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Analysis of the Efficiency of Precipitation on the Evolution of Agricultural Production in Upper-Casamance (South Senegal) between 1985 and 2018

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Abstract: In Senegal, rainfall is the main factor affecting agricultural production. In Upper-Casamance, it is a major equator for the development of agriculture, makes farmers vulnerable, and leads to changes in farming systems. The objective of this study is to analyze the evolution of agricultural production over the last 34 years in Upper-Casamance and the impact of rainfall variability on yields. To this end, data on cereal production (millet, sorghum, corn, rice and fonio) and industrial production (groundnut, cotton and cassava) in tons between 1985-1986 and 2018-2019 from the Regional Directorate of Rural Development (RDRD) of Kolda and precipitation data over the same period acquired at ANACIM was used. Production data are processed on the basis of statistical tests, including descriptive statistics, Pearson correlation, and simple linear regression. The calculation of rainfall data is based on the calculation of the annual average rainfall, the Standardized Precipitation Index (SPI), the number of rainy days per year, the average precipitation per day of rain, and the start and end date of the "agronomic" monsoon, and its duration. Analysis of the results showed an increase in agricultural production as rainfall conditions are good. The simple linear regression calculation for each product at the $p<0.05$ threshold indicated that rice, corn, groundnuts and cassava are the crops that depend significantly on the annual rainfall period. Analysis of the start and end dates showed that the length of the agronomic season (on average 112 days) appears to be favorable for the production of millet and groundnut.

Keywords: Agricultural production, Rainfall variability, Agronomic monsoon, Statistical analysis, Upper-Casamance

Introduction

Climate is the most important factor governing food production and causes inter-annual variability in socio-economic and environmental systems related to the availability of water resources (Djaman et al., 2017) and their use. In West Africa, agriculture is a major economic sector and is most vulnerable to climate change (Roudier et al., 2011). For the West African monsoon, which rhythms the agricultural calendar, is becoming shorter as we move north, and its abundance is becoming smaller (Descroix et al., 2015); those, despite a return to wet rainfall conditions noted since 1999 (Bodian, 2014) and wetter from 2008 (Nouaceur, 2020). In Senegal, particularly in Upper-Casamance, our area of interest, the monsoon represents a major equation for the development of agriculture. It makes farmers vulnerable, especially since the main part of agricultural production is during the rainy season, and leads to changes in farming systems.

Senegal and other UN member countries have committed themselves to the 2030 Sustainable Development Goals, of which food security and sustainable agriculture are the main priorities (FAO, 2011). Moreover, the agricultural sector contributes 17% to the gross domestic product (GDP) (MEFS, 2011), provides 15.3% of the country's exports, and employs more than 60% of the labor force in 2014 (Ndiaye, 2018).

In Upper-Casamance, the agricultural sector mobilizes about 80% of the assets over a period of 8 to 9 months of the year (ANSD, 2017). Its importance is mainly due to the fact that the region has long hosted migrants of various origins, who have come in search of agricultural land (Sidibé, 2005; Fanchette, 1999). The production is mainly based on industrial crops (groundnuts, cotton and cassava) and food crops (millet, sorghum, corn, rice and fonio). However, in addition to the variability of rainfall conditions, the sector faces land degradation, water erosion, and the seeding of rice fields (Mballo et al., 2019). In addition, there is a lack of control of water by farmers, crop cycles, varieties to be used, dates of the beginning and end of the rainy season and duration. These latter variables are, however, the most important at the agronomic and agro-climatic level (Balme et al., 2005); Descroix et al., 2015) for the development of the sector.

For a better understanding of the evolution of agricultural production and its constraints, this study attempts to: 1) analyze the evolution of cereal and industrial production over the last thirty-four years in Upper-Casamance; 2) and analyze the evolution of the average annual rainfall and its impact on yields.

Materials and Method

Study Area

Upper-Casamance is located in the south of Senegal between 12 ° 20 and 13 ° 40 latitude North, and between 13 ° and 16 ° longitude West. It is limited to the East by the region of Tambacounda, to the West by the region of Sedhiou (Middle Casamance), to the North by the Republic of Gambia and to the South by the Republics of Guinea and Guinea-Bissau (Figure. 1). It corresponds administratively to the Kolda region according to Law N 2008-14 of 18 March 2008 modifying the contours of the administrative division of the national territory. It covers an area of 13,721 km² or 7% of the national territory.

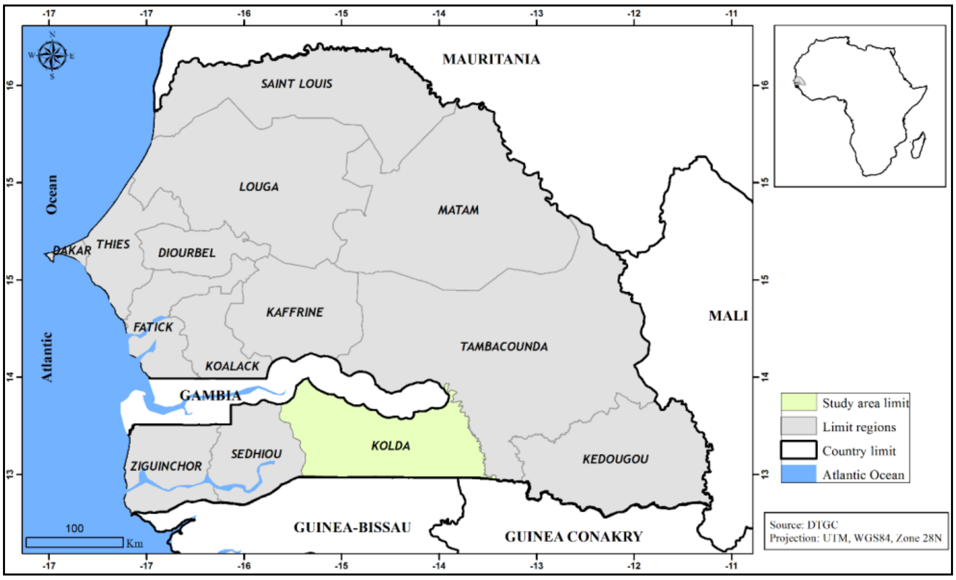


Figure 1. Localization of study area

From a climatic point of view, it belongs to the Sudanese domain. One part is in the northern zone and another in the southern zone (Sagna, 2005). Precipitation varies between 500 and 1500 mm. It has two distinct seasons. A dry season characterized by the presence of the maritime trade winds and a rainy season influenced by the arrival of the monsoon. The duration of the rainy season is six months (May to October).

Data Used

Two types of data are used in this study. First, we have data on cereal and industrial production in tons of Upper-Casamance between 1985-1986 and 2018-2019. These data come from the Regional Directorate for Rural Development (RDRD) of Kolda. Next, we have precipitation data from the stations of Kolda, Vélingara, Medina Yoro Foulah, Dabo, Kounkane, and Bonconto for the period 1985-2018. These data are provided by the National Civil and Military Aviation Agency (NCMAA). The role of temperature on agricultural production will not be studied in this study, as it is a major role (Sarr and Traoré, 2010; Sultan, 2012).

Methods

Statistical Processing of Agricultural Production Data

Data on agricultural production were processed on the basis of statistical processes using the SPSS software. Processing began by organizing the data and dividing the series into three periods: 1985-1998, 1999-2007 and 2008-2019. The first period corresponds to the great drought of the years 1970-1980 and is characterized by a general weakness of precipitation in Senegal. The second period corresponds to the return to wet rainfall conditions. The third period corresponds to the return to wetter conditions (Nouaceur, 2020). Thus, this subdivision of the series allows us to see the different trends in agricultural production depending on whether the period is dry (1985-1998), wet (1999-2007) or very wet (2008-2018).

The second step was to calculate the descriptive statistics. These include trend measures (mean, median and mode), dispersion measures (standard deviation, variance, range, and percentiles), minimum and maximum. Similarly, correlation and simple linear regression were calculated for each product. Correlation measures the linear relationship between two variables. It is essential to verify the linearity of the relationship. It can take values between -1 and 1. When it is close to -1, there is a strong negative relationship. When it's close to zero, there is no linear relationship. When it's close to 1, we're talking about a strong positive linear relationship.

Simple linear regression not only measures the linear relationship between two continuous variables, but also the effect of an independent variable on a dependent variable, depending on the number of samples and the nature of the variables studied. In this study, the dependent variable is products; while the independent variable is rainfall. For this, we used Adjusted R Square and ANOVA. The threshold of significance is 0.05 or a confidence threshold of 95%.

Rainfall Data Processing

Rainfall data processing is based on the calculation of: the evolution of annual average rainfall, the Standardized Precipitation Index (SPI) (McKee et al., 1993), the number of rainy days per year, and the average rainfall per rainy day.

The standardized precipitation index is used by several authors to characterize rainfall in many parts of West Africa (Bodian, 2014; Descroix et al., 2015). It measures weather droughts and quantifies precipitation deficits at multiple time scales that reflect impacts on the availability of different types of water resources. It is obtained on the basis of the difference between the precipitation during a year and the series average, on the standard deviation of the series, which is the formula:

$$SPI= (Pi – Pmoy)/\sigma$$

Where; Po= rain of the year i; Pmoy= average rain of the series; σp= Standard deviation of the series

The SPI values were interpreted according to the criteria given by WMO (2012). The average precipitation per rainy day was calculated by dividing the annual average precipitation by the number of rainy days in the year. Knowing that the number of rainy days of the year corresponds to the total sum of each rainy day. In addition to these calculations, we determined the start and end date of the "agronomic" monsoon, as well as the duration. This is based on the work of Balme et al., (2005), and Sivakumar (1988). In agronomic terms, the start of wintering corresponds to the first precipitation or a set of events producing more than 20 mm in less than three days and not followed by a dry phase of more than 7 days in the following month (Balme et al., 2005); whereas the end of wintering is the last event of more than 10 mm not preceded by a dry episode of more than 20 days (Sivakumar, 1988). The length of the rainy season corresponds to the difference in days between the end and beginning dates of the rains. All the treatments carried out were spatialized by the Thiessen polygon method.

Results and Discussions

Analysis of the Evolution of Cereal Production from 1985-1986 to 2018-2019 in Upper-Casamance

The evolution of cereal production over the various periods is shown in Figure 2. The result generally indicates a change in production as we move away from the dry period. Indeed, R^2 indicated a significant trend in agricultural production during the wetter period (R^2=0.4205), and not significant during the intermediate period (R^2=-0.076). It is even less so during the dry period (R^2=-5,747). However, it should be recalled that, despite these encouraging productions in recent years, projections from climate models all foresee decreases in crop yields (in the range of 11 to 18%) in West Africa mainly due to warming (Roudier et al., 2011), increased sweating and decreased soil water content (Léauthaud et al., 2011).

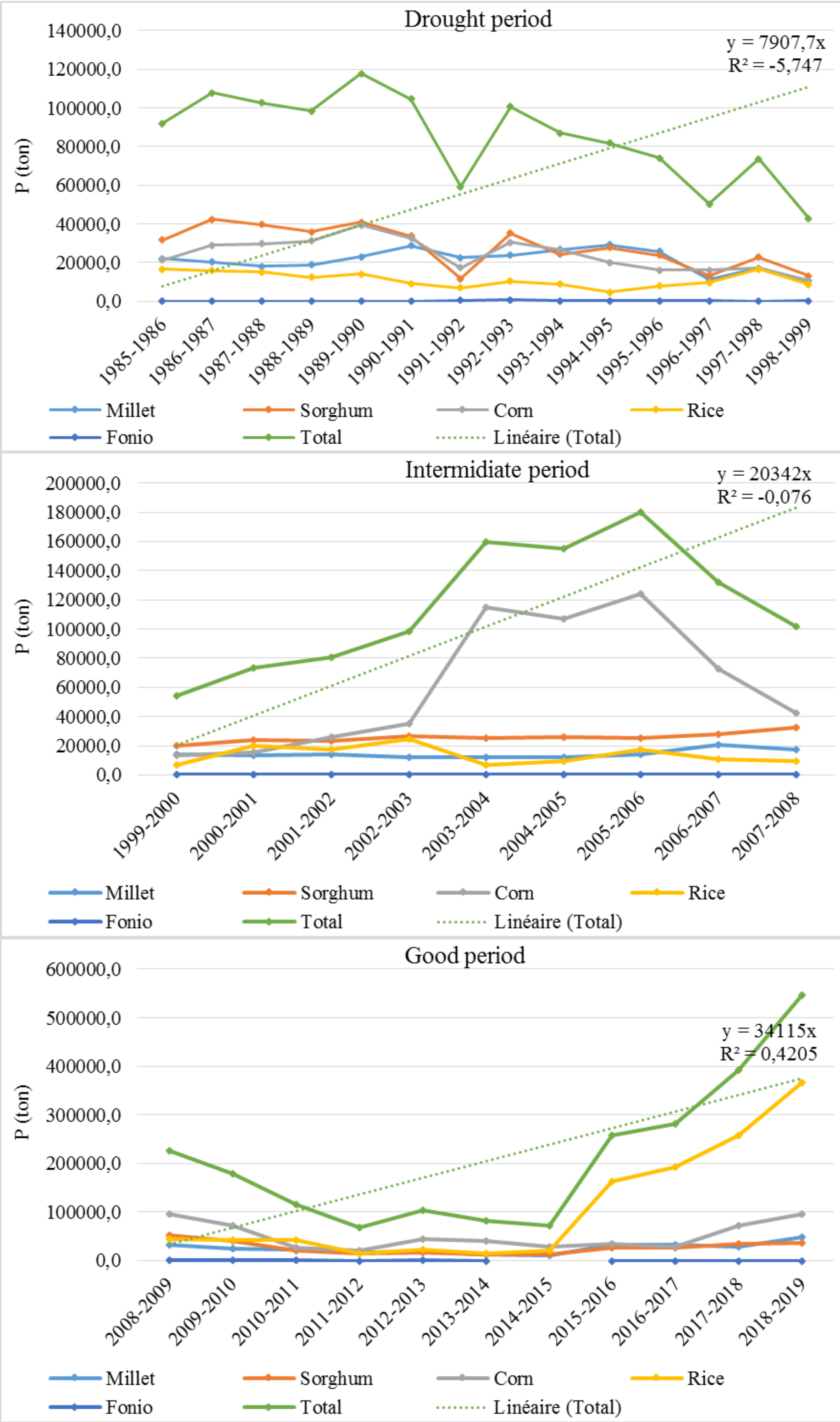


Figure 2. Evolution of cereal production (in tons) during the periods 1985-1998, 1999-2007 and 2008-2018 in Upper-Casamance

The results of the descriptive statistics for each product are shown in Table 1. They show that during these three periods, the minimum production of millet is 10,472.3 tons and the maximum production is 47,732 tons. The average production is 20 999 497 tons. For sorghum, corn and rice, the minimum production is 11,596.7 tons, 10,567.5 tons and 4,659.7 tons respectively; whereas the maximum is 51,568.8 tons, 123,816.5 tons and 366,081 tons. The average production is 27,134,071 tons, 42,631,826 tons, and 42,984,162 tons, respectively. The results also indicate that, over the last 34 years, fonio has been the lowest producing product; rice, the highest production, especially since the 2014-2015 crop year.

Table 1. Descriptive statistics of the different cereal crops

	N Statistic	Range Statistic	Minimum Statistic	Maximum Statistic	Mean Statistic	Std. Error
YEARLY-PERIOD	34	2	1	3	1.91	.148
Millet	34	37259.7	10472.3	47732.0	20999.497	1428.0642
Sorghum	34	39972.1	11596.7	51568.8	27134.071	1689.2600
Corn	34	113249.0	10567.5	123816.5	42631.826	5432.2510
Rice	34	361421.3	4659.7	366081.0	42984.162	13752.5336
Fonio	34	1766.9	.0	1766.9	214.576	53.6262
Valid N (listwise)	34					

	Std. Deviation Statistic	Variance Statistic
YEARLY-PERIOD	.866	.750
Millet	8326.9734	69338486.240
Sorghum	9849.9939	97022379.246
Corn	31675.1942	1003317929.236
Rice	80190.3620	6430494163.486
Fonio	312.6918	97776.193
Valid N (listwise)		

The Pearson correlation calculation yielded the following results: 0.213 for millet, -0.071 for sorghum, 0.388 for corn, 0.503 for rice, and 0.040 for fonio. These results indicate that there is a strong positive linear relationship between rice production and rainfall, which is the dependent variable. For corn, the result indicates a weak positive linear relationship. However, for sorghum, there is a strong negative linear relationship. For mil, the result indicates that there is a relationship, but it is not linear. For the fonio, there is no relationship, indicates the result.

The simple linear regression equation applied for each product at the $p<0.05$ threshold indicated that rice and corn are cereal crops that are significantly dependent on the annual rainfall period (Table 2 and 3).

Table 2. Result of the simple linear regression applied to rice

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics: R Square Change	F Change	df1
1	.503[a]	.253	.230	70383.8861	.253	10.836	1

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	53681781940.624	1	53681781940.624	10.836	.002[b]
	Residual	158524525454.416	32	4953891420.451		
	Total	212206307395.040	33			

Coefficients[a]

Model		Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	-46077.206	29625.683		-1.555	.130
	YEARLY-PERIOD	46585.946	14151.898	.503	3.292	.002

For rice, a significant linear regression equation was found with b=0.503, (1,32)=-1.555, $p<0.05$. Adjusted R^2 gives us 23%. This means that rainwater quantities in Upper-Casamance explain almost the variance in rice production. For corn, the regression equation was found to be significant with b=0.38, (1,32)=1.24, $p<0.05$. Adjusted R^2 is 12.4%. The results also indicate that the more rainfall conditions improve, the more rice and corn production.

Table 3. Result of the simple linear regression applied to corn

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics: R Square Change	F Change	df1
1	.388[a]	.151	.124	29642.4738	.151	5.681	1

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4991851604.583	1	4991851604.583	5.681	.023[b]
	Residual	28117640060.204	32	878676251.881		
	Total	33109491664.786	33			

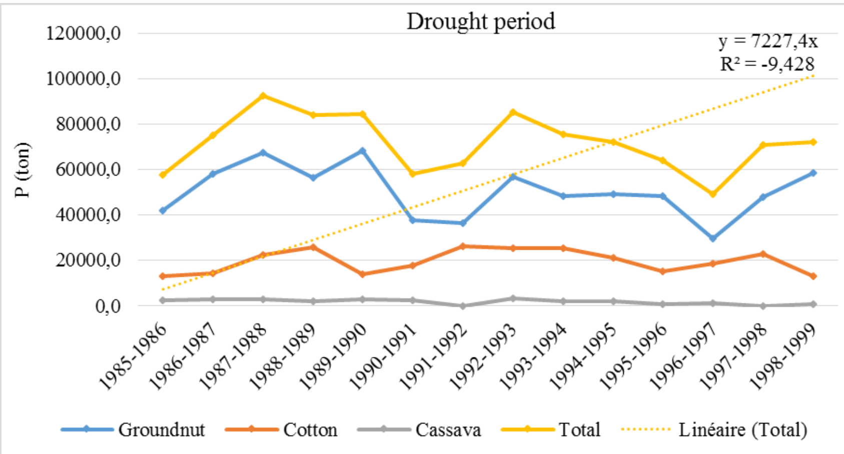
Coefficients[a]

Model		Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	15473.267	12476.983		1.240	.224
	YEARLY-PERIOD	14206.016	5960.132	.388	2.384	.023

For millet, sorghum, and fonio, the simple linear regression equation was found to be non-significant ($p>0.05$). P is 0.227, 0.691, and 0.821, respectively. Adjusted R^2 is 1.5%, -2.6%, and -3%, respectively.

Analysis of industrial production evolution from 1985-1986 to 2018-2019 in Upper-Casamance

The evolution of industrial production over the various periods is shown in Figure 3. Like cereal production, industrial production is also dependent on rainfall conditions. Through R^2, we can see a change in production as we move away from the dry period.



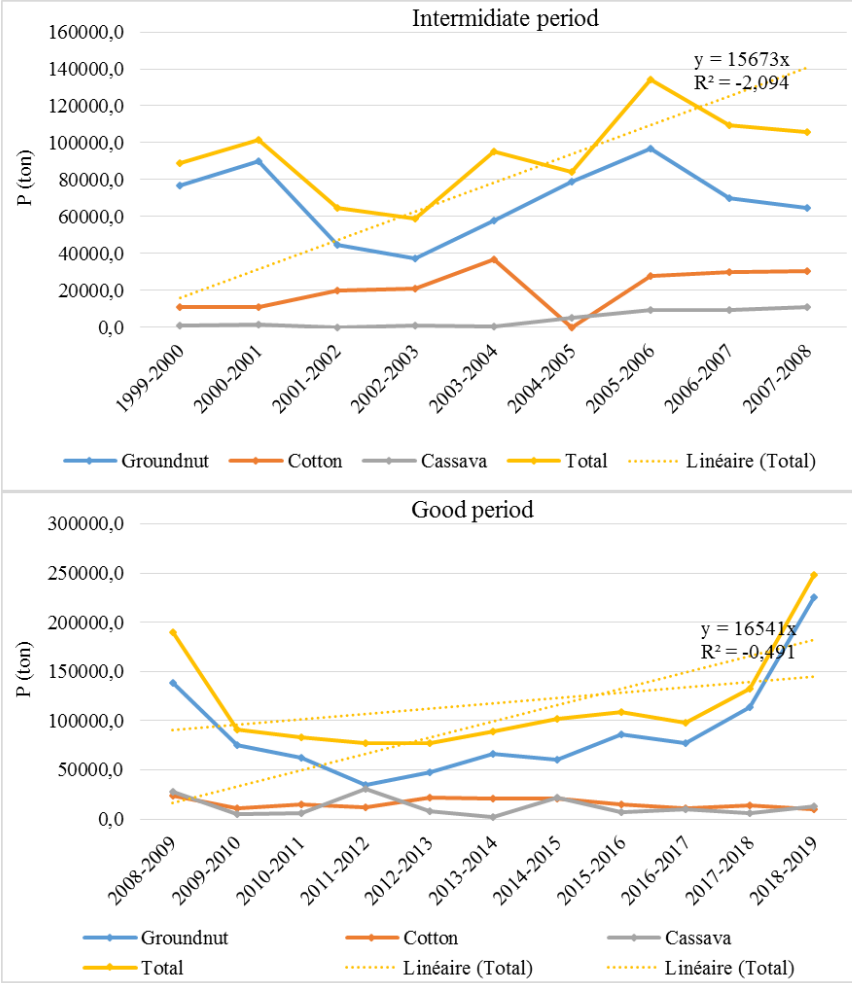


Figure 3. Evolution of industrial production (in tons) during the periods 1985-1998, 1999-2007 and 2008-2018 in Upper-Casamance

The results of the descriptive statistics indicate high production for groundnuts, followed by cotton and cassava. The maximum production is 225,654 tons, 36,855 tons and 30,538 tons respectively for the three speculations. The average is 67,840.93 tons for groundnuts, 18,661.07 tons for cotton, and 5,903.47 tons for cassava.

Table 4. Descriptive statistics of the different industrial crops

		YEARLY -PERIOD	Groundnut	Cotton	Cassava
N	Valid	34	34	34	34
	Missing	0	0	0	0
Mean		17.50	67840.93	18661.07	5903.47
Median		17.50	59472.81	19139.68	2671.44
Mode		1[a]	29561[a]	25407	0
Std. Deviation		9.958	36157.245	7465.983	7491.783
Variance		99.167	1307346354.144	55740905.591	56126808.143
Minimum		1	29561	0	0
Maximum		34	225654	36855	30538
Sum		595	2306592	634477	200718
	25	8.75	47687.95	13008.97	1159.38
Percentiles	50	17.50	59472.81	19139.68	2671.44
	75	26.25	76838.98	23820.51	8161.32

The simple linear regression equation applied to different products shows that groundnuts and cassava are the industrial crops that depend significantly on the annual rainfall period (Table 5 and 6). For groundnut, the regression equation was found to be significant with b=0.471, (1,32)=2.21, $p<0.05$. Adjusted R^2 is 19.7%. This also shows that rainfall explains the variance of groundnut production in Upper-Casamance; although, during the dry period, it still met the water needs of groundnuts (Sene, 2007).

For cassava, the linear regression equation gave b=0.606, (1,32)=-1.620, with $p<0.05$. Adjusted R^2 is 34.8%. An increase in production is predicted, if trends continue.

Table 5. Result of simple linear regression applied to groundnuts

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics R Square Change	F Change	df1
1	.471[a]	.222	.197	32392.860	.222	9.116	1

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	9564913660.757	1	9564913660.757	9.116	.005[b]
	Residual	33577516026.002	32	1049297375.813		
	Total	43142429686.759	33			

Coefficients[a]

Model		Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	30247.112	13634.664		2.218	.034
	Y PERIOD	19664.458	6513.145	.471	3.019	.005

Table 6. Result of simple linear regression applied to cassava

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics R Square Change	F Change	df1
1	.606[a]	.368	.348	6050.580	.368	18.593	1

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	680680218.909	1	680680218.909	18.593	.000[b]
	Residual	1171504449.814	32	36609514.057		
	Total	1852184668.722	33			

Coefficients[a]

Model		Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	-4125.294	2546.784		-1.620	.115
	Y PERIOD	5245.816	1216.574	.606	4.312	.000

For cotton, on the other hand, the regression equation was found not significant with b=-0.214, (1,32)=7.116, $p>0.05$. Adjusted R^2 is 0.16%; which is very small. This means that cotton production does not depend on rainfall conditions. In fact, it depends on the policies of reimbursement to SODEFITEX (which finances its activities) and on the perception of the population on the product used for fertilization of the land (which is dangerous for their health and contributes to the degradation of their land).

Evolution of average annual rainfall and its impact on yields

The evolution of average annual rainfall between 1985 and 2018 indicates significant variation with values that are both above average (946.7 mm) and below (Figure 4a). This is especially the case for the period 1985-1999, during which we recorded both 7 rainy and 7 dry years; with two years (1990 and 1991) with moderately dry indices (Figure. 4b). The cumulative effects of the drought on the availability of water reserves of the various dams in the Anambe basin that could not fill up (Dacosta et al., 2002) would explain by extension the low production of rice during this period. Because, compared to other speculations and outside the fonio, it is the one that recorded the lowest productions during this period. The year 1999, which indicates the return to wet conditions in Senegal (Bodian, 2014), was more rainy after 2003 with an index considered to be very wet. Between these two dates, the quantities of precipitated water were worrying, as they were well below average.

The years 2001 and 2002 were the most deficit in the series studied. The period from 2003 to 2010 was the most rainy with indices ranging from near normal to moderately wet. Only 2006 had a negative index, however close to normal. During this period, all productions experienced almost an increase compared to the dry period. The period from 2011 to 2018, on the other hand, recorded overall precipitation below average. However, all positive and negative indices are close to normal. This would explain the results sometimes good, sometimes bad of production; but not to the values of the previous two periods.

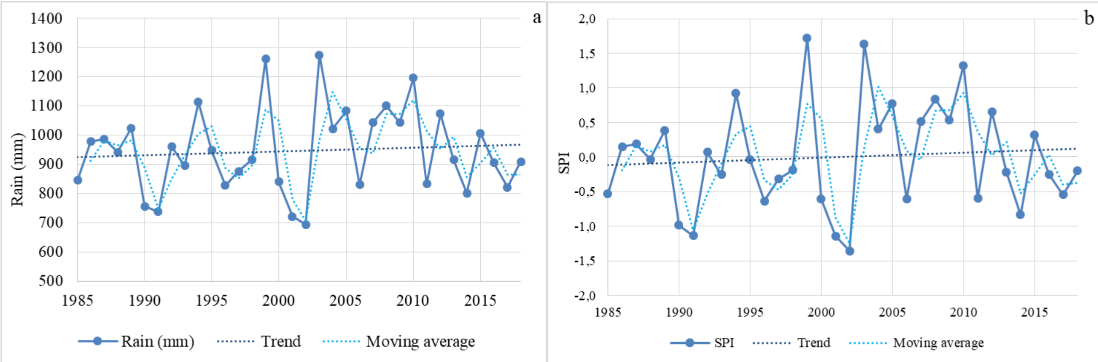


Figure 4. a) Evolution of average annual rainfall and b) Standardized Precipitation Index in Upper-Casamance between 1985 and 2018

Calculating the number of rainy days per year indicated that rainfall ranged from 81 in 1999 to 43 in 2017 (Figure 5), an average of 60 days on the series studied. Compared to the results of Sane et al., (2008), which recorded an average of 79 days of rain in Kolda and 60 days in Vélingara between 1951 and 2000, or an average of 69 days, our results show a continuous decline in the number of days of rain The average rainfall per day ranged from 12.4 mm in 2001 to 19.1 mm in 2017. Unlike the number of rainy days that are declining, the average rainfall per rainy day appears to be increasing since 2003; or since 2009 in Senegal (Descroix et al., 2015). This indicates a tightening of precipitated quantities over the duration of the season.

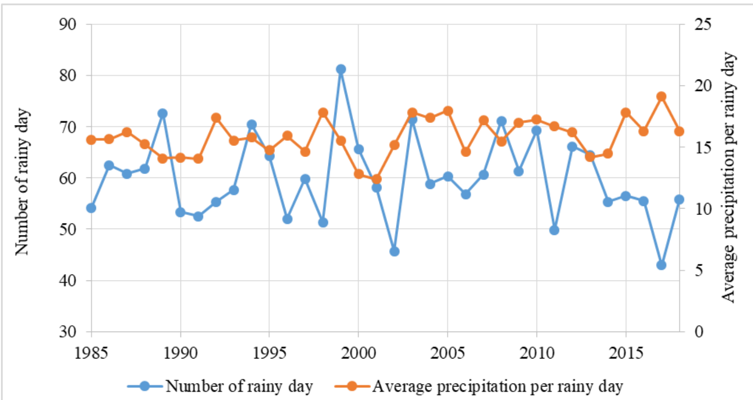


Figure 5. Change in the number of rainy days per year and the average rainfall per rainy day in Upper-Casamance between 1985 and 2017

In terms of the length of the agronomic season, analysis of the start and end dates shows a relatively early start compared to the dry period (Balme et al., 2005) and a relatively late end. Indeed, over 33 years, nine showed that the beginning of the agronomic season begins in the third decade of June (178th day), and six years showed that it begins in the second decade of the same month. For the end, 12 out of 33 years reported the second decade of October (290th day), and 11 years reported the third decade of the same month (Figure 6). The duration of the season is on average 112 days. However, for the beginning of the season, Sane et al., (2008) had recorded an 80% start in the second decade of July. For the duration, Balme et al., (2005) had averaged 105 days. Compared to the millet growth cycle (90-120 days for constant-cycle varieties), the duration of the current agronomic season in Upper-Casamance seems favorable to production. However, this does not seem to be perceived by farmers who tend to blame the rain for the loss of millet production. According to Descroix et al., (2012), the fact that the return of rain, which is generally very positive for rural societies, is not always perceived or recognized may be linked to the degradation suffered by soil and vegetation during the drought phase. For, our results are similar to those of Descroix et al., (2015) They noted that in reality the rainy season is now significantly longer than during the dry phase, although in recent years in the Central Sahel (even in Upper-

Casamance) there has been a return of "bad" wintering in the agronomic sense of the term. In addition, they noted that Upper-Casamance had no "failed" agronomic season; in other words, these winters, which have become relatively longer in recent years, have experienced a good distribution of the rains during the season.

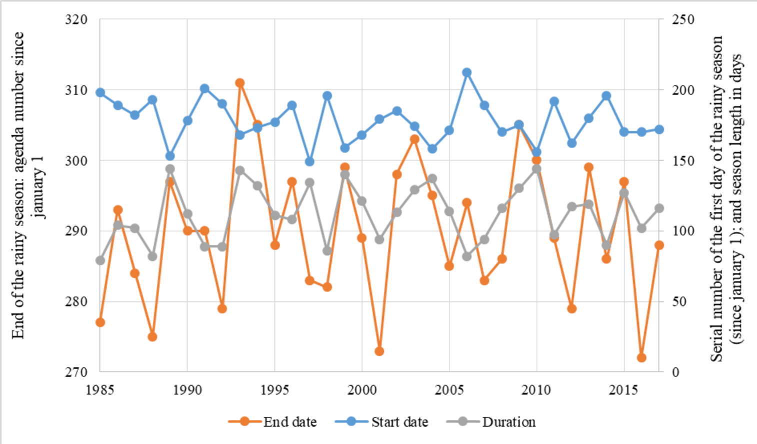


Figure 6. Start and end date and duration of the rainy season in Upper-Casamance between 1985 and 2018

However, for millet culture, Balme et al., (2005) proposed the use of faster maturing varieties (constant cycle mil of 90 days or less, photoperiodic mil) if the season starts late. For their part, Sane et al., (2008) proposed that the farmers of Upper-Casamance should match their farming activities between the second half of July and the second half of October to minimize the risks associated with the late start and early end of wintering. The risk of climate hazards to agricultural activities is lower during this period.

Conclusion

The purpose of this study was to analyze the evolution of agricultural production over the last thirty-four years in Upper-Casamance. It was coupled with the analysis of the annual average change in precipitation to determine their impact on yields. The results showed that agricultural production is increasing as we move away from the dry period. The Pearson correlation calculation showed that there is a positive linear relationship between rice, corn, groundnut and cassava production at rainfall. The simple linear regression applied to the different products at the $p<0.05$ threshold indicated that these four speculations are significantly dependent on the annual rainfall period; this is not the case for millet, sorghum, fonio and cotton. The analysis of the evolution of rainfall indicated favorable conditions for good agricultural production. The "agronomic" season, which averages 112 days, appears to be sufficient for the cultivation of millet and groundnut, which require an average of 4 months of good rainfall. For rice and corn, the results also indicated that the better the rainfall conditions, the better the production.

These results are important to farmers, development actors, and the branches and programs responsible for the country's agricultural production and the achievement of national food self-sufficiency. However, the study did not take into account certain parameters that also influence production, such as: agricultural policies, technical constraints, and organizational constraints. The study therefore recommends that these parameters be included in future analyzes.

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