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RESEARCH PAPER

Trend analysis of climate change and it impact on sorghum productivity in the Sudanian and Sahelian zones of Mali (West Africa)

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Abstract

The present study aims at assessing the effect of the variability of climatic paramanders and their effects on sorghum yield in Mali for suitable adaptation strategies. Thus, yields of sorghum of the past 31 years were collected at the ministry of Agriculture's offices and the climatic data were collected at the Agency for Safandy and Air Navigation in Africa and Madagascar (ASECNA) in Mali. Trend analysis was performed on sorghum yields and climatic data. The results indicate that the climatic paramanders are marked by remarkable inter-annual fluctuations. Average rainfall (from 1987 to 2018) at Katibougou's area showed a regressive trend (regression rate of 3.10%) while San's area an increasing (growth rate of 3.5%) trend was observed. However, on both stations, upwards trend of the temperature (growth rate of 0.02%) was observed. Upward trend of sorghum yields (growth rate of 2.88%) was observed while Katibougou showed a downward trend (regression rate of 2.65%). Only the annual rainfall is correlated (r = 0.56; p < 0.001) with sorghum yields. The study suggests as perspective the dandermination of appropriate sowing dates especially in the early growing season to improve sorghum productivity in the two zones.

Keywords: Climate factors, rainfall index, productivity, climate change, adaptation strategies

Introduction

The Sahel is recognized as one of the area's most vulnerable to climate change (Parry *et al.,* 2007). The variability of previous drought cycles as well as rainfall has significantly affected the entire region. In Sub-Saharan Africa like Mali, the rainfed crops are major contributor to the national economies. Indeed, the majority (80%) of populations of the countries in this region lives in rural areas and these populations live from agriculture and livestock whose performance are closely subjected to manifestation of the climate (Alhassane *et al.,* 2013).

Indeed, a decline in rainfall over the last 50 years has been observed in the southern and northern regions of the country (Sissoko *et al.,* 2018). In the half of the century, rainfall has decreased from 95 mm to 70 mm in the north and from 1360 mm to 1181 mm in Sikasso in the south (Sissoko *et al.,* 2018). In this context, a decrease in food availability is to be feared for the populations, especially for important crops such as sorghum (Traoré, 2014).

Sorghum is one of the main cereals as staple diet of Sahelian populations and is a strategic crop in maintaining food security (Sidibé *et al.,* 2016; Sissoko *et al.,* 2017; Mundia *et al.,* 2019). It is the second most important dry cereal crop after millet (FAO, 2012; Sissoko *et al.,* 2017). Nevertheless, sorghum yields are lower than those of rice and maize (1 t ha-1 compared to 3,267 t ha-1 and 2,880 t ha-1 respectively) (FAOSTAT, 2018). Indeed, between 2008 and 2018 a yield increase of 3% was recorded for an average increase in the area of 2.64% (FAOSTAT, 2018). Despite its importance, sorghum crop is exposed to climatic hazards such as recurrent and irregular droughts, rainfall deficits, heavy rainfall events, devastating floods, andc. (Traoré *et al.,* 2001; Mertz *et al.,* 2010; Sultan *et al.,* 2014; Faostat, 2018; Akinseye *et al.,* 2020 ;). These constraints negatively affect sorghum yields (Sissoko *et al.,* 2018). These agro-climatic constraints coupled with the often unfavourable socio-economic and political context explain the low level of crop production (Lobell *et al.,* 2008; Traoré *et al.,* 2011; Traoré, 2014).

This situation is due to the recurrent variability of productivity which is becoming increasingly worrying. Most of the farmers are obliged to adopt or develop strategies to mitigate the effects of climate change on crop productivity (Sissoko *et al.,* 2018). To deal with climate risks, it is urgent to prevent climatic hazards by developing appropriate adaptation strategy such as drought resistant crop varieties, and determination of optimal sowing periods. A good knowledge of the major climatic risks on sorghum cropping is essential since it is well known that climate variability and change have and will have far reaching consequences for smallholder farmers in sub-Saharan Africa where majority of farmers depend on agriculture for their livelihoods (Amouzou *et al.,* 2019; Akinseye *et al.,* 2020).

The present study was designed to determine the effects of variation in climatic parameters on sorghum productivity in the Sudanian and Sahelian zones of Mali. Specifically, the study aims at: (i) analyzing the past trend over the last 31 years and the inter-annual variability of climatic factors in the Sudanian and Sahelian zones of Mali, (ii) analyzing the evolution of sorghum production in the Sudanian and Sahelian zones of Mali over the same period, and finally (iii) determining the effects of climate change on sorghum yield in the Sudanian and Sahelian zones of Mali.

Materials and Mandhods

Study area

The study was carried out in two different districts: Koulikoro and San (Figure 1) in Mali. The Koulikoro district is located in the Sudanian zone at 60 km from Bamako, the capital of Mali. It is at -8.9° 32' West longitude, 12° 56' North latitude and at an altitude of 332 m above sea level on the 900 mm isohyet (Bakary, 2010). The climate is Sudano-Sahelian with an average annual rainfall of 700-900 mm (Bakary, 2010). The cropping season generally begins in early June and ends in October. It is an agro pastoral zone. The main food crops are milland, sorghum, maize, rice, fonio and cowpea. The vegandation is dominated by *Faidherbia albida, Adansonia digitata, Vitelaria Paradoxa, Balanites aegyptiaca,Ceiba pentandra, Khaya senegalensis, Parkia biglobosa* andc. The soils are clayey, sandy, lateritic and gravelly in some areas.

San's discrict, is located in the Ségou region in the Sahelian zone at -4° 9' West longitude, 13° 3' North latitude and at an altitude of 287 m above sea level. The average annual rainfall varies between 500 mm and 800 mm. The rainy season also begins in mid-June lasting in October. There is also a shift in the rainy season with an average of 3 months of rainfall (Coumbiti, 2019). It is an excellent agro pastoral zone. The main food crops are millet, sorghum, maize, rice, fonio and cowpea. The vegetation is characterized by shrubby savannah. The herbaceous is dominated by annual grasses. The soils are clayey, sandy, lateritic and gravelly.

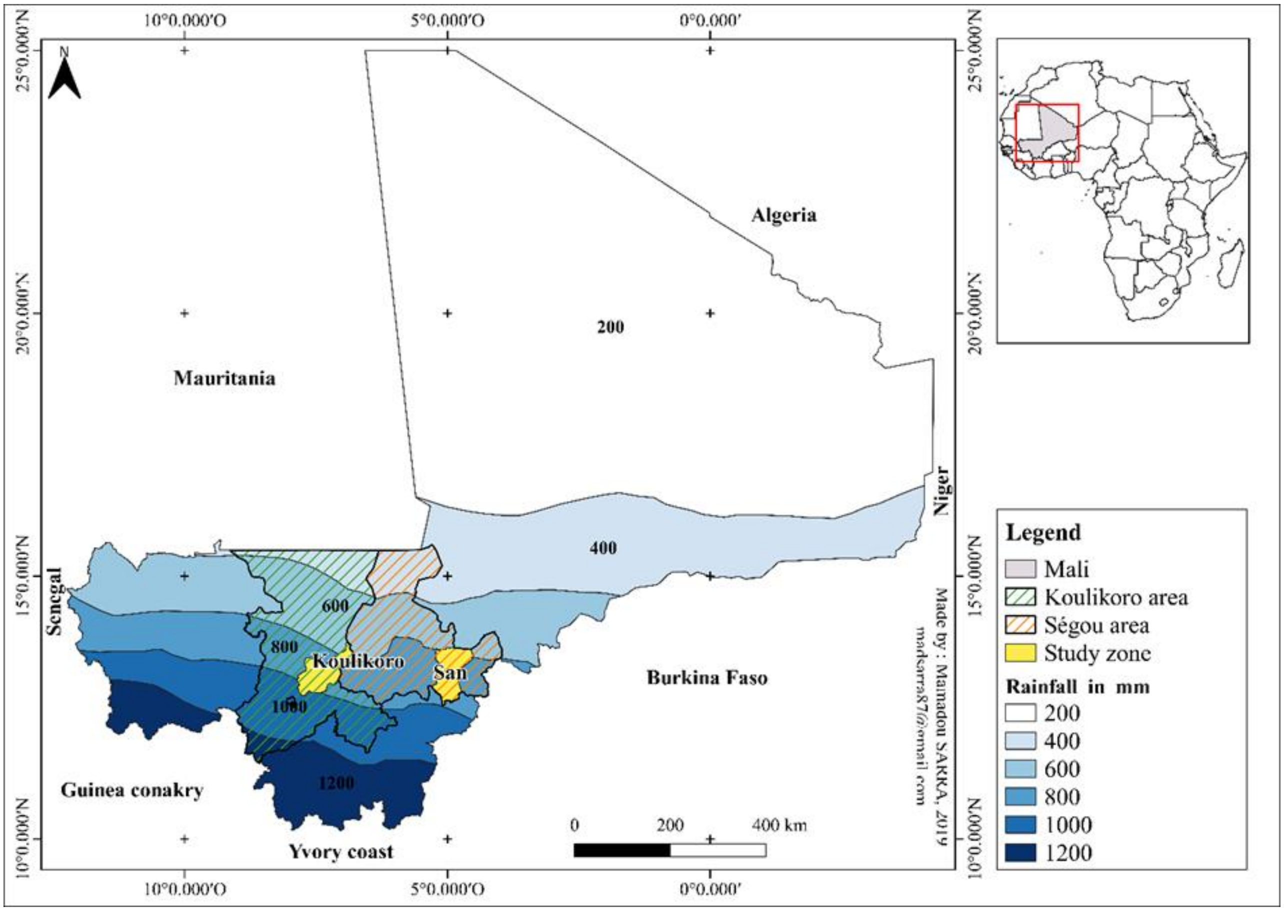

Figure 1: Spatial location of the two study sites in the sorghum production areas of Mali

Climate and sorghum yield data used

Climatic data were collected at two meteorological stations of the Agency for Safety and Air Navigation in Africa and Madagascar (ASECNA) in Mali. According to the World Meteorological Organization (WMO), the recommendations of a climate analysis are only taken into account when the data collected on climate series exceed 30 years (Robson *et al.,* 2000). Climatic data were therefore collected over the period 1987 to 2018 in both zones. The daily climatic data collected included maximum and minimum temperature (°C), daily precipitation (mm of rain), wind speed (m/s), potential evapotranspiration (FTE in mm) and maximum and minimum air humidity (%). Sorghum grain yield data from 1987 to 2018 were collected at the statistic department of the National Direction of Agriculture (DNA) of the Malian Ministry of Agriculture.

Statistical analyses

To reduce errors from data related to the measures and visualized the dry and wand periods, high and low temperature periods, the Mean standardized anomaly index (Vcr) were calculated from the formula (i) proposed by Lamb (1982):

$$V_{cr} = \frac{x_i - \bar{x}}{\sigma}$$

With Vcr = the rainfall index (or temperature index for temperature data), x_i (mm) = rainfall (temperature, for a station in year i), $\bar{x}$ (mm) = average annual rainfall (or temperature) at the station during the study period, σ = standard deviation of rainfall or temperature for that period.

Similarly, in order to study the stationary characters of the time series from 1987 to 2018 for each of the climatic variable per zone, the linear adjustment with the time series analysis, and precisely the trend analysis were performed following the method described by Bowerman and O'Connell (1993) and Bello *et al.* (2016). This trend was assessed taking into account regression equations with R^2 coefficient of determination (Rimi *et al.,* 2011; Bello *et al.,* 2016).

Regarding the possible effect of climatic variability and changes in sorghum production in the two zones, yield data were collected considering the area of production and the year. The yield data were then subjected to trend analysis taking into account the regression equation and the R^2 coefficient of determination in order to analyze the trend direction. Climatic data from the last 31 years were then correlated with sorghum yields of 31 years (Oguntunde *et al.,* 2014; Bello *et al.,* 2016) to analyze the effect of each factor on sorghum yield in each production area. All of these analyses were performed using MS Office Excel and Minitab 14 software.

Results

Temporal analysis and progressive trend of climatic paramanders of both study zones

In all of the sorghum production areas, rainfall is marked by remarkable inter-annual fluctuations with a succession of dry and wand periods (Figure 2). At the Katibougou station, a long and dry period is observed from 1989 to 2010, while the wand period is observed from 1993 to 2000. In general, the evolution of the mean water level between 1987 and 2018 shows a regression trend (regression rate of 3.10%) (Figure 2). However, in San, there was a rainfall deficit from 1990 to 2002, while a wand period is observed in 1991, 1994, 1998, 2003, 2009, 2010, 2012, 2015 and 2018 (Figure 2). It is observed from the Figure 2 that the evolution of the average water level between 1987 and 2018 shows an increasing trend (growth rate of 0.02%).

However, the trends were less linear and did not have defined pattern regarding the determination coefficients R^2 which are low in all of these cases.

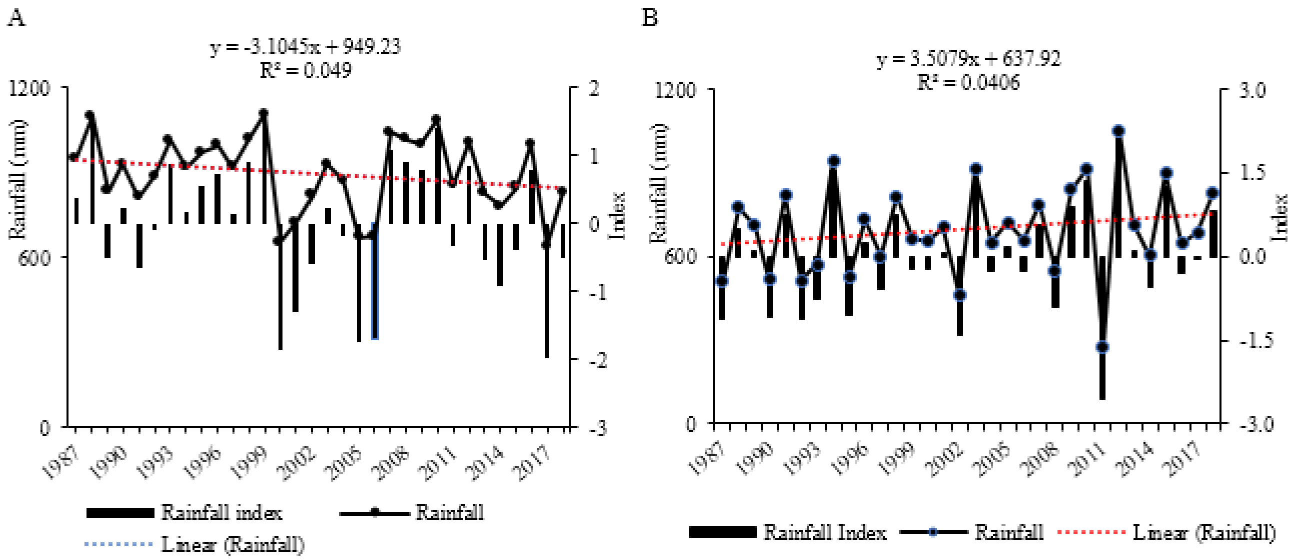

Figure 2: Inter-annual variability and trend in rainfall at Katibougou (A) and San (B) from 1987 to 2018

The analysis of the climatic data for the annual mean temperature recorded at the Katibougou site showed a gradual rise from 2005 to the present (Figure 3). The last fifteen years (2004-2018) were significantly warmer than the previous periods.

In addition, in the San region, a gradual e significant ($R^2 = 0.03$; $P < 0.05$). There is a clear inter-annual variability in mean temperature (ranging from 21°C to 35°C) increased from 2004 to date is found. As in the first study area, there is also an inter-annual variability in the mean temperature from 23°C to 36°C. The last fifteen years (2004-2018) were significantly warmer than the previous ones ($R^2 = 0.36$; $P < 0.05$) (Figure 3).

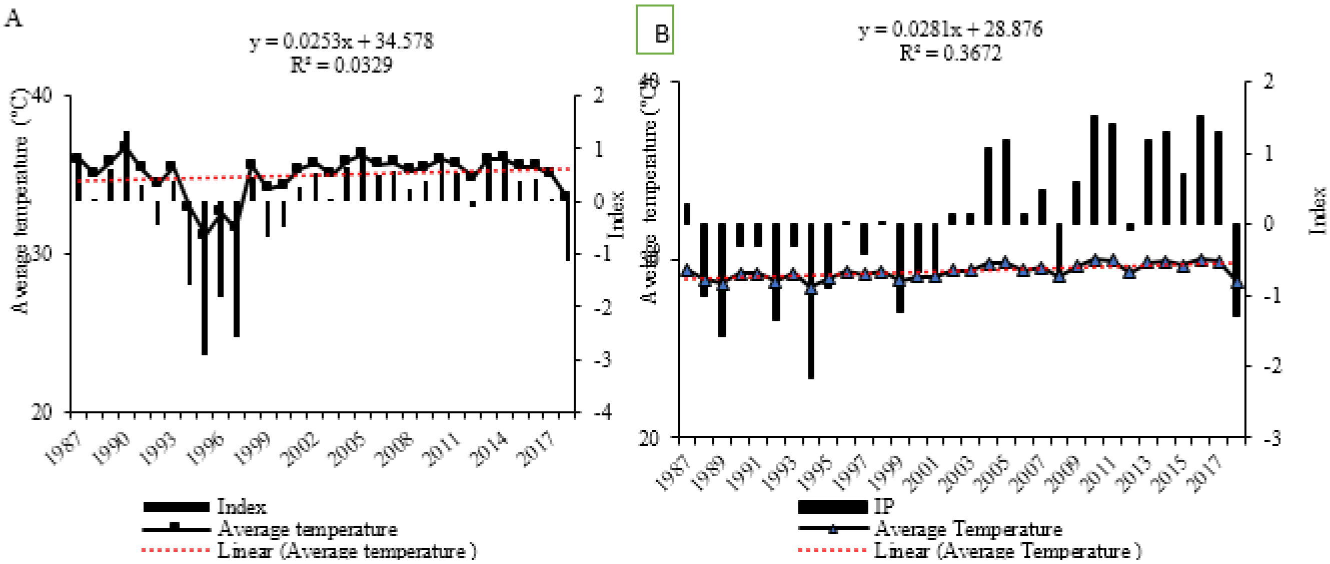

Figure 3: Inter-annual variability and trend in temperature at Katibougou (A) and San (B) from 1987 to 2018

With regard to the air humidity, there was a slight decrease in both study areas. Katibougou station was marked by remarkable inter-annual variability over the last 31 years with high humidity observed in 1996 (Figure 4) and lower in 2018. However, at the San region, high air humidity was only observed from 1990 to 1995 and then a decrease was observed to date (Figure 4).

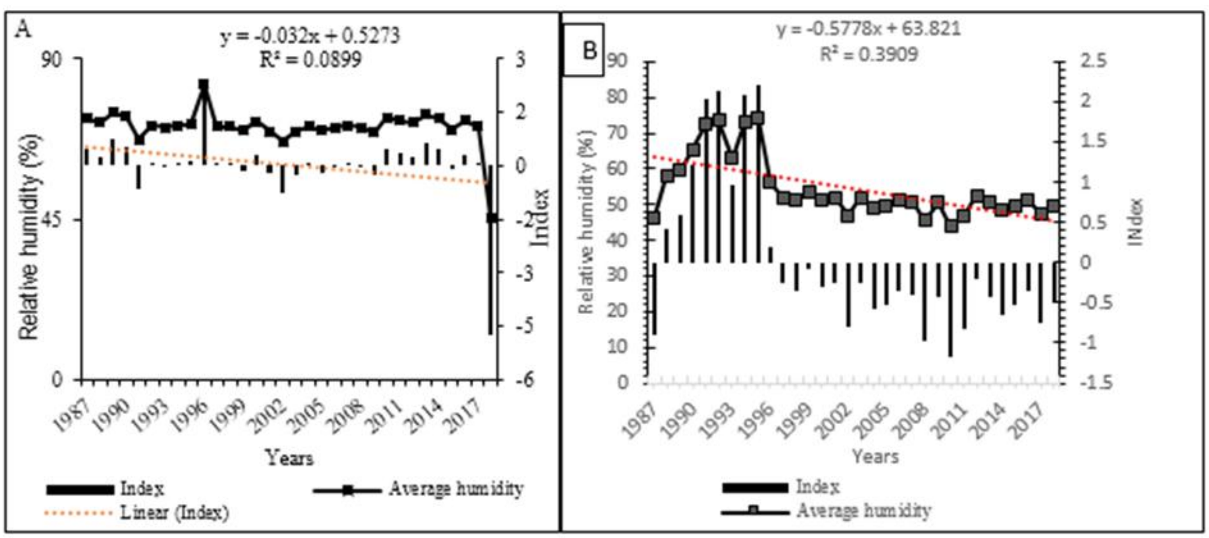

Figure 4: Inter-annual Variability and Trend in Relative Humidity at Katibougou (A) and San (B) from 1987 to 2018

Figure 5 shows the annual average wind speed recorded in both areas. A gradual trend was observed from 1987 to 2018. A high winds were observed in 1991, 1994, 2006 and 2017 at Katibougou. At the San station, the graphs show a slight decrease between 1987 and 2018 and high winds over several years (Figure 5).

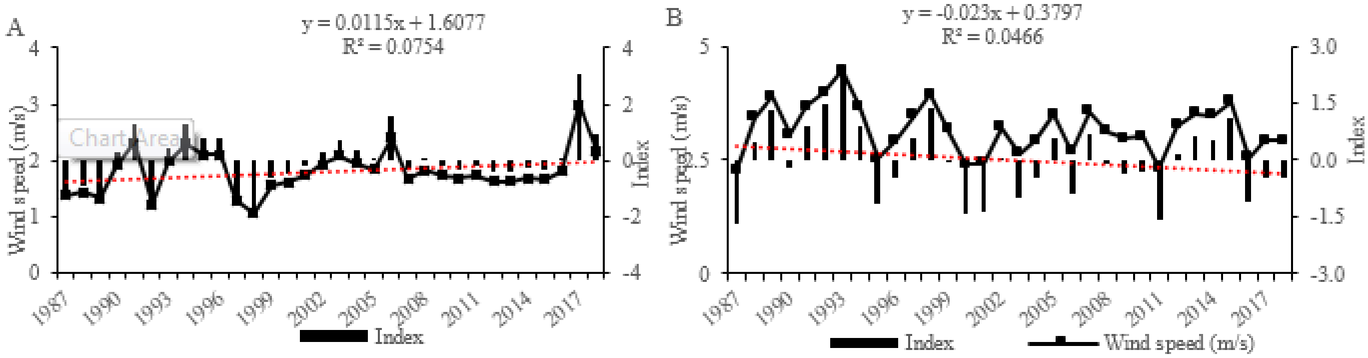

Figure 5: Inter-annual variability and trend in wind speed at Katibougou (A) to San (B) from 1987 to 2018

With regard to the number of rainy days in both area (Figure 6), the graphs show a high inter-annual variability marked by an alternation of high rainy days and periods with low rainy days. At the Katibougou site, an increasing trend in the number of rainy days with an increase rate of 0.91% is observed. However, at San site, the graphs indicate a regression trend in the number of rainy days with a regression rate of 0.005%. Though, the trends were less linear and do not show a definite pattern with regard to the coefficients of determination which are less than 50% and not significant (P > 0.05).

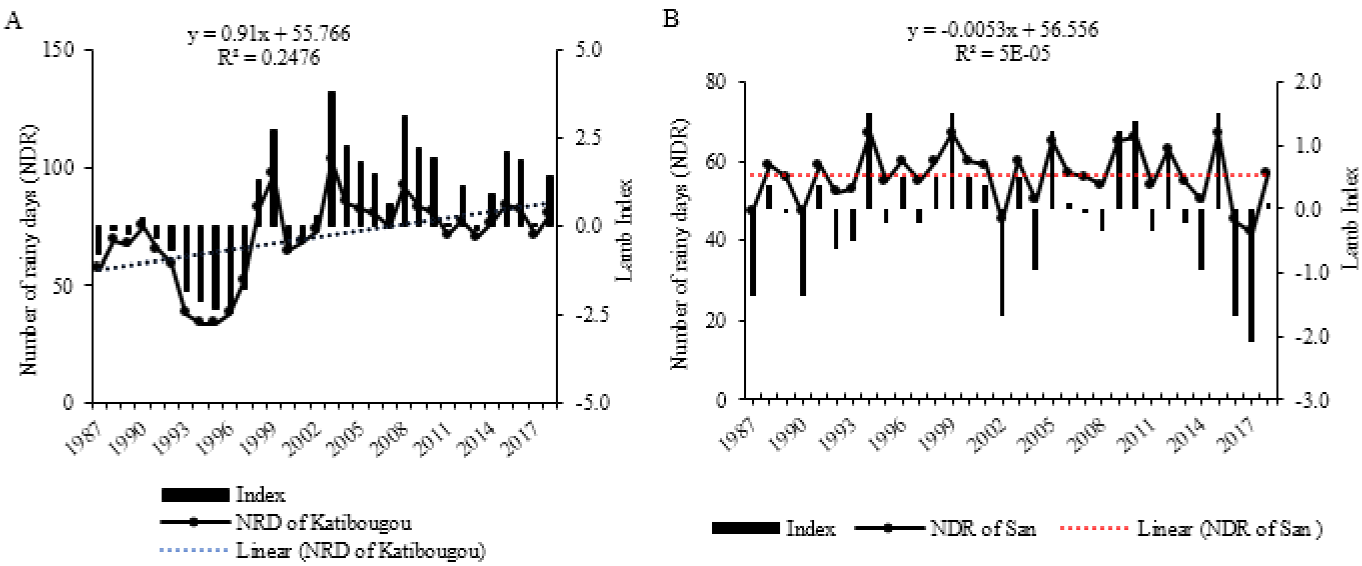

Figure 6: Inter-annual variability and trend in the number of rainy days at Katibougou (A) and San (B) from 1987 to 2018

The graphs in Figure 7 show that the Katibougou agro ecological zone is characterized by four-months rainy season with two months wand period (July and August). Furthermore, the graphs indicate that the San agro ecological zone is marked by three months rainy season with an abundant period in August.

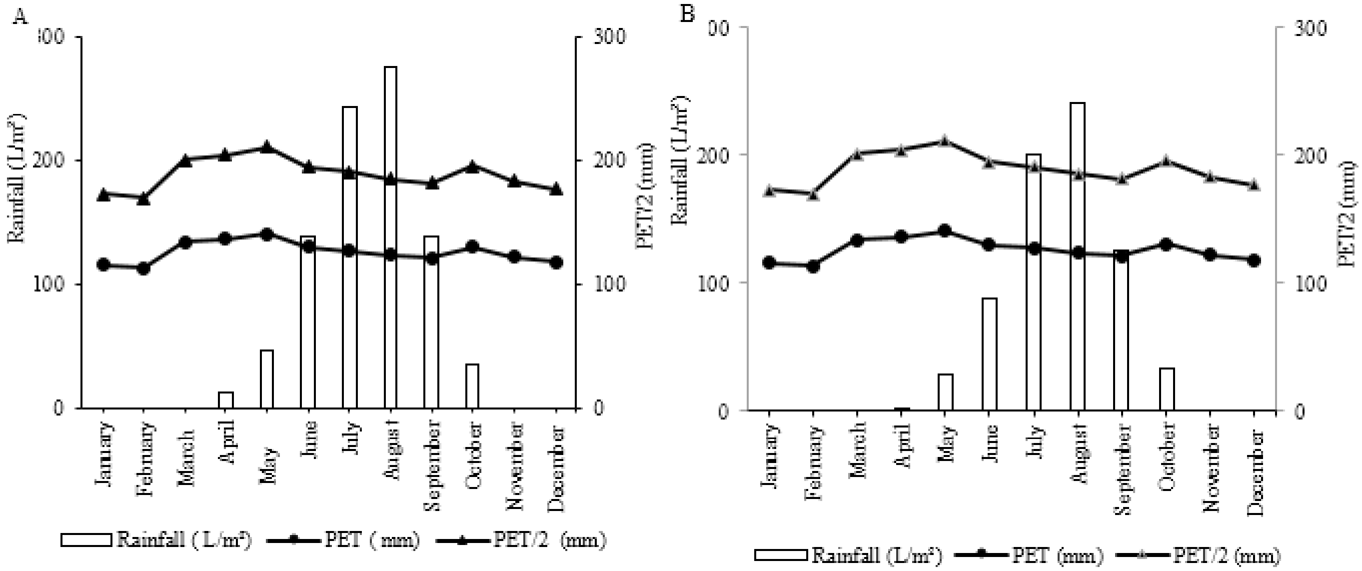

Figure 7: Katibougou (A) and San (B) Water Balance from 1987 to 2018

Trend and variability of sorghum grain yields regarding the production zone

Figure 8 shows evolution and variability of sorghum grain yields during the cropping seasons of 1986/1987 to 2017/2018 in the both production zones. Large inter-annual variability in sorghum yields in the two study areas is observed. In general, sorghum yields in Koulikoro show a downward trend, whereas in San area a low increase of 2.88% is observed with low R^2 coefficients of determination.

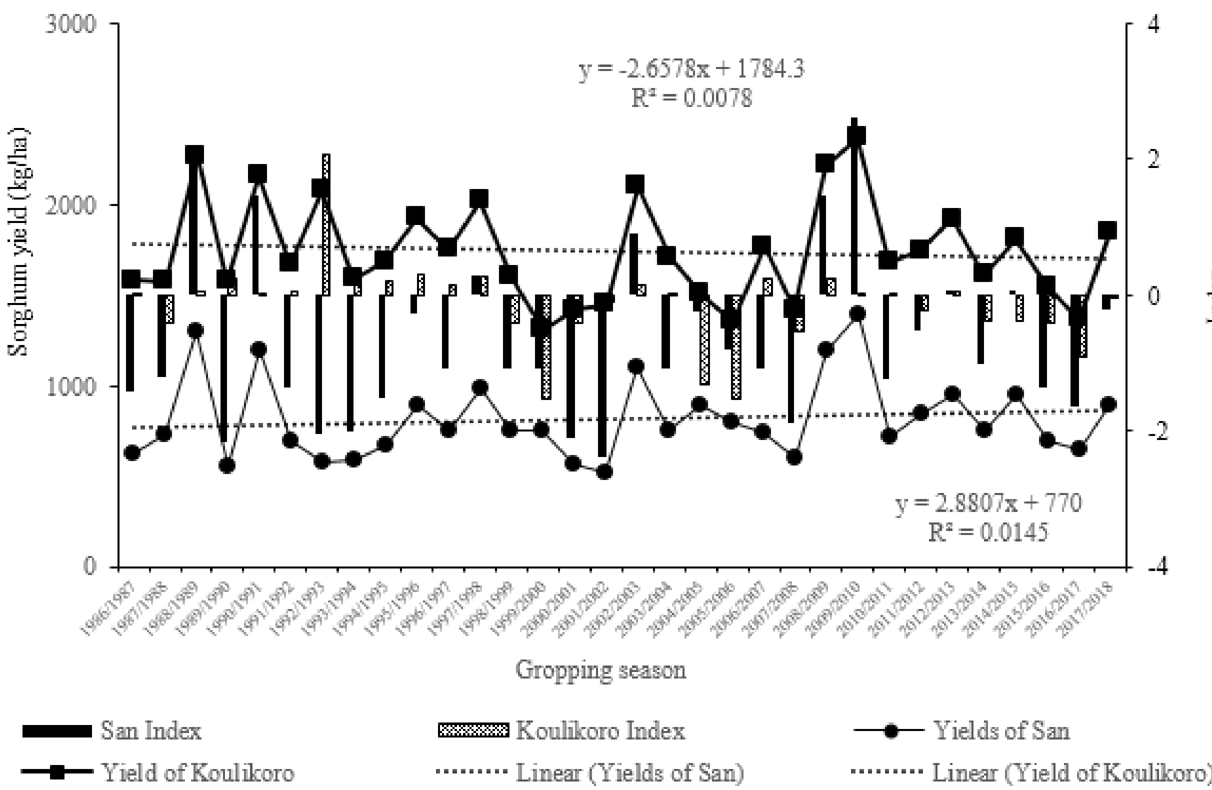

Figure 8: Evolution of sorghum grain yields at Katibougou and San

Effect of the climatic factors variation on the sorghum grain yield in both study zones

Variation in rainfall and temperatures between 1987 and 2018 showed a downward trend in both areas. The correlation (Table 1) results between sorghum grain yields and climatic parameters (rainfall, temperature, potential evapotranspiration, air humidity and wind speed) showed that only mean annual rainfall data were positively and significantly correlated with sorghum grain yields in both areas ($r = 0.56$; $p = 0.001$ in Koulikoro and $r = 0.55$; $p = 0.001$ in San).

Table 1: Pearson correlation between sorghum grain yields from 1987 and 2018 and the inter-annual climatic parameters

Climatic factors	Sorghum production areas (ha)			
	Katibougou		San	
	Pearson correlation coefficient (r)	Probability	Pearson correlation coefficient	Probability
Annual rainfall (mm)	0.56	0.001	0.55	0.001
Number of rainy days	-0.143	0.434	-0.065	0.724
Average temperature (°C)	-0.11	0.54	-0.21	0.23
Average ETP (mm)	0.171	0.350	-0.058	0.758
Average Humidity (%)	0.03	0.85	-0.00	0.99
Wind speed (m/s)	-0.14	0.44	0.24	0.18

Climatic factors determining sorghum production

Table 2 presents regressions between sorghum grain yields and climatic factors results for the cropping season of 1986/1987 to 2017/2018. The annual rainfall was the climatic factor affecting the most variation in the sorghum grain yields in both study areas, and the annual potential evapotranspiration (PAND) also affected variation in sorghum yields in San site. The results of the statistical analysis revealed that the selected variables significantly affected ($p < 0.01$ and $p < 0.001$) the validity of the multiple regression models used.

Table 2: Results of multiple regression and statistical tests showing the effect of climatic factors on sorghum production in Koulikoro and San zones

Climatic factors	Sorghum production areas (ha)			
	Katibougou		San	
	Coefficient	Pr > (t)	Coefficient	Pr > (t)
Constante	317	0.72	-434	0.169
Rainfall (mm)	0.77	0.002	0.81	0.001
Mean temperature (°C)	-1.1	0.96	122.8	0.135
Average humidity (%)	-1.65	0.74	0.85	0.867
Wind speed (m/s)	35.7	0.63	39	0.557
Average ETP (mm)	-3067	0.476	821.24	0.000
R^2	33.31		37.48	
R^2 adj	23.44		28.22	

Discussion

Trends in climatic parameters in the Sudanian and Sahelian zones of Mali

Results of the temporal and trend analysis of climatic parameters showed remarkable inter annual variations in rainfall in the study area. These trends are characterized by a succession of dry periods and marked wand periods. The trend observed in this study corroborates the results of Alhassane *et al.* (2013), stating that increase rainfall variability can make planning in the agricultural activity more difficult.

At the Katibougou area, results of the analysis of the evolution of the average rainfall between 1987 and 2018 showed a downward trend while the evolution of the average rainfall showed an increasing trend in the Sudano-Sahelian zone. However, the trends are less linear and do not show definite patterns with regard to the R^2 coefficients of determination, which are low at both sites. These results are similar to those found by Lebel and Ali (2009). Alhassane *et al*. (2013) have shown that since the mid-1990s, there has been a random rainfall conditions in the Sahel, with, however, increased inter- and intra-seasonal variability in rainfall. Nevertheless, this apparent random of wand conditions coincides with an increasing rate of global warming worldwide (Parry *et al.,* 2007). These favourable conditions are most often associated with more frequent heavy rains, causing flooding and extensive damage in West Africa (Sarr *et al.,* 2011, Alhassane *et al.,* 2013). According to Rimi *et al.* (2011) and Bello *et al.* (2016), this variability in the climatic factors constitutes a major bottleneck for good agricultural production in the poor regions of the world. Several authors have also reported similar results in Sub-Saharan Africa (Loko et al., 2013, Badjana *et al.,* 2014, Ezin et al., 2014, Oguntunde *et al.,* 2014, Balogoun *et al.,* 2016, Bello *et al.,* 2016).

Analysis of the temperature data showed a gradual increase from 2005 at the Katibougou site. Real inter annual temperature variability ranging from 21°C to 35°C was noted. The last fifteen years (2004 - 2018) have been significantly warmer than the previous ones in the Sudanian zone and these are valid (variation from 23°C to 36°C) in the Sudano-Sahelian zone. These results corroborate Bougma *et al*. (2018) finding showing that the inter- and intra-annual variability of temperature was particularly high in the Sahelian zone with risks of drought.

The air humidity data at the two study areas showed a slight decrease. The Katibougou station has been characterized by very inter annual variability during the last 31 years with high humidity noted in 1996 and a low in 2018. In opposite, in the San zone, high humidity was observed from 1990 to 1995 then a decline was noticed until today. These results corroborate finding by Sultan *et al.* (2013) showing an increase of 6°C of the temperature and a decrease of 20% of the rainfall.

The results of the annual average wind speed at the two research areas showed a progressive trend from 1987 to 2018. The winds were violent in 1991, 1994, 2006 and 2017 at Katibougou with an inter-annual average of 1.80 m/s. While at the San station, a slight decrease was observed between 1987 and 2018 and the wind speeds were strong over several years with an inter annual average of 3.25m/s. These results corroborate those found by Renard and Vandenbelt (1990) and Rajot *et al.* (2009).

The results of the analysis of the number of rainy days in the two zones showed high inter annual variability which is characterized by an alternation of periods with high number of rainy days followed by sequences of periods with a low number of rainy days. In the Katibougou zone, an increasing trend in the number of rainy days with an increase rate of 0.91% was observed. Furthermore, in the San region, the results indicated a downward trend with a regression rate of 0.005%. The number of rainy days is one of the most important factors for the success of an agricultural season. Boyard-Micheau (2013) showed that the number of rainy days is one of the most important products for the calculation of seasonal rainfall accumulation. According to the author, it can be considered as the combination of several intra-seasonal descriptors (ISD) between the number of rainy days and the average daily intensity of rainfall integrated over season. The duration is calculated between a season start date and a season end date.

The results of the rainfall and potential evapotranspiration (PAND) analysis showed that the Katibougou zone is marked by four months of rainy season and two-month period rainfall (July and August). In opposite, San zone is marked by three months of rainy season with an abundant period of one month (August). This shows that the Sahelian zone is much more affected by the manifestations of climate change compared to the Sudanian zone.

In summary, we can conclude that the variability of rainfall, the number of rainy days and the length of the rainy season showed very remarkable inter annual variations that significantly affect sorghum production in both study zones. This effect on sorghum production is more pronounced in the Sahelian zone than the Sudanian. This is explained by the reduction in the number of rainy days. These results corroborate those of Boyard-Micheau (2013), Bougma *et al.* (2018) who showed that the inter- and intra-annual variability of rainfall is particularly high in the Sahelian zone with marked drought risks. This rainfall variability is often combined with extreme climatic events that have disastrous consequences on agricultural production (Traoré *et al.,* 2000).

Expected impacts of climatic variability on sorghum yields

The results of the present study showed that both zones experienced high decrease in rainfall volume. This is also confirmed by Nicholson (2001); Le Barbé *et al.* (2002); Bell and Lamb (2006); Alhassane *et al*. (2013). These authors mentioned also a clear break in the rainfall series from the years 1968 to the early 1990s. These results are similar to those of Hulme (2005); Sultan *et al.* (2014), who showed that rainfall and temperature were the main climatic factors directly affect agricultural production in Sub-Saharan Africa. The inter annual variability of climatic parameters is a major constraint for sustainable development of rainfed agriculture in this region (Bello *et al.,* 2016). The analysis of temperature data has shown a gradual increase and agricultural activities are negatively impacted by the loss of crop species. High temperatures cause a considerable reduction in pollen viability leading to negative effects on yields (Bougma *et al.,* 2018).

In addition, there is great variability in sorghum grain yields in both zones from one year to another. Coefficients of determination are low. Faye *et al.* (2018) have shown that the increase in sorghum grain yields is not only related to the area sown but rather to other factors including the total annual rainfall, the spatial and temporal distribution of rainfall, the length of the rainy season, and soil fertility management. Indeed, in this study, average rainfall was positively correlated with sorghum grain yields over the last 31 years. This shows that the amount of rainfall recorded during these years covers the water needed by sorghum. This result corroborates that of Sene (1995) who showed that rainfall needs to be well distributed between 500 to 600 mm for a short cycle sorghum varieties, 650 to 800 mm for a medium cycle varieties and 950 to 1100 mm for a long cycle varieties in order to ensure optimal yield under conditions of good soil fertility. Traoré *et al*. (2001), Sarr *et al.* (2011), Faye *et al.* (2018) have shown that it is rather the poor spatial and temporal distribution of rainfall that significantly affects sorghum production, which was not the case in our study. We did not obtain significant correlations between the number of rainy days and sorghum grain yields. This could probably be explained by the drought resistant varieties adopted by producers today as climate change adaptation strategy. In fact Sorghum's drought tolerance and ability to withstand water logging make it an important crop for maintaining productive agroecosystems under a changing climate (Tonitto and Ricker-Gilbert, 2016). Indeed, a study in the zone revealed high adoption rate of drought resistant short-cycle varieties which would have contributed to an improvement in water use efficiency. In general, the irregularity of rainfall has as a corollary the variability of sowing dates, the length of the rainy season and a greater occurrence of water deficits (Traoré *et al.,* 2001, Sarr *et al.,* 2011). This rainfall variability is often coupled with extreme climatic events that have adverse consequences on agricultural production. For example, the droughts of the 1970s and 1980s and the recurrent heavy rains that fell on the zone during the 1990s and 2000s constituted one of the extreme events that would undoubtedly be amplified by climate change (Nicholson, 2001; Le Barbé *et al.,* 2002; Bell and Lamb, 2006; Sarr *et al.,* 2011; Alhassane *et al.,* 2013). This being the case, it is essential to take into account all these data for the improvement of land productivity, especially in a context of greater variability of climate factors in the Sahelian zone.

Our results showed that other climatic parameters such as temperature, relative humidity are not a limiting factor for agricultural production except for strong winds which could cause damage to sorghum production. From these results, it is therefore obvious that rainfall is the main factor that determines sorghum production from one year to the next. Moreover, if adaptation measures are not taken, yield reductions could be expected in Sub-Saharan Afric (SSA) by 2050 (Fandohan *et al.,* 2015). Indeed, according to Sultan (2012); Berg *et al.* (2013); Roudier *et al.* (2016) for the coming years, the hypotheses of changes in rainfall patterns could have an overall negative effect on the production of crops such as millet, maize and sorghum. This would affect food security in many parts of West Africa.

In Burkina Faso, Barro *et al.* (2006) and Clavel and al. (2008) and in Mali, Traoré *et al.* (2013) and Sissoko *et al*. (2017) have shown that several strategies can be used to reduce the vulnerability of sorghum cultivation to climate change. Due to its status as a staple grain, improved sorghum management can provide smallholder farmers with stability in their household nutritional needs (Tonitto and Ricker-Gilbert, 2016). These include the adoption of cultivation practices that allow the crop cycle to adapt to climatic conditions (Tonitto and Ricker-Gilbert, 2016; Akinseye *et al.,* 2020). Determining planting dates for the different varieties of sorghum grown by farmers associated with drought resistant varieties would be an opportunity to mitigate the effect of climate change (Haussmann *et al.,* 2012; Akinseye *et al.,* 2017). These various adjustments in cultural practices should also be coupled with the local knowledge of the populations to ensure true effectiveness (Mundia *et al.,* 2019).

Conclusion

This study showed that rainfall, number of rainy days and temperatures varied from one year to another in the Sudanian and Sahelian zones of Mali. The last ten years have been particularly wand at the San station. However, at the Katibougou station, a slight decrease in rainfall was noticed, an increase in the number of rainy days and a slight increase in temperature were also noticed. Rainfall is the main climatic factor that has shown a positive correlation with grain yields over the last 30 agricultural seasons. In this context, the implementation of adaptation strategies to deal with the effects of temperature and rainfall variability for sustainable sorghum production in the Sudanian and Sahelian zones of Mali is a necessity. Therefore, determination of sowing dates for the different sorghum variandies adopted by farmers is an objective for improving sorghum productivity in the study area.

References

Akinseye F. M., Adam M., Agele S. O., Hoffmann M. P., Traore P. C. S. and Whitbread A. M. (2017). Assessing crop model improvements through comparison of sorghum (sorghum bicolor L. moench) simulation models: a case study of West African variandies. Field Crops Research, 201, 19-31.

Akinseye F. M., Ajeigbe H. A., Traore P. C., Agele S. O., Zemadim B., and Whitbread A. (2020). Improving sorghum productivity under changing climatic conditions: A modelling approach. Field Crops Research, 246, 1-13.

Alhassane A., Salack S., Ly M., Lona I., Traoré S. B. and Sarr B. (2013). Évolution des risques agroclimatiques associés aux tendances récentes du régime pluviométrique en Afrique de l'Ouest soudano-sahélienne. Science and changements planétaires/Sécheresse, 24(4), 282-293.

Amouzou K. A., Lamers J. P., Naab J. B., Borgemeister C., Vlek P. L. and Becker M. (2019). Climate change impact on water-and nitrogen-use efficiencies and yields of maize and sorghum in the northern Benin dry savanna, West Africa. Field Crops Research, 235, 104-117.

Badjana H. M., Selsam P., Wala K., Flügel W. A., Fink M., Urban M. and Akpagana K. (2014). Assessment of land-cover changes in a sub-catchment of the Oti basin (West Africa): A case study of the Kara River basin. Zentralblatt für Geologie und Paläontologie, Teil I, 151-170.

Bakary K. (2010). Andude de l'efficacité agronomique de microdosage dans un système de rotation biennale de sorgho, niébé dans les conditions de l'IPR/IFRA de katibougou, Mali. Thèse de mémoire du diplôme d'Ingénieur de l'IPR/IFRA de Katibougou.Mali.78 pages.

Balogoun I., Ahoton L. E., Saidou A., Bello D. O., Ezin V., Amadji G. L. and Ahanchede A. (2016). Effect of climatic factors on cashew (Anacardium occidentale L.) productivity in Benin (West Africa). Journal of Earth Science & Climatic Change, 7(1), 1-10.

Barro N., Bello A. R., Savadogo A., Ouattara C. A. T., Iiboudo A. J. and Traoré A. S. (2006). Hygienic status assessment of dish washing waters, utensils, hands and pieces of money from streand food processing sites in Ouagadougou (Burkina Faso). African Journal of Biotechnology, 5(11), 1107-1112.

Bazzaz F. A. and Sombroek W. G. (1996). Global climatic change and agricultural production: An assessment of current knowledge and critical gaps. In Global climate change and agricultural production: direct and indirect effects of changing hydrological, pedological, and plant physiological processes. Food & Agriculture Organization, 199-235.

Bell M. A. and Lamb P. J. (2006). Integration of weather system variability to multidecadal regional climate change: the West African Sudan–Sahel Zone, 1951–98. Journal of Climate, 19(20), 5343-5365.

Bello O. D., Akponikpè P. B. I., Ahoton E. L., Saïdou A., Ezin A. V., Kpadonou G. E. and Aho N. (2016). Trend Analysis of Climate Change and Its Impacts on Cashew Nut Production (Anacardium occidentale.) In Benin. Octa Journal of Environmental Research, 4(3), 181-197.

Berg A., de Nobland-Ducoudré N., Sultan B., Lengaigne M. and Guimberteau M. (2013). Projections of climate change impacts on potential C4 crop productivity over tropical regions. Agricultural and Forest Mandeorology, 170, 89-102.

Bougma L. A., Ouerdraogo M. H., Sawadogo N., Sawadogo M., Balma D. and Vernooy R. (2018). Perceptions paysannes de l'impact du changement climatique sur le mil dans les zones sahéliennes and soudano-sahélienne du Burkina Faso. Afrique Science, 14(4), 264-275.

Boyard-Micheau J. (2013). Prévisibilité potentielle des variables climatiques à impact agricole en Afrique de l'Est and application au sorgho dans la région du mont Kenya. Thèse de doctorat, Université de Dijon, France. 356p

Clavel D., Barro A., Belay T., Lahmar R. and Maraux F. (2008). Changements techniques and dynamique d'innovation agricole en Afrique sahélienne: le cas du Zaï mécanisé au Burkina Faso and de l'introduction d'une cactée en Andhiopie. [Vertigo] La revue électronique en sciences de l'environnement, 8(3), 1-10.

Coumbiti D. (2019). Effand de la fertilisation sur le comportement du riz irrigué en système de riziculture intensif (SRI) dans les conditions agroclimatiques de San, Mali. Thèse de mémoire du diplôme d'Ingénieur de l'IPR/IFRA de Katibougou, Mali. 40p.

Ezin V., Yabi I., Kochoni E. G. M. and Ahanchédé A. (2014). The menace of climate change to agricultural production and food security in Benin Republic. Journal of Mandeorology and Climate Science, 12(1), 90-100.

Fandohan A. B., Koko I. K. E. D., Avocevou-Ayisso C., Gouwakinnou G. N., Savi M. K., Assogbadjo A. E. and Kakai R. G. (2015). Lantana camara (verbenaceae): a potential threat to the effectiveness of protected areas to conserve flora and fauna in Benin. Agronomie Africaine, 27(2), 115-126.

FAO. (2012). Twenty-Seventh FAO Regional Conference for Africa. ARC/12/REP, Brazzaville Congo, 23-27 April 2012, Rev.1.

Faostat(2018).http://Www.Fao.Org/Faostat/En/#Data/QC.Consult éle 18/01/2020

Faye M., Fall A., Faye G. and Van Hecke E. (2018). La variabilité pluviométrique and ses incidences sur les rendements agricoles dans la région des Terres Neuves du Sénégal oriental. Belgeo. Revue belge de géographie, 1, 1-18.

Gachon P., Gauthier N., Bokoye A. I., Parishkura D., Cotnoir A., Tremblay Y. and Vigeant G. (2007). Working Group II. Variabilité, extrêmes and changements climatiques au Sahel: de l'observation à la modélisation. Rapport des contributions canadiennes au projand ACDI-CILSS (# Ao30978-002); appui aux capacités d'adaptation aux changements climatiques. Montréal, environnement Canada, Vol II., 208 pages

Haussmann B. I., Fred Rattunde H., Weltzien-Rattunde E., Traoré P. S., Vom Brocke K. and Parzies H. K. (2012). Breeding strategies for adaptation of pearl milland and sorghum to climate variability and change in West Africa. Journal of Agronomy and Crop Science, 198(5), 327-339.

Hulme P. E. (2005). Adapting to climate change: is there scope for ecological management in the face of a global threat?. Journal of Applied ecology, 42(5), 784-794.

Lamb P. J. (1983). Sub-saharan rainfall update for 1982; continued drought. Journal of Climatology, 3(4), 419-422.

Le Barbé L., Lebel T. and Tapsoba D. 2002. Rainfall variability in West Africa during the years 1950–90. Journal of climate, 15(2), 187-202.

Lebel T., Diedhiou A. and Laurent H. (2003). Seasonal cycle and interannual variability of the Sahelian rainfall at hydrological scales. Journal of Geophysical Research, 108 (D8), 1401–1411.

Lobell D. B., Burke M. B., Tebaldi C., Mastrandrea M. D., Falcon W. P. and Naylor R. L. (2008). Prioritizing climate change adaptation needs for food security in 2030. Science, 319(5863), 607-610.

Loko Y. L., Dansi A., Agre A. P., Akpa N., Dossou-Aminon I., Assogba P. and Sanni A. (2013). Perceptions paysannes and impacts des changements climatiques sur la production and la diversité variétale de l'igname dans la zone aride du nord-ouest du Bénin. International Journal of Biological and Chemical Sciences, 7(2), 672-695.

Mertz O.,Mbow C., Nielsen J.Ø.,Maiga A.,Diallo D.,Reenberg A.,Diouf A.,Barbier B.,Moussa I.B.,Zorom M.,Ouattarra I., and Dabi D. (2010). Climate factors play a limited role for past adaptation strategies in West Africa. Ecology and Sociandy, 15(4), 1-14.

Mundia C. W., Secchi S., Akamani K. and Wang G. (2019). A regional comparison of factors affecting global sorghum production: The case of North America, Asia and Africa's Sahel. Sustainability, 11(7), 1-18.

Nicholson S. E. (2001). Climatic and environmental change in Africa during the last two centuries. Climate research, 17(2), 123-144.

Oguntunde P. G., Lischeid G., Abiodun B. J. and Diandrich O. (2014). Analysis of spatial and temporal patterns in onsand cessation and length of growing season in Nigeria. Agricultural and forest mandeorology, 194, 77-87.

Parry M., Parry M. L., Canziani O., Palutikof J., Van der Linden P. and Hanson C. (2007). Climate change 2007-impacts, adaptation and vulnerability: Working group II contribution to the fourth assessment report of the IPCC (Vol. 4). Cambridge University Press UK.

Rajot J. L., Karambiri H., Ribolzi O., Planchon O. and Thiebaux J. P. (2009). Interaction entre érosions hydrique and éolienne sur sols sableux pâturés au Sahel: cas du bassin-versant de Katchari au nord du Burkina Faso. Science and changements planétaires/Sécheresse, 20(1), 17-30.

Renard C. and Vandenbeldt R. J. (1990). Bordures d'Andropogon gayanus Kunth comme moyen de lutte contre l'érosion éolienne au Sahel. L'agronomie tropicale, 45(3), 227-231.

Rimi F., Macolino S., Leinauer B. and Ziliotto U. (2011). Green-up of seeded Bermuda grass cultivars as influenced by spring scalping. HortTechnology, 21(2), 230-235.

Robson A., Bardossy A., Jones D. and Kundzewicz Z. W. (2000). Statistical mandhods for testing for change. Dandecting trends and other changes in hydrological data. World Climate Programme-Water, World Climate Programme Data and Monitoring, WCDMP-45, WMO/TD, (1013), 49-88.

Sarr B., Kafando L. and Atta S. (2011). Identification des risques climatiques de la culture du maïs au Burkina Faso. International Journal of Biological and Chemical Sciences, 5(4), 1659-1675.

Sene L. (1995). Réponse de la variété de sorgho CE 145-66 à l'alimentation en eau: effand du stress hydrique sur les rendements and la qualité des semences. Mémoire de fin d'étude, École Nationale des cadres ruraux CNRA, de Bambey, Sénégal. 59p

Sidibé D., Sanou H., Bayala J. and Teklehaimanot Z. (2017). Yield and biomass production by African eggplant (Solanum aandhiopicum) and sorghum (Sorghum bicolor) intercropped with planted Ber (*Ziziphus mauritiana*) in Mali (West Africa). Agroforestry Systems, 91(6), 1031-1042.

Sissoko K., Savadogo K., Vaksmann M., and Tiemtore A. (2018). Cereal crops choices and economic resilience face to climate

variability in southern Mali. Journal of Agriculture and Environmental Sciences, 7(1), 116-126.
Sissoko P., Aune J. B., Senneväg G., Teme B. and Lebailly P. (2017). Vulnerability evaluation of milland and sorghum cropping system to climate change and adoption of new technologies in Mali. Asian Journal of Science and Technology, 8(1), 4176-4182.
Sissoko P., Berti F., Gry S. and Lebailly P. (2018). Effands de l'adoption de la technique du microdosage d'engrais sur la disponibilite and l'accessibilite cerealiere des exploitations agricoles a base de mil and de sorgho au Mali. Agronomie Africaine, 30(2), 193-204.
Sultan B. (2012). Global warming threatens agricultural productivity in Africa and South Asia. Environmental Research Landters, 7(4), 041001.
Sultan B., Guan K., Kouressy M., Biasutti M., Piani C., Hammer G. L., McLean G and Lobell D. B. (2014). Robust features of future climate change impacts on sorghum yields in West Africa. Environmental Research Landters, 9(10), 1-13.
Tonitto C. and Ricker-Gilbert J. E. (2016). Nutrient management in African sorghum cropping systems: applying manda-analysis to assess yield and profitability. Agronomy for sustainable development, 36(1), 1-19.
Traore B. (2014). Climate Change, Climate Variability and Adaptation Options in Smallholder Cropping Systems of the Sudano – Sahel Region in West Africa. PhD, Wageningen University. 163 pages.
Traoré B., Corbeels M., Van Wijk M. T., Rufino M. C., Giller K. E. (2013). Effects of climate variability and climate change on crop production in southern Mali. European Journal of Agronomy, 49, 115-125.
Traoré S. B., Alhassane A., Muller B., Kouressy M., Somé L., Sultan B. and Diop M. (2011). Characterizing and modeling the diversity of cropping situations under climatic constraints in West Africa. Atmospheric science landters, 12(1), 89-95.