ISSN : 0974 - 7451 Volume 9 Issue 5

Environmental Science
An Indian Journal
Current Research Paper

ESAIJ, 9(5), 2014 [177-185]

Influential factors on the Sahelian agricultural production yield under a changing climate

Somé Yélézouomin Stéphane Corentin
Joint Research Center for Water and Climate, International Institute for Water and Environmental Engineering (2iE) 01 BP 594, Ouagadougou 01, Rue de la science
E-mail : some_y@yahoo.fr

INTRODUCTION

The climate is characterized by a stable tendency over a long period of weather characteristics specific to a given geographical environment. But this stability is very often disturb by various causes (very often natural), involving a sustainable modification which one names: climatic change. Indeed, the climate over the land already underwent several cyclic modifications and other evolutions during geological ages as many paleo-climatological studies attest it. The climate change is a phenomenon which occurs in a world which already is severely prone to serious problems of disparity in terms of development. Changes in the climate system and land cover have important consequences on regional and global water resources management and on the agricultural production[13]. However, the distribution of impacts is likely to be inherently unequal and tilted against many of the world's poorest regions, which have the least economic, institutional, scientific, and technical capacity to cope and adapt. As pointed by the Intergovernmental Panel on Climate Change (IPCC), Africa as a whole is highly vulnerable to climate change[7,8] because of widespread poverty and consequential limited adaptation and coping capabilities. Africa's variable climate is already contribut-ing significantly to its development problems, because the key development sector of agriculture is particularly sensitive to climate variability. On the other hand, an estimated 70% of the populations of sub-Saharan Africans survive through agriculture (which represents the principal economic activity); their livelihoods depend fundamentally on rain, and may fail when the precipitations fail[5,6].

Rainfall in the Sahel is characterized by its seasonal pattern, as most rainfall (quantity wise) typically occurs from July to September[10,12]. As in all arid and semi-arid regions, rainfall is highly variable in both space and time, and drought is a common feature of the region. These recurrent droughts are usually attributed to the variability (scarcity) of rainfall in this region, while the influence of other climate parameters is ignored in several studies over this zone. It is well accepted that rainfall has recovered a good pattern in the Sahel since the middle of 1990s; with cumulative annual rainfall being above the long-term mean. This was accompanied by an increase in vegetation in some areas, in part due to rainfall increases[14]. Similarly, rainfall has increased progressively since the late 1990s in the Sahel, but this increased portion is less important compared to the variation of main rivers flow in the region[9]. Nevertheless, the agricultural production is still under threat (persistence of food insecurity) despite of the recognized increasing trend of rainfall pattern over the Sahel. This may be due to the fact that the Sahelian climate is influenced by many complex, interacting processes, and it is likely that land surface conditions and other climate factors such as temperature play some role in mediating rainfall and drought conditions, even if they cannot explain the onset and longevity of drought[4,22].

It is found through several studies, three main issues related to environmental and climate stresses along with human management of resources are noticeable in Burkina Faso: the first issue is the impact of climate extremes (heavy rainfall and flooding, drought, storms) and variability (changes in rainfall seasons and year-to-year variability in rainfall and temperature). The second is the aspect of river management. The third issue relates to access to land and water for pasture and agriculture. All these aspects lead to searching for the means to ensure food security which is under serious threat as climate changes.

In the past, people (especially rural population) exposed to climate variability have adapted their livelihoods to fluctuating natural resources[2,11]. Adaptations based on livelihood diversification, local knowledge and social networks are able to increase the resilience to climate impacts. However, the most vulnerable, often the poorest and most marginalized, commonly remain vulnerable[3]. Thus, in this context of climate changes and their future impacts in a country as Burkina Faso, where the productivity of the arable lands still remains very low and facing also a chronic food insecurity, lead us to address the problem if the types of agriculture are not considered in the near future. Also, another handicap is how to reduce the vulnerability vis-a-vis the climate changes, and adaptation measures in order to support the socio-economic development of the country. Hence, it is important to find the leading factors to low production yield despite of the increasing rainfall pattern. It is for this purpose that this paper aims to help decision makers and stakeholders to take good decision through (a) identify the most significant climatic factors determining the agricultural yields of the main cereal speculations in Burkina Faso (b) find the most dependent speculations on climate parameters to avoid the recurring food insecurity and finally (c) identify the most vulnerable geographical areas for cereal productions due to climatic factors.

Two hypotheses are made as well as two indicators for testing and checking them.

- cereal production yield in Burkina Faso is contrasted by the drought
- precipitation and temperature strongly contribute to the improvement of the cereal production in Burkina Faso.

The next section briefly describes the study area with its full characteristics and the data (hydrological and cereal production) used in this study. Section 3 provides a summary of the methodology used to attain the above objectives. Section 4 presents and discusses the results obtained from the analysis. Finally, the last section concludes the study with some suggestions for the next future work.

METHODOLOGY

Study area

Burkina Faso is located in West Africa between 13° north latitude and 2° west longitude. It lies between the Sahara desert and the Guinea Gulf, south of the loop of the Niger river (Figure 1). According to the national institute of statistics and demography, the population of Burkina Faso is estimated as 17275115 habitants in 2012, and 77.3% of this population is from rural areas where living conditions are hard due to the extreme poverty: level of poverty 46.7%[18]. This poverty is increased by the climate variability and changes, making the country under recurrent food insecurity situation.

Climatic and pedologic characteristics

The climate of Burkina Faso is a tropical type with soudano-sahelian predominance, characterized by alternation between a short season of rains and a long dry season. The continentality of the country and its position not far from the Sahara predispose its climate to a strong diurnal and annual variability. Three main climatic zones are found: the sahelian zone in the north part with an annual cumulative rainfall lower than 600 mm, the northern soudanian zone in the center with an annual cumulative rainfall ranging between 600 and 900 mm and the southern soudanian zone in the south with an annual cumulative rainfall higher than 900 mm, with a rainy season of almost 4 months. But this rainfall pattern is subjected to a strong spatial and temporal variability with a downward trend which changes towards an increasing pattern in the middle of 1990s. The climatic characteristics of these three zones are illustrated in TABLE 1.

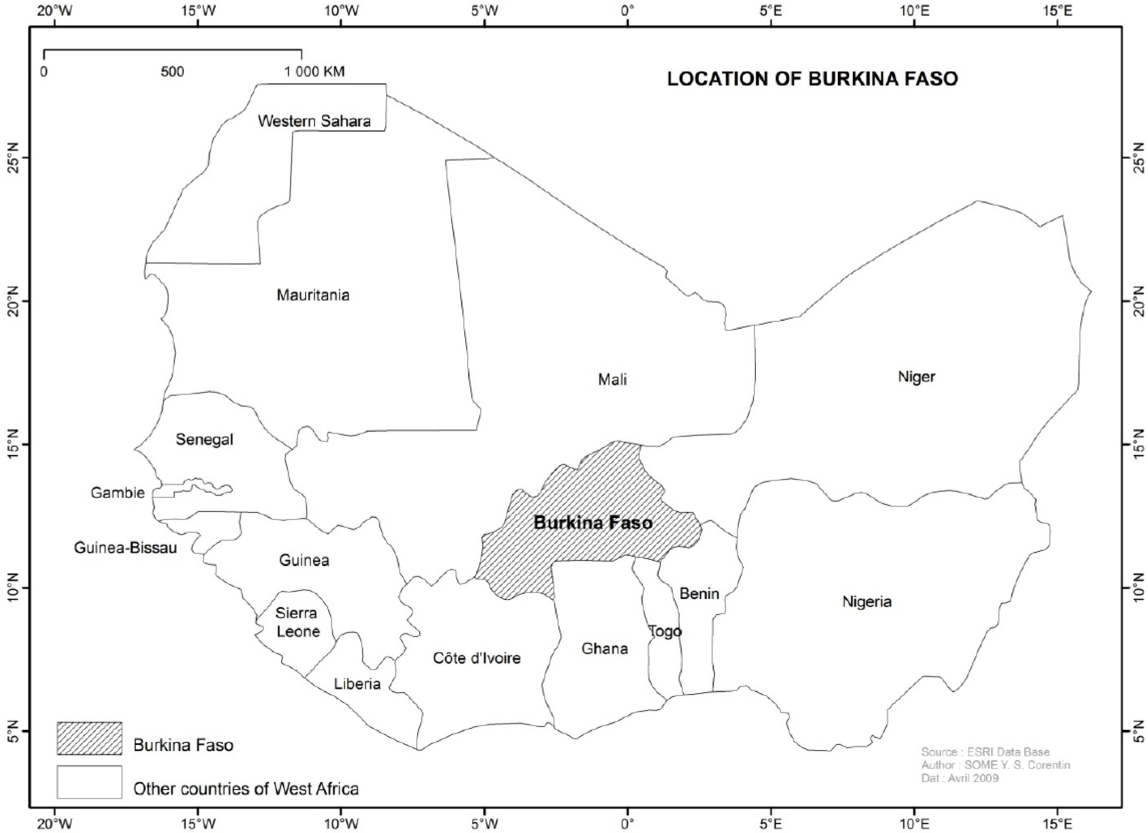

Figure 1 : Location map of Burkina Faso

The values of the potential evapotranspiration (ETP) remain very high throughout the year. The space distribution of the ETP is uneven. It decreases of more than 2260 mm/year in the north (Sahelian zone) to less than 1800 mm in the south-west part of the country (soudanian zone). Throughout the whole country and over the entire year, low values of relative humidity vary between November and February, while high values are observed during May and September with a peak in August. Broadly the relative humidity of the air remains higher than 10% and lower than 95% during the year. Regarding the values of sunlight, they are high over the year ranging between 6h and 10h per day except for Gaoua and Bobo Dioulasso where they are lower than 6h during August. The duration of the sunlight varies irregularly in time and space.

Burkina Faso is characterized by a pedological heterogeneity due to the long geomorphological evolution and the diversity of the geological cover. The studies carried out in 1955 to now denote 9 classes of soils (as indicated in TABLE 2) according to the commission of pedology and soil mapping.

TABLE 1 : Characteristics of climate zones in Burkina Faso

Climate Parameters		Climate zones		
		South soudanian	North soudanian	Sahelian
Annual rainfall (mm)		900-1200	600-900	300-600
Length of rainy season (in days)		180-200	150	110
Number of days of rainfall (days)		85-100	50-70	<45
Annual mean temperature (°C)		27	28	29
Seasonal amplitude (°C)		5	8	11
Mean humidity of air (%)	Dry season	25	23	20
	Rainy season	85	75	70
Annual Evaporation :bac class A (mm)		1800-2000	2600-2900	3200-3500

Agro-climatic zones

The agricultural sector dominates the economy of Burkina Faso; it represents approximately 40% of the Gross domestic product (GDP) and contributes for 60% of total exports. According to FAO, agriculture covers on average 10% of the country area and less of the third of the cultivable lands. Food crops occupy 88% of land surface with a broad predominance of sorghum and millet (81%); while 12% of lands are reserved for the crops of high income primarily made up of cotton as a whole. It is noted that the agriculture in Burkina Faso is still remains an agriculture of subsistence.

TABLE 2 : Characteristics of soil types in Burkina Faso

Soil types	Percentage (%)	Constraints	Potential characteristics
Mineral soils	3	Agronomic interest: weak to none	Area of pasture
Not very advanced soils	26	Coarse texture, availability out of less water, low in organic matter	Some facies rich in Ca and Mg, area of terrace cultivation
Vertisol	6	Heavy at the wet state, hard at the dry state, overdrawn state out of NPK	Good water holding capacity, rich in minerals are appropriate for sorghum, millet, cotton and rice production
HumicIso soils		Worst physical properties, low availability of water, low NPK content	Good water holding capacity, is appropriate for cotton and rice production
Brunified soils	6	possible hydromorphy	Rather good mineral richness
Soils with manganese and iron sesquioxides	39	Massive structure in duration, low content of nutritive elements	Leguminous cereal plant and arboriculture production
Ferralitic soils	2	Less water reserve	Production of millet, leguminous plant and arboriculture
Sodic Soils or salsodic	5	Massive structure, tendency to be alkaline	Production of cereals after improvement
Hydromorphic soils	13	hydromorphy	Production of sorghum and rice (rainy season) and dry season

According to the agro-climatic char acteristics, the country is subdivided, into five (5) agricultural zones in accordance with the administration management: Sahelian zone, Centre zone, North zone, East zone and West zone (Figure 2). The Sahelian zone is the driest area of the country, but it is a cattle-breeding area. Millet is the principal culture while sorghum occupies the second place. For the second and third zones, annual rainfall varies from 600mm in the north to 900mmin the south. The farming system in these areas is cereal base as in the east zone. Sorghum and millet occupy the first place (80% land surface). The East zone is regarded as a producing area of cereals. The farming systems are marked by prevalence of sorghum and millet in rotations. For the last zone, the rainfall is between 900mm and 1100mm. This is the area which has the best agricultural potential: maize is the principal food crop in this zone, while rainy season rice is also developed. It should be noted that, the most cereal crops cultivated are maize, millet and sorghum in the country.

Data presentation

For the purpose of this study, climate and agricultural dataset are used. The decadal climate data spanning from 1981-2010 cover the five agro-climatic zones and are obtained from the National Office of Meteorology (Burkina Faso). These climate variables are mainly rainfall, temperature (maximum, mean and minimum), number of days of rainfall and the length of rainy season.

Regarding the agricultural data, they include: production area, type of crops and production yield. They span over the period 1984-2009 and are provided by the National Office of Agricultural Statistics (Burkina Faso). It is noted that, even though the historical agricultural dataset does not have a temporal coverage reaching that of the climate data, no gaps are observed in the records at the decadal scale for the study period.

Also, some indicators are used to check the hypothesis initially made. These include indicators of drought description (amount of precipitation ; climate type; evolution of rainfall pattern ; temperature ; evapo-

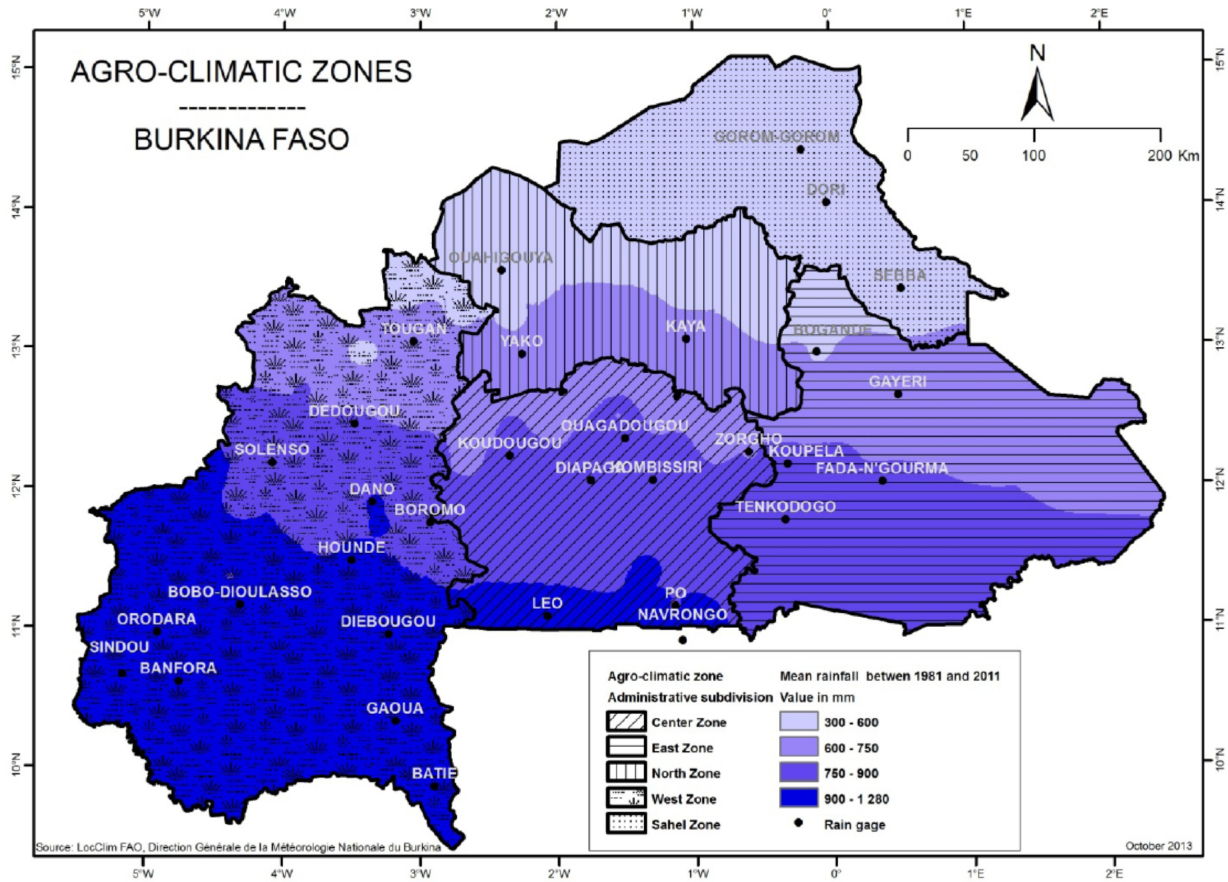

Figure 2 : Agro-climatic zones of Burkina Faso

transpiration ; sunlight) and the indicators describing the cereal production yield (level of production, area of production, type of production, production yield per crop).

Methods

Regarding the purpose of this study which consists to understand the impact of climate variables on the cereal production yield, some simple statistical methods are used. These include the Bartlett test of sphericity, principal component analysis (PCA) and the Bravais-Pearson correlation coefficient. The Bartlett test[21] is based on the Khi2 test and allows knowing if variables (both climate and agricultural) are perfectly correlated prior applying PCA. It is used to test the null hypothesis (H_0: correlation matrix is an identity matrix) is tested under a significance level of 5% using the correlation matrix. After being sure that the determinant of the correlation matrix is not zero and different from 1, then PCA is applied. One more reason for using the Bartlett test is to take account of outliers as PCA is badly affected by outliers. PCA is a factorial method which aims to compute the most meaningful basis to re-express a noisy, garbled data set. It involves computing the eigen vectors and eigen values of the variance-covariance matrix or correlation matrix as the first step. It is chosen for this study due to the fact it is the most widely used multivariate statistical method in the atmospheric sciences and especially due to its simplicity (Saporta, 2006). It gives complete information about the generated results such as eigen values, correlations of the variables with the factorial axes, contributions of variables to axes as well as that of individuals, and so on. In this study, 2 quantitative variables are used for the PCA. The first variable has 6 modalities (precipitations, maximum, mean and minimum temperature, number of days

TABLE 3 : Results from Bartlett test on agro-climate variables

Bartlett test of sphericity:	
Khi² (observed value)	180.831
Khi² (critical value)	50.998
Degree of freedom	36
p-value (unilateral)	< 0.0001
Alpha	0.05

of rainfall and length of rainy season), while the second relative to cereal production has 3 modalities (production yield of sorghum, maize and millet). The correlation coefficients obtained from the PCA analysis are that of Pearson. The PCA is applied separately on each climate variable against the three production yield data set. The outputs are analyzed, before running again PCA for all climate and production variables together. This splitting process aims to understand the weight (influence) of each climate variable individually on a given production variable without the presence of its other neighbor climate variable. The PCA is carried out using both the XLSTAT application and TANAGRA software[17].

For each agro-climatic area, the different correlation matrices are analyzed to find the linear relationship between variables. This also includes analyzing the contribution of variables to different factorial axes as well as the relationship between variables and factorial axes.

Indeed, the rationale behind this technique is to check the effect of each climate variable (taking individually and group wise) on cereal production parameters and the most affected agricultural variable.

The absolute values of variables coordinates, biplots of variables on factorial axes as well as the correlation matrix are then all analyzed for both cases (individually and group wise). Then, the climate variable having the most effect (significant correlation) is checked including its probable leading reason.

RESULTS AND DISCUSSION

The results obtained from the Bartlett test (see TABLE 3) show that the hypothesis of significant correlation between variables is accepted at a significance level of 5%. Therefore, there is a significant correlation between the two groups of variables which allows carrying out a PCA analysis based on the tested data.

The correlation analysis is carried out based on the five agro-climatic areas over the country. It covers the parameters of rainfall, temperature, number of days of rainfall, length of rainy season, production yields of sorghum, maize and millet. For the agro-climatic area named Centre Zone, a high significant correlation (more than 0.5) is found between temperatures (mean and minimum) and the production yields of sorghum and millet compared to that of maize (0.4). All production yields are less correlated to precipitation as well as maximum temperature (see TABLE 4). This can be justified due to the fact that some crops in the Sahel are more dependent on temperature than rainfall for their growing.

Regarding the West Zone, the correlation between agro-climate variables, it has the more pronounced correlation between production yields and other variables reaching more than 60%. Indeed, the same pattern of dependence is found for the North and East zones where the correlation between cereal production yields and climate variables are also significant especially with mean temperature. However, a particularity is observed re-

TABLE 4 : Correlation matrix of variables for the centre zone

	VARIABLES					
	PCP	**Max Temp.**	**Min Temp.**	**Mean Temp.**	**Number Days of Rain**	**Rainyseasonlength**
PCP	1	-0.166	0.067	0.077	0.406	0.389
Max Temp.	-0.166	1	0.704	0.789	-0.345	-0.001
Min Temp.	0.067	0.704	1	0.874	-0.116	-0.100
MeanTemp.	0.077	0.789	0.874	1	-0.416	0.032
Number Days of rain	0.406	-0.345	-0.116	-0.416	1	0.126
Rainyseasonlength	0.389	-0.001	-0.100	0.032	0.126	1
Millet yield	0.335	0.322	0.561	0.596	-0.028	0.056
Maizeyield	0.284	0.315	0.395	0.415	0.137	0.005
Sorghumyield	0.259	0.367	0.569	0.607	-0.043	0.053

garding the Sahel zone where the temperature is usually high. In fact, a relative significant correlation (50%) is observed (see TABLE 5). This is mainly due to the non dependence of crops growing on high temperature (r=6% with maximum temperature), but they required a minimum too mean temperature which are constant for having a good yield.

Observing the histograms of eigen values (Figure 3) between variables for the entire 5 agro-climatic zones, it is found that the first two axis represent around 80% of the inertia (information) and this is in accordance with Kayser and Catell criteria. Therefore, these correlations are highly representative.

The analysis of the results of this study reveals the impact of climate parameters on the yield of various cereal speculations and also shows that the most significant parameter on which must be centered all adaptation measures of agriculture against climate change could be the temperature. The most important climate parameter playing a great role in cereal production yield in this part of West Africa is found to temperature (especially mean temperature and minimum temperature). Thus, this study confirm the work of Parry et *al*.[16] who found that cereal crops (specifically Sorghum) depend greatly on climate variables especially mean temperature in the Sahel. This assertion also lines up with the work of Ferrari cited by Siband[20], who described the ecological requirements of millet and sorghum in Senegal: needs of high temperatures for germination and growth, great tolerance towards soil dryness, but sensitive to excess water. However, each species or variety is characterized by its requirements in temperature during its various growing phases. These needs are translated by the concept of quantity of useful heat (called degree-days). Moreover, the optimum temperature for the development and growth of plants is around 30°C. The increase in temperature will result in a reduction of the duration of the developmental stages and total duration of the cycle. In addition, the more resistant popularization of cereals species and better adapted to climatic conditions is another option to be considered. Scarcity of the rains

TABLE 5 : Correlation matrix of variables for Sahel zone

	VARIABLES					
	PCP	**Max Temp.**	**Min Temp.**	**Mean Temp.**	**Number Days of rain**	**Rainyseason length**
PCP	1	-0.577	0.221	-0.083	0.778	0.839
Max Temp.	-0.577	1	0.078	0.386	-0.520	-0.499
Min Temp.	0.221	0.078	1	0.836	0.129	0.341
MeanTemp.	-0.083	0.386	0.836	1	-0.136	0.078
Number Days of rain	0.778	-0.520	0.129	-0.136	1	0.746
Rainyseasonlength	0.839	-0.499	0.341	0.078	0.746	1
Millet yield	0.058	0.006	0.527	0.527	-0.038	0.038
Maizeyield	0.093	0.014	0.532	0.539	-0.029	0.061
Sorghumyield	0.102	0.012	0.537	0.513	-0.009	0.057

Indeed, it is noticed in general that the minimal and mean temperatures influenced positively the yields of millet, sorghum and maize. But for the Sahel zone, maximum temperatures show a weak correlation which could be a potential danger to cereal production in this zone due to the fact that maximum temperatures often reach 40°C during the rainy season period in this zone. Nevertheless, this rise of the temperature will be beneficial for the South and West zones. Concerning precipitations, the correlations show their relative importance for cereal yield although their importance in the calorific stage of cereals is less significant. Their significant prolonged reduction in some agricultural zones like the Sahel and North could very quickly become a major constraint. Therefore, the analysis of all relations between climate variables and production yield parameters show that the Sahel zone is the most vulnerable geographical are for cereal production. This is due to the high temperature observed (as stated above) which is not favorable to crops and the lack of a minimum quantity of rainfall required for cereal crops grow. This result is in accordance with the thorough study[1] on the most vulnerable provinces of Burkina Faso (for comparison purpose with other countries) under climate change. They argued that the Sahel region in Burkina Faso is the most exposed area to climate changes due to its increasing temperature, rainfall scarcity and the land use.

These results found above lines with the perception of rural people in these agro-climatic zones. This perception is confirmed by Ouédraogo et *al*.[15], who found through enquiries that the perception of the climate is related to the agro-climatic zone according to rural people in Burkina Faso. Also, they found that 76% of people interviewed relate the decrease in production yield to the decreasing trend of precipitation. However, this concept of rural people (regarding precipitation pattern) is not really true due to the increasing trend observed for West African precipitations especially in the Sahel. In the same line, 23%, 45.6% and 28.2% of rural people (respectively for the West, Centre and Sahel zones) thought that production yield is not really so related to precipitations as most of people are pretending[15]. Therefore, it is obviously interesting that rural people perception of the climate has to be taking into account while dealing with the Sahel rainy agricultural production. This leads to conciliate the scientific predictions and traditional perception of rainy season in terms of production yields and climate parameters.

CONCLUSION

In this work, we used simple and easy methods such as Bartlett test of sphericity, PCA. These methods especially the correlation of Pearson is easy to understand and apply. These approaches are frequently used by researchers and experts in order to understand the connection between two phenomena and to facilitate the decision-making in atmospheric science.

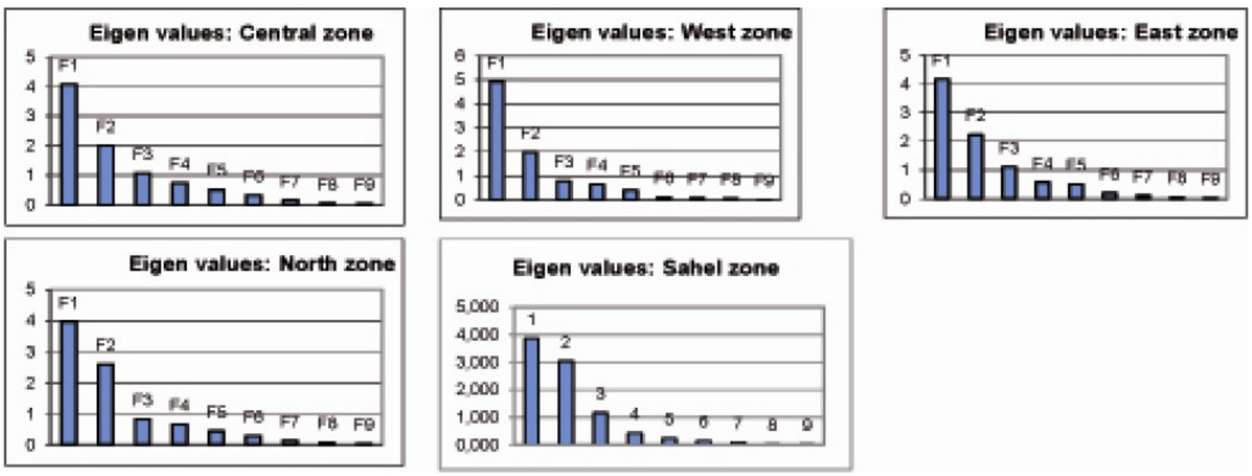

Figure 3 : Histograms of Eigen values for the 5 agro-climatic zones

This paper highlighted the effects of climate changes through climate variables regarding the agricultural production. Indeed, since the few decades it is observed: an increased trend of the mean temperature as well as a slight increase trend of rainfall in time. Despite this last raising, the production yield is not changing positively. This study shows the limit of rainfall compared to temperature in production yield for some crops in Burkina Faso according to its agro-climatic zones. These simple methods enabled obtaining significant results showing a clear correlation between the cereal yield and temperature, which makes it as the most significant climate factor determining the agricultural yields of the main cereal speculations in Burkina Faso under a context of climate change.

Therefore, it is judicious to carry out some projections of production yields for these cereal crops based on the IPCC results of projected climate variables over West Africa. Hence, the next steps of this study consist to develop a model enabling to simulate the impact of each climate parameter (as well as combined climate variables) on the production yield in the Sahel for each crop. Thus, this model can provide a prediction guide for food security over Burkina Faso as well the entire West Africa.

REFERENCES

[1] S.J.Beddington, M.Asaduzzaman, M.Clark, T.Mamo; Atteindre la sécurité alimentaire dans le contexte du changement climatique. Résumé de la Commission sur l'agriculture durable et le changement climatique à l'attention des décideurs politiques. www.ccafs.cgiar.org/commission, **(2011)**.

[2] S.Davies; Adaptable livelihoods: Coping with food insecurity in the Malian Sahel. London: Macmillan, **(1996)**.

[3] M.Goulden, L.O.Næss, K.Vincent, N.Adger; Accessing diversification, networks and traditional resource management as adaptations to climate extremes in W.N.Adger, I.Lorenzoni, K.O'Brien; (Eds); Adapting to Climate Change: Thresholds, Values, Governance. Cambridge: Cambridge University Press, 448-464 **(2009)**.

[4] W.J.Hiu, B.I.Cook, S.Ravi, J.D.Fuentes, P.D'Odorico; Dust-rainfall feedbacks in the West African Sahel, Water Resources Research, **44**, **(2008)**.

[5] K.R.Hope; Poverty, livelihoods, and governance in Africa: fulfiling the development promise. New York: Palgrave Macmillan, **(2008)**.

[6] International Research Institute for Climate and Society -IRI. A Gap Analysis for the Implementation of the Global Climate Observing System Programme in Africa. IRI Technical Report 06-01, **(2006)**.

[7] IPCC, Climate Change; The scientific basis. Contribution of Working Group I in The Third Assessment Report of the Intergovernmental Panel on Climate Change, J.T.Houghton, Y.Ding, D.J.Griggs, M.Noguer, P.J.Van der Linden, X.Dai, K.Maskell, C.A.Johnson, (Eds); Cambridge University Press, Cambridge, 881 **(2001a)**.

[8] IPCC, Climate Change; Impact, adaptation and vulnerability. Contribution of Working Group II in The Third Assessment Report of the Intergovernmental Panel on Climate Change, James J.McCarthy, O.F.Canziani, N.A.Leary, D.J.Dokken, K.SWhite, (Eds); **(2001b)**.

[9] T.Lebel, A.Ali; Recent trends in the Central and Western Sahel rainfall regime (1990-2007), Journal of Hydrology, **375**, 52-64 **(2009)**.

[10] C.McSweeney, M.New, G.Lizcano; UNDP Climate Change Country Profiles: Mali. Technical Report UNDP, **(2012)**.

[11] M.J.Mortimore, W.M.Adams; Farmer adaptation, change and crisis in the Sahel, Global Environmental Change-Human and Policy Dimensions, **11**, 49-57 **(2001)**.

[12] S.E.Nicholson, J.P.Grist; A conceptual model for understanding rainfall variability in the West African Sahel on interannual and interdecadal timescales. International Journal of Climatology, **21(14)**, 1733-1757 **(2001)**.

[13] P.G.Oguntunde, J.A.Babatunde; The impact of climate change on the Niger River Basin hydroclimatology, West Africa. ClimDyn (2013), **40**, 81-94 **(2012)**.

[14] L.Olsson, L.Eklundh, J.Ardo; A recent greening of the Sahel - trends, patterns and potential causes, Journal of AridEnvironments, **63**, 556-566 **(2005)**.

[15] M.Ouédraogo, Y.Dembelé, L.Somé; Perceptions et stratégies d'adaptation aux changements des précipitations : cas des paysans du Burkina Faso. Sécheresse, **21(2)**, 87-96 **(2010)**.

[16] M.Parry, A.Evans, M.W.Rosegrant, T.Wheeler; Climate Change and Hunger: Responding to the Challenge. Rome, Italy: World Food Program, **(2009)**.

[17] R.Rakotomalala; Pratique de la régression linéaire multiple, diagnostic et sélection des variables. Université Lumière Lyon II, 109 **(2008)**.

[18] RGPH; La croissance urbaine au Burkina Faso, thème 09. Ministère de l'Economie et des Finances. Burkina Faso, **(2006)**.

[19] G.Saporta; Probabilités, analyses des données et statistiques. 2ème Edition, Technip., 138-370 **(2006)**.

[20] P.Siband; Croissance, Nutrition et Production du mil; Essai d'analyse du fonctionnement du mil en zone sahélienne. Thèse de doctorat. Académie de Montpellier. Université des Sciences et Techniques du Languedoc, **(1981)**.

[21] G.W.Snedecor, W.G.Coharan; Statistical methods, Eighth Edition, Lowa State University Press, **(1989)**.

[22] M.Yoshioka, N.Mahowald, A.J.Conley; Impact of Desert Dust Radiative Forcing on Sahel Precipitation: Relative Importance of Dust Compared to Sea Surface Temperature Variations, Vegetation Changes, and Greenhouse Gas Warming, Journal of Climate, **20(8)**, 1445-1466 **(2007)**.