increase in rainfall since 2008 followed by an extension of the rainy season in the Sudanian zone of Côte d'Ivoire. The inadequate perception of the season by farmers can be explained by the occurrence of dry periods of more than 5 days during the rainy season followed by a high rainfall variability observed in recent years in the various localities. Indeed, the cumulative annual rainfall alone does not determine the weakness or importance of agricultural yields. Other factors, such as delays in the onset of rains, dry spells in the middle of the rainy season, or an extension of the rainy season, disrupt the agricultural calendar, and consequently reduce agricultural yields [66]. As in the Sudanian zone, the poor perception of the evolution of the rainy season by farmers has been revealed in studies conducted in the Sahelian and Sudanian zones of Niger [67]. This discrepancy can be attributed to the tendency of farmers to focus on the negative events in a series characterized by high variability. Thus, the high variability of rainfall parameters has led to a disruption of the agricultural calendar among farmers in the Sudanian zone of Côte d'Ivoire. Contrary to the poor perception of certain rainfall parameters, farmers' perceptions of the increase in temperature in their locality corroborate the scientific data perfectly. The variation in meteorological parameters (temperature, rainfall) has had considerable impacts on agricultural activities, more negative than positive. The decrease in the duration of rainy days and the appearance of dry seasons during the rainy season correlated with the increase in temperature which led to the decrease in agricultural production mentioned by many farmers in the Sudanian zone of Côte d'Ivoire. Several authors have shown the impact of temperature increase. The rise in temperature can influence the length of the growing season of crops while reducing the growth cycle [60]. In addition, it can have a significant impact on the water balance while increasing water stress due to increased evaporation, especially in regions where water is often a limiting factor [8]. In addition, higher temperatures accelerate the rate of crop development, resulting in an overall increase in crop water requirements [68]. The impact of increased temperature on crop yields, particularly those of millet, sorghum and maize in West Africa and Europe, has already been demonstrated by several authors [26,69,70].

4.3. Adaptation Measures of Farmers to Face Climate Variability in the Sudanian Zone of Côte d'Ivoire

Farmers have implemented numerous strategies to cope with the high climatic variability in the Sudanian zone of Côte d'Ivoire and its innumerable negative effects on crops. The implementation of adaptation strategies by farmers may result from their good perception of the different manifestations of climate variability. In addition, this can be justified by the long agricultural experience (28 years on average) of the farmers. Indeed, with experience, farmers become more aware of the problems facing the farm over time. Thus, long experience allows farmers to broaden their diagnostic horizons, to improve their actions in case of shocks, or to predict certain future changes such as the evolution of rainfall [71]. Among the strategies adopted by farmers, the most common was the adaptation of the cropping calendar through the changing of sowing dates. Indeed, the beginning of May was the period during which most farmers carried out sowing. However, with the disruption of the rains, sowing is performed at the end of May or even in June. Farmers mentioned the technique of adapting the cropping calendar as being effective in that it allows crops to reduce or cancel the effects of water stress [29]. Despite its benefits, shifting planting dates can reduce the time available for crop maturation and thus lead to a delay in crop development, which can potentially reduce final yield. In addition, climatic variability has forced many farm managers to acquire draught oxen, with an average number of draught oxen ranging from 5 to 11 per farm. The use of oxen allows farmers to plow large areas quickly and easily, thus increasing the cultivable area [68]. In addition, it allows large ridges to be formed in a shorter time. Increasing the size of the ridges is widely adopted by farmers because this strategy not only limits the damage caused by floods, but also forms drainage channels for the water in the fields to facilitate its evacuation. Ridges are effective for water catchment due to their ability to retain rainwater and control runoff compared with conventional tillage [72]. Another strategy of farmers is to shift from crops that they consider to be very sensitive to climate variability to more resilient crops. They favor early maturing crops or improved short-cycle seeds for which production techniques have been improved, such as maize, short-cycle rice, and cotton, over long-cycle crops such as millet, yam, sorghum, and cassava. In addition to these strategies, some farmers use manure made from ox dung or household waste to optimize production. Farmers with oxen keep them on a plot in the field or in another area. Then when the agricultural season approaches, this portion of land is recovered and dumped on the crop plot. The manure dumped on the farm plot acts as a fertilizer, as farmers report that crops planted on these plots produce more than those planted elsewhere. The organic manure helps to maintain a good soil structure and improve its water retention capacity [73]. Dumping manure on the farm plot provides a more stable form of carbon in the soil over the long term, thus contributing to climate change mitigation [74]. The majority of farmers are aware of the relevant benefits of manure for agricultural plots but very few have the material and financial means to practice it. Thus, other farmers are using crop diversification. Crop diversification is one of the important adaptation options in agriculture because it not only compensates for potential economic losses on certain crops but also guarantees a minimum income [60,71,75]. Thus, many farmers, especially men, are increasingly interested in cashew cultivation, which, in addition to being drought resistant, provides financial income to compensate for losses caused by the decline in food crop production. The official minimum field price for cashew nuts has increased from 200 FCFA/kg in 2008 to 500 FCFA/kg in 2018, providing farmers with approximately 500,000 FCFA/ton [76]. Moreover, crop diversification is essential to reduce the massive use of agricultural inputs such as pesticides, fertilizer, and water and the environmental nuisances associated with their excessive use [77,78]. In addition, in some localities in the Sudanian zone, such as Tengréla, crop rotation is highly valued. Crop rotation is based on the organization of an orderly and repeated succession of crops on the same plot. It is mainly practiced between cotton and maize by farmers in Tengréla. Indeed, when farmers grow cotton on a plot one year, the next year they grow maize in place of cotton on the same plot, and so on. According to Lupwayi et al. [79] and Zaatra [71], the rotation preserves soil structure and organic matter content, while reducing pathogen and disease damage and lowering production quality. One of the strategies also adopted is the burning of cotton stalks on the agricultural plot. This consists of gathering the cotton stalks in small piles on the plot and proceeding with burning after the harvest season. Several farmers have testified to the good productivity of crops planted on plots where the stalks have been burned. Finally, the practice of agroforestry is increasingly adopted by farmers. It consists of sparing numerous plant species in the fields, notably shea (*Vitelaria paradoxa*) and nere (*Parkia biglobosa*). The species kept on the plot provide many ecosystem services that reduce the impact of climate variability. The fruits of these species are used as food during the lean season, and the seeds are sold on the local and regional markets, thus providing additional income to the farmers, especially the women. During the survey phase, many women revealed that shea butter can bring in up to 100,000 CFA/year and nere up to 150,000 CFA/year. According to Seghieri and Harmand [80], agroforestry is one of the solutions for sustainable use of limited natural resources and for adaptation to global demographic, economic, and climatic changes. Some strategies adopted by farmers are illustrated in Figure 9.



(**a**) (**b**) (**c**) (**d**)

Figure 9. Illustration of some coping strategies adopted by farmers in the Sudanian zone of Côte d'Ivoire. Source: Field survey 2019. (**a**) Agroforestry plot with shea trees and corn in Tengréla; (**b**) Organic manure dumped on a cultivation plot in preparation in Tengréla; (**c**) Diversification of crops on the agricultural plot (corn-sorghum-cotton) in Ouangolodougou; (**d**) Conversion of a plot of land dedicated to fonio into a cashew plantation in Tienko.

5. Conclusions

The approach used in this study highlighted the different manifestations of climatic variables in the Sudanian zone of Côte d'Ivoire, the perceptions of farmers and the strategies adopted by them to cope to with the different impacts of climate change on their agricultural practices. Thus, the Lamb index showed a fluctuation of deficit and surplus rainfall periods in the time series from 1987 to 2018. Moreover, within the same time period, an increase in temperature was observed. As the agricultural practice in this northern zone is strongly dominated by rain-fed crops, these different manifestations of rainfall and temperature have negative impacts on agriculture. This finding was confirmed by almost all farmers in the region during interviews. These individuals stated that they had perceived the different manifestations of climate variability in their locality as well as the impacts on their crops. The impacts mentioned included disruption of the cropping calendar, reduced crop yields due to crop desiccation, crop flooding, and poor crop germination. In response to the negative impacts of climate variability on crops, farmers have adopted many coping strategies. The most important of these are the modification of sowing dates, diversification of crops on the farm plot, use of improved seeds, use of organic manure based on ox dung, adaptation of the agricultural calendar, and especially the allocation of land to more drought-resistant crops and the conversion of land to cashew plantations. These different strategies used by farmers in the Sudanian zone of Côte d'Ivoire were implemented on the basis of their local knowledge, personal experience, and also due to the advice of other farmers in the locality. It is clear from this study that farmers in the Sudanian zone of Côte d'Ivoire remain particularly vulnerable to climate change insofar as the strategies used by farmers in the Sudanian zone are still rudimentary. It is therefore necessary that the strategies already adopted by farmers to cope with climate variability be better reinforced by specialized agronomic structures (State or NGO) in order to improve them and then popularize them in other regions of Côte d'Ivoire and Africa. In addition, the study revealed a low representation of women as farm managers in this region, with a greater share of domestic expenses being devoted to women. It would therefore be important to increase women's empowerment by facilitating their acquisition of agricultural plots and access to agricultural inputs (fertilizers, agricultural equipment, etc.) in order to increase their agricultural productivity. In addition, based on the results of this study and other studies conducted elsewhere, there is a need for the state to put in place capacity building programs for farmers. This program may include training in agro-climate intelligence to be developed by agricultural extension agents while building the capacity of agricultural extension systems. It is also important to provide farmers with a climate change education program with ICT innovations such as cell phone applications. However, following the present study, it will be necessary to define in further research the factors that determine the choice of adaptation methods used by farmers in the Sudanian zone of Côte d'Ivoire and to evaluate the relevance of these factors.

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